Bridging the Epistemic Divide: A Design Based Research Project on Laboratory Work at Upper Second Level in Ireland

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Appendices (set out according to chapter number)

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Referencing and formatting in this thesis follow the APA style as defined in the Publication Manual of the American Psychological Association, 6th edition.

The following exceptions to the formatting requirements are as follows:

- Quotations from interview participants are 1.15 line spaced and indented to distinguish them from the main body of the text
- Quotations from interview participants are in *italics* where they are integrated into the main body of the text
- Table 2.1 and Table 3.1 are presented in landscape view for ease of reading

Abstract

Practical work in science education has been the subject of much international criticism over the last four decades for its use of recipe-style didactic instruction. Recent advances in education policy and academic literature have not been translated into practice in the science classroom. The Irish biology curriculum, first introduced at upper secondary level two decades ago, explicitly states that practical lessons should be enquiry-based, and that they should follow a scientific method of enquiry, however scoping stage investigations conducted at the beginning of this research indicate that neither of these two stipulations are enacted in practice.

The Design Based Research methodology used in this study addresses the policy-practice divide by accommodating iterative research cycles of design and development of an educational artefact, each preceded by a comprehensive literature review and followed by evaluation of the artefact in two target settings – the senior cycle biology classroom with in-service teachers, and the third level biology laboratory with pre-service teachers. The resulting artefact, the Framework for Teaching Enquiry Activities, is supported by two further research outputs, a theory of enquiry specific to practical activities, grounded in the work of John Dewey, and a programme for professional development grounded in the work of Etienne Wenger.

The findings add new knowledge to the field of science education in terms of articulating the complexity of enquiry as a pedagogical construct, and of presenting a form of enquiry that bridges the epistemic divide between policy and practice. Within the epistemology proposed here for the Irish biology curriculum, is a pragmatic, future-oriented approach to knowledge acquisition that promotes teachers as curriculum makers. This timely research has the potential not only to inform upcoming changes to senior cycle science curricula, but also to support teachers in making the transition to a new, more equitable, signature pedagogy.

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List of Acronyms

COP	Community of Practice
DES	Department of Education and Skills
DBR	Design Based Research
FTEA	Framework for Teaching Enquiry Activities
FTPA	Framework for Teaching Practical Activities
GOI	Government of Ireland
IST	In-Service Teacher
LC	Leaving Certificate
PAAI	Practical Activity Analysis Inventory
PBTM	Practical Biology Teaching Module
PST	Pre-Service Teacher
RP	Research Practitioner
SEC	State Examinations Commission
SEOS	Structured Enquiry Observation Schedule
STEM	Science Technology Engineering and Mathematics
TDT	Teacher Design Team
TP	Teacher Practitioner

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Chapter 1

Introduction

1.1 Introduction to the Research

In Ireland pupils attend secondary school between the ages of 12-18. Senior cycle education takes up the latter part of the secondary school experience, where students follow a two-year Leaving Certificate (LC) programme, with the option of taking an additional Transition Year at the beginning of their senior cycle. At the end of the senior cycle most students take the Leaving Certificate examination. Generally students take seven subjects for examination, three of which are mandatory – Irish, English and Mathematics. The remaining four subjects are chosen by the students from a wide range of 33 approved Leaving Certificate subjects. Subjects can be examined at either higher or ordinary level, with Mathematics and Irish offering a further foundation level examination paper.

The Leaving Certificate programme offers learners a "broad and balanced education while allowing for some specialisation" (Government Of Ireland (GOI), 2001, p.2). The certificate is used as a method of selection into further education, employment, training and higher education.

Outside of the mandatory subjects, the State Examinations Commission (SEC, 2021) confirms that biology is the most popular LC subject with 61% of students who sat the LC examination in 2021 choosing to study biology. This compares to uptake of the second most popular subject, geography, at 43% and uptake of other science subjects, physics (14%) and chemistry (17%). In addition, the vast majority of students who sat the biology LC examination in 2021 took the higher level paper (88%). This compares to 40% of mathematics students who sat higher level papers. The popularity of biology could potentially be explained by its accessibility to a wider student cohort (compared to chemistry or physics), because it does not require learners to also study higher level mathematics, and it is accepted by third level institutions as a pre-requisite to gain entry to Science, Technology, Engineering and Mathematics (STEM) undergraduate courses.

The Leaving Certificate system has been roundly criticised in recent years for the "washback effect" that the terminal examination has on classroom practices (Hyland, 2011). In the science classroom, this has led to a prioritisation of rote memorisation of factual knowledge over the development of scientific thinking (Cullinane and Liston, 2011), with biology pedagogies, in particular, affected by the low level of critical thinking and creativity included in the terminal examination paper (Burns et al., 2018). The Department of Education has set out a STEM Education Policy (DES, 2017) to address these issues and has made significant changes to the Junior Cycle STEM curriculum in recent years. However, in a more recent Department of Education report (DES, 2020), learner participation in STEM education was deemed to be less than satisfactory for one in every five STEM lessons taught at secondary school and the lack of real and meaningful engagement with learners was identified as a cause for concern. The National Council for Curriculum and Assessment (NCCA, 2019) conducted a review of the Leaving Certificate physics, chemistry and biology syllabi in light of these recent policy developments which endeavours to address the imbalance between an over-emphasis on propositional knowledge (which leads to a focus on rote-memorisation) and an under-emphasis on procedural and epistemic knowledge (evidenced by a dearth of understanding and critical thinking at LC level). New specifications for all LC science subjects, including biology, are currently in the development stage.

In the two decades since the previous LC reforms were implemented, science education has come under heavy scrutiny internationally, with practical activities in particular subjected to widespread criticism for the recipe-based manner in which they are enacted in the classroom. Enquiry practices at secondary school level are rare, as practical lessons typically follow a prescribed list of instructions to generate a pre-determined phenomenon (Abrahams and Millar, 2008; Capps et al., 2012; Osborne, 2015).

Changes to STEM policy documents internationally mirror current academic thinking around best practice in science education, and have led to policy concepts such as the incorporation of "science practices" in the USA (NRC, 2012), and the "working scientifically" approach to teaching and learning in England (Department of Education, 2015). However, these changes in policy have failed to translate into practice among the wider science teaching community (Scientix, 2018). Of greater concern perhaps is a study by Capps and colleagues (2013) that reported on a dearth of enquiry practices among some of the "best" science teachers, despite the teachers' own beliefs that they were actually teaching enquiry-based lessons. This situation cannot be a surprise to anyone who has turned to the research literature for a clear definition or characterisation of enquiry, and found that there is no agreement as to what enquiry is or how it should be implemented in science classrooms (Minner et al., 2010). Policy documents do not help matters because they are grounded in constantly advancing academic research which promotes a completely different epistemology than that of the majority of practicing teachers. This has led to a widening of the gap between research and practice, whether teachers and policy makers realise it or not (Scientix, 2018). Teachers are being asked to engage with a signature pedagogy that they do not understand, because it is culturally unfamiliar to them (Schulman, 2005), and as a result they do not have the confidence or the tools necessary to effect meaningful changes in their own practice.

It is within the context of this research-practice gap and the transitional stage between the old and new curricula that this research dissertation is situated. In 2002 the senior cycle biology curriculum in Ireland was reformed to reflect a move towards enquiry-based teaching and learning (GOI, 2001). However, as with the USA, England and the wider European Community, this research shows that reform efforts towards enquiry in the Irish senior cycle biology curriculum do not manifest as enquiry-based teaching in practical classes. This work confirms the recipe-based nature of biology practical lessons and the absence of enquiry-based teaching and learning in Irish second level schools. Almost two decades later, the Irish biology curriculum is again facing reform in the wake of a national STEM policy aimed at developing critical thinking skills through the application of innovation and creativity grounded in STEM education (DES 2020; NCCA, 2019). However, in the words of Stenhouse (1975), "there can be no curriculum development without teacher development", and while there is reference within STEM policy to a quality assured programme of STEM professional development (PD), there is no clear explanation of what form this professional development will take (DES, 2017). Developing a quality assured programme may prove problematic in light of national and international misunderstandings of the nature of enquiry-based teaching and learning (Capps et. al, 2013; Osborne, 2015; Scientix, 2018). If, as Osborne (2015) suggests, policy makers accept practical work for what it currently represents – a nice way to observe a scientific phenomenon – then there is no issue with how practical work is currently taught. However, the use of enquiry-based pedagogies and practices is written into both Irish and international policy, without any clear guidelines on how enquiry should be enacted by teachers and students in science classrooms. The sloganising of enquiry masks an underlying confusion about what it means among science educators and policy makers, which has created what Rittel and Weber (1977) call a "wicked problem" -that is, one whose solution contains many complex elements that make it frustrating to attain or potentially unattainable.

This dissertation begins by exploring the "wicked problem" in an Irish context – the complexity of aligning the written and enacted curriculum. It then uses a Design Based Research (DBR) approach to investigate how potential alignment between curriculum and practice might be achieved. DBR has been shown to be particularly suited to finding design solutions for wicked problems (Kelly, 2013). DBR generally results in one of three potential outputs: an educational artefact that is usable in a classroom situation, a novel theory or "ontological innovation", or a programme for professional development (van den Aker, 2006). Realigning the written curriculum with its enactment in practice required all three outputs during the course of this research (artefact, theory and professional development).

A comprehensive scoping examination of the Irish context was carried out followed by iterative cycles of design, development and refinement of a potential solution. Each cycle of design and development emerged from the findings of the preceding cycle and addressed its own specific research question. The research questions addressed are as follows:

Chapter 3

How is practical work currently experienced by teachers and students in the Irish biology classroom? How does this experience compare with written curriculum intentions for biology students?

Chapter 4

What are the characteristics of a framework for teaching practical activities that will enable teachers to transition from recipe-style experiments towards a more hands-on/minds-on approach to teaching practical activities in upper secondary biology classrooms?

Chapter 5

What are the characteristics of a theory of enquiry that can be used to articulate curriculum intentions for enquiry-based practical activities in the Irish biology classroom?

How does this theory translate into an artefact that teachers can use to teach practical activities?

Chapter 6

What are the characteristics of a programme of professional development that would enable teachers to understand, design and teach enquiry-based lessons, and how can they be enacted?

A potential solution emerged following the design of an educational artefact, the development of a theory of enquiry (and refinement of the artefact to reflect the epistemological underpinnings of the theory), and finally the development of a programme for professional development (and further refinement of the artefact).

1.2 Organisation of the Dissertation

Chapter one situates the research within the context of evolving policy around science education and states the research questions being addressed over the course of the study. It then provides a description of the contribution of each chapter to the research process.

Chapter two justifies the pragmatic nature of DBR as being appropriate in the context of the complexity of this research. It details how DBR is interpreted for this dissertation as one main macrocycle of research divided into three mesocycles, each of which is further subdivided into microcycles of analysis and exploration, design and construction, and evaluation and reflection (see Figure 1.1). DBR's iterative structure provides the scaffold by which new perspectives are brought to bear on the problem with each new research cycle (Grimes, 2017). The chapter then describes the evolution of the sample size in terms of interactive units for each design cycle, and details the research methods undertaken within each design cycle (Gobo, 2008). The Chapter concludes with a description of the ethical issues associated with the work and how they were addressed.

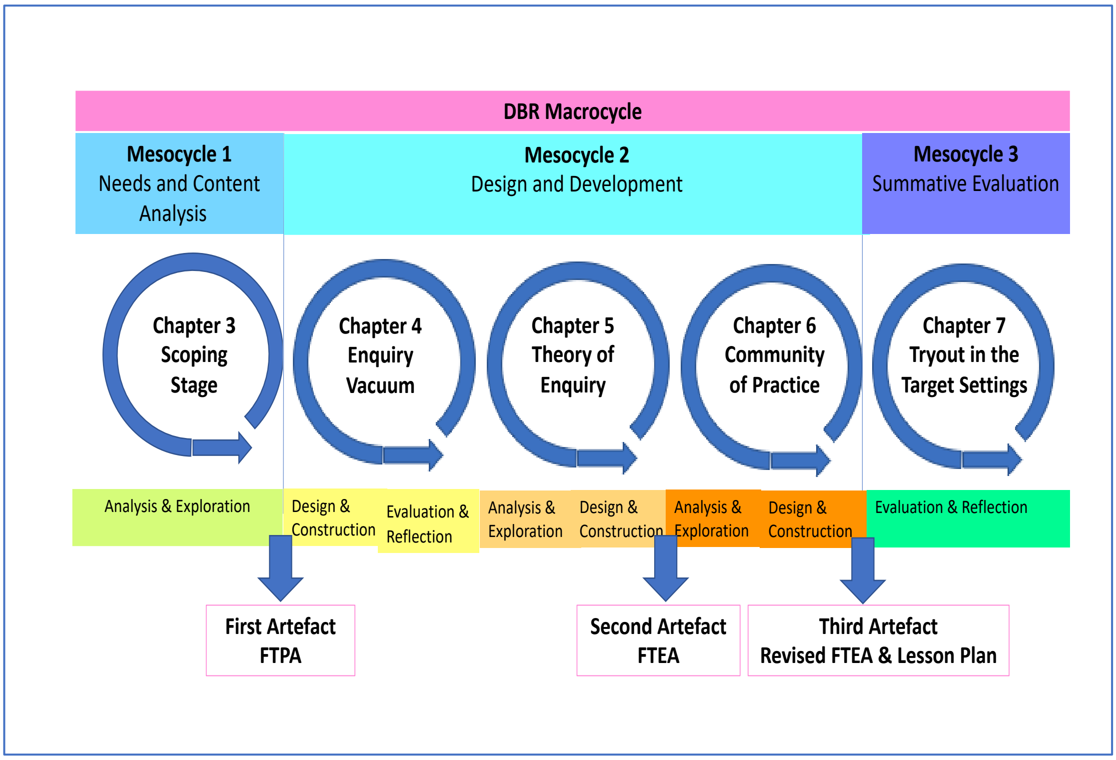

Figure 1.1: Outline of the overall structure of the research process which is represented by one main macrocycle of DBR research divided into three mesocycles, each of which is further subdivided into microcycles of analysis and exploration, design and construction, and evaluation and reflection. Successive microcycles of research refine the educational artefact.

Chapter 3 is organised into three main sections to present a needs and content analysis of how practical activities are enacted in the senior cycle curriculum. It begins with a review of the literature in this domain, identifying an international misalignment between the written policy for practical work which recommends enquiry-based teaching and learning, and the enactment of that policy in the science classroom, which is overwhelmingly comprised of recipe-style practical activities that are evaluated as hands-on but minds-off (Abrahams and Millar, 2008).

The second section focuses on a scoping exercise carried out within a selection of Irish senior cycle biology classrooms to compare policy and practice within an Irish context. The third section makes the connection between the manner in which teachers prepare, conduct, and conclude practical work and the dearth of minds-on (or enquiry) activities at senior cycle. The chapter concludes with recommendations for design guidelines going forward into the design and development stage of the research.

In Chapter 4, conversion of the design guidelines from Chapter 3 into design principles leads to the development of the first prototype - the Framework for Teaching Practical Activities (FTPA). This chapter illustrates how all three outputs of DBR (artefact, theory and professional development) required further development in order to provide a possible solution to "the wicked problem" faced here. This included the "humble theory" (Svihla, 2014) being used to encourage teachers to think about where they can incorporate minds-on work into their lessons, developing the FTPA further as an educational tool for planning for hand-on *and* minds-on lessons, and delivering professional development relating to the use of the FTPA to pre-service and in-service teachers. Evaluation of, and reflection on the use of the FTPA with these two participant cohorts revealed that the outputs were not sufficient for bringing about any kind of significant pedagogical change to practical lessons. Design principles for the next two design and development cycles focused on using theory to improve the artefact (Chapter 5) and using theory to develop a more appropriate programme for professional development (Chapter 6).

Chapter 5 begins with an analysis and exploration of the literature around enquiry, which adds a further dimension to the difficulty of providing a solution to the research problem by outlining the lack of consensus among academics around a description, definition or characterisation of 'enquiry'. Without finding a view of enquiry in recent academic literature that can bridge the recipe-enquiry divide in the Irish classroom, the chapter takes the advice of Osborne (2015) who believes science education is best served by using knowledge of how people learn rather than knowledge of how science is carried out. The design and construction aspect of this iterative research cycle turns to Dewey's Complete Act of Thinking (Dewey, 1910/2012), by developing a theory of enquiry as an "ontological innovation" (Gravemeijer and Cobb, 2013), which proposes an alternative epistemological view of learning as future-oriented, uncertain and moving along a continuum towards an end-in-view (Dewey, 1925/1958). This led to the redesign of the original FTPA into a new Framework for Teaching Enquiry Activities (FTEA), embedding the epistemological outlook and the language of enquiry within an inductive-deductive frame.

Chapter 6 presents a Community of Practice approach (COP) to professional development (Wenger, 1998). It was first used reflectively to explore why there was limited change to teacher's practice at the beginning of the second mesocycle of research. The findings were then used to support and inform the development of two DBR methodologies (Walkthrough and Micro-evaluation), to provide scaffolded professional development for teachers. This scaffolded approach was designed to ease teachers into an understanding of enquiry from the learner's perspective during the Walkthrough, and then supporting them in designing and teaching enquiry-based lessons using the FTEA and through additional collaborative Micro-evaluations. The final section of the chapter outlines the benefits of taking a scaffolded approach to professional development in stages, each stage underpinned by three modes of learning – engagement, alignment and imagination.

Chapter 7 presents a summative evaluation of the research process in two target settings – in a third level laboratory module for pre-service teachers (PSTs), and in the second level biology classroom. The COP approach to professional development views PSTs as peripheral members of the enquiry community, and the Walkthrough DBR methodology was used throughout the module, with the three modes of learning integrated into the practical activities they undertake. During the semester PSTs move from the learner perspective into the designer perspective and eventually used the FTEA to design their own lesson. Evaluation of the module via the three modes of learning provided indications that this novel approach to enquiry integrated more thinking into practical activities, by incorporating enquiry skills into lesson design. It also challenged PSTs beliefs about teaching and learning by exposing them to the signature pedagogy of enquiry (Shulman, 2005).

The second part of chapter 7 presents the programme for professional development in the target setting. In-service teachers (ISTs), working as fully participating members of the enquiry COP, demonstrated an ability to understand, design and teach enquiry-based lessons to senior cycle students. The learning that occurred demonstrates how reintegration of the hand and mind in the practical classroom is possible. Quantitative data analysis shows marked increases in the use of enquiry skills, student discourse and effective questioning. These improvements are supported by qualitative data that speaks to a change towards a pedagogy of enquiry brought about by the collaborative nature of the relationships within the COP, leading teachers to adopt a future-oriented, student-centred approach to teaching practical activities.

Chapter 8 presents an overview of the research process from the point of view of the three research outputs; the FTEA, the theory of enquiry and the programme for professional development. The type of curricular change that is required to improve practical activities in the senior cycle classroom is contingent on the interdependence of all three of these outputs. Supported by the DBR methodology, each output is crafted specifically to address the deeply complex challenge of changing the signature pedagogy of practical teaching. At the end of the process, teachers developed an "inquiry identity" (Deneroff, 2016), which endowed them with a different, more equitable, lens through which enquiry-based lessons could be designed and delivered. The final section is a discussion of the implications of this research for STEM policy in Ireland and closes with a review of the limitations of the research.

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Chapter 2
Research Methodology and Instruments

2.1 Introduction

Design Based Research (DBR) is defined by Nieveen and Folmer as follows:

> "The systematic analysis, design and evaluation of educational interventions with the dual aim of generating research based solutions for complex problems in educational practice, and advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them."
>
> (2013, p.153)

DBR was the most appropriate research methodology for this project, since there are three intertwined goals embedded in the above description that it specifically addresses – research, design and pedagogical practice (Joseph, 2004) – which are necessary to bring about a change in pedagogy towards enquiry-based practical activities at upper secondary biology. While there is no rigid structure to the methodology with DBR, the three widely agreed stages to any DBR project are listed below (Gravemeijer and Cobb, in van den Akker et al., 2013; McKenney and Reeves, 2018). See Figure 2.1, below for an overview of these stages;

1. Needs and content analysis - this scoping stage is utilised to get a better understanding of the problem and involves a comprehensive literature review combined with analysis of lesson observations and interviews (Chapters 3).

2. Design, development and formative evaluation - this stage involves the theoretically grounded design and development of an educational innovation. Its cyclic character allows for multiple iterations of design and refinement until a

suitable innovation has been developed that can be trialled in the target environment.

3. Semi-summative evaluation – this stage is concerned with evaluation informed by retrospective consideration of the innovation that informs the wider educational community of its practicality and effectiveness in the target setting (Plomp, 2013).

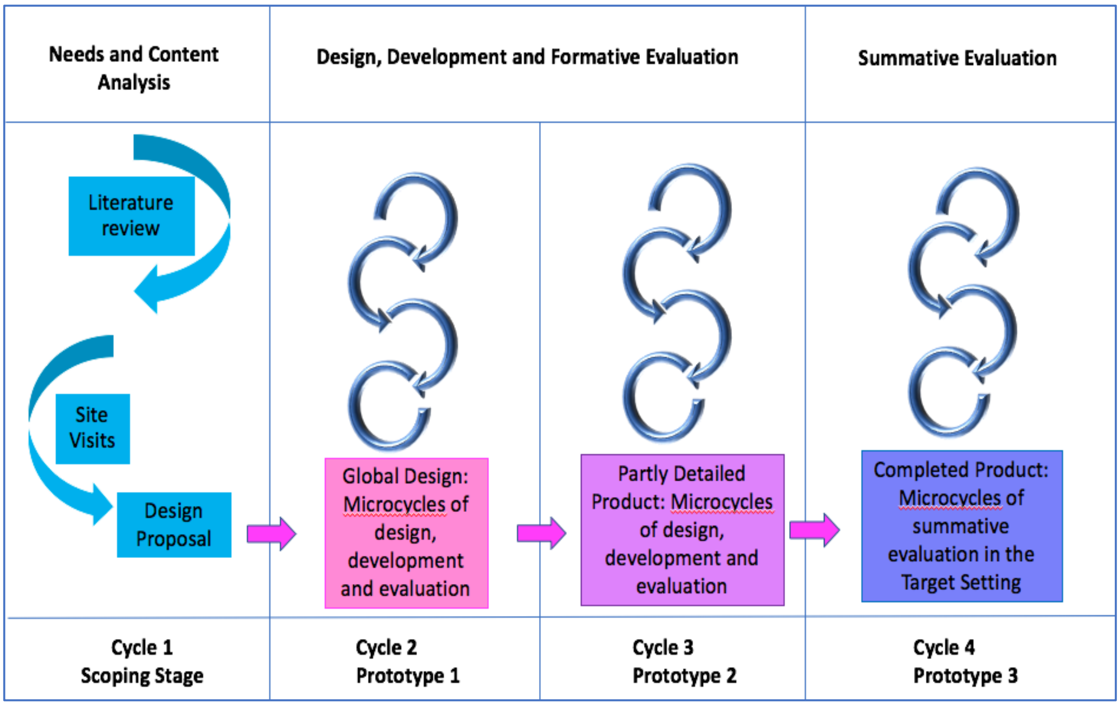

Figure 2.1: Process Display Model of this DBR Study

The diagram shows three clearly defined stages in the research project but the reality of DBR means that the stages can sometimes overlap (Nieveen and Plomp, 2013). Section 2.3 gives a detailed account of how the generic design was adapted for this research project.

The philosophical stance that DBR is most closely associated with is pragmatism (Anderson and Shattuck, 2012; McKenney and Reeves, 2018). “The most important question to ask from the point of view of pragmatism is not ‘What is true?’ but ‘What is the problem?’” (Biesta, 2014). The answer to this question lies in a systematic inspection of the meaning of the situation, with “situation” referring to the interaction of the organism and its environment (Dewey, 1938/2015), in this case examining how teachers and students experience practical activities in the biology classroom. The first step is to identify and state the problem, with subsequent steps concerning the development of suggestions for addressing the problem (Biesta, 2014). The implication is that action is required in order to develop knowledge, but that action must be intelligent (to distinguish it from blind action) which requires thinking or reflection (Dewey, 1916/2011). Therefore, each cycle of action must be followed by reflection and evaluation, which leads to knowledge about the situation. Knowledge in itself then becomes "literally something we do", grounded in the consequences of the actions we take (Dewey, 1916, p.367). As a result, it can only offer possibilities but not certainty, i.e. we can learn what works or does not work in a particular situation as a result of the actions we take in that situation. Sometimes this action is transferable, and sometimes it is not. Therefore, through the pragmatic lens, the outcomes of this research are akin to "warranted assertions" rather than claims to truth (Biesta, 2014). Whether or not these assertions will work in other similar situations can only be determined when we act upon them, meaning knowledge is always about the relationship between intelligent actions taken and the consequences that occur as a result. It is a future-oriented search for the end-in-view, where the outcomes predicted are always possible but uncertain (Dewey, 1925/1958). This pragmatic theory of knowing forms the basis of the structure of any DBR project: initially a needs and content analysis identifies and states the problem and is followed by cycles of design, testing and refinement of an intervention or artefact, which have inbuilt systems of evaluation and reflection to inform subsequent design cycles.

This means that if an ideology or intervention works satisfactorily, it can be accepted as true *in that particular situation,* while impractical ideas or interventions that are not suited to a purpose can be rejected as impractical. The pragmatic lens enables DBR to be used as a tool to design educational interventions through multiple cycles of testing and refinement, to create an intervention that is trustworthy, credible and usable in a classroom setting. The emphasis on function - of the design and the resulting learning ecology in a realised context - is central to the methodology (Cobb et al., 2003). Grounding DBR in Dewey's philosophy of enquiry, promotes a system of enquiry "rooted not in claims of truth, but rather in the viability of theories to explain phenomena and produce change in the world", which adds methodological rigour and epistemological coherence to the study (Barab and Squire, 2004, p.7). Dewey's philosophy forms the backbone of the theory of enquiry, developed in Chapter 5, and underpins the development of the educational intervention (designed for teachers to employ enquiry-specific pedagogies for biology). In the spirit of pragmatism, and the words of Lewin, “there is nothing so practical as a good theory”.

Ann Brown (1992), felt compelled to defend her pioneering DBR research against what she termed ‘the Dewey Effect’; namely, that her work was merely a recapitulation of Dewey. It is undeniable that Dewey heavily influenced her work philosophically but it is the process of translating his abstract theories into practical, educational innovations that situates her work firmly in pioneering territory. This is one of the key characteristics of DBR.

2.2 Why Design Based Research?

DBR evolved to bridge the “credibility gap” between educational research and educational practice by filling the “need for new research approaches that speak directly to problems of practice and that lead to the development of ‘usable knowledge’” (Design Based Research Collective, 2003, p.5).

The problem of practice in this research, is the lack of a clear definition of enquiry and a lack of clear guidelines on how to implement enquiry teaching in the classroom, combined with a culture of recipe-style instruction. If teachers cannot find usable, transferable, enquiry-based instructional pedagogies that are convincingly superior to the current recipe-style instruction, they will not risk tinkering with students’ prospects of achievement in a system that culminates in a one-off terminal exam. Ironically, recipe-style instruction does not lead to meaningful understanding of the scientific concepts and principles that underpin practical work, as explicated in Chapter 3. This project was centered around building a framework for enquiry with solid theoretical foundations, that delivers clear, practical and usable design principles for teachers.

Kelly (2013, p.137) outlines instances when DBR is recommended, all of which can be applied to this research project:

1. When there is a substantial problem facing learning and teaching and there are no available guidelines for addressing the problem (Chapter 3)
2. When the solution to the problem would lead to a significant reduction in malfunction in the education system (Chapter 5)

3. When there is little agreement on how to solve the problem (Chapter 3)

4. When the literature review reveals the ambiguous nature of solutions to the problem (Chapter 3, 5)

5. When the initial state of the problem and the potential solution is unclear (Chapter 3)

6. When the method of moving from the initial state to the goal solution are unclear (Chapter 4)

In other words, when the researcher is faced with a “wicked problem” (Rittel and Weber, 1977) - such as changing the historical and cultural pedagogy around practical teaching - whose solution contains many complex elements that make it frustrating or potentially unattainable, the nature of DBR makes it a suitable methodology for engineering pragmatic solutions.

There are some universally agreed characteristics of DBR that recommend it to providing the solution to the problem of practical pedagogy (Plomp, 2013):

1. DBR is theoretically oriented –

What distinguishes DBR from other research approaches is that a theoretical understanding of enquiry is used to frame not only the research, but also to shape the design of a Framework for Teaching Enquiry Activities (FTEA) as a practical solution to the problem. Gravemeijer and Cobb (2006; 2013) describe the emergent theoretical intent of their DBR research as an “ontological innovation”. DiSessa and Cobb liken the difficulty of defining the technical terms of science (enquiry) to “finding and validating a new category of existence in the world”, (2004, p.84). The role of an ontological innovation is to:

“….develop theoretical constructs that empower us to see order, pattern and regularity in the complex settings in which we conduct design experiments. Ontological innovations are attributions we make to the world that necessarily participate in our deepest explanatory frameworks.”

(ibid, p.84)

The dearth of a theoretical framework to underpin practical activities for science education in Ireland, necessitated the development of an ontological innovation that specifically embedded a comprehensive understanding of the type of enquiry best suited to teaching practical work in this particular context. There was also a need to put clear language and guidelines around enquiry teaching to make it accessible to practitioners. Ontological innovations play a dual role in DBR:

> "On the one hand they can serve as lenses for making sense of what is happening in a complex, more-or-less real world instructional setting in which a design study is conducted. On the other hand, ontological innovations can function as guidelines or heuristics for instructional design"
>
> (Gravemeijer and Cobb, 2013, p.80)

Common to ontological innovations, the theory emerges during the course of the design experiment as a need to create a lens through which to envisage enquiry teaching. Deng contends that there are challenges in "modifying theory for practical considerations and relating theory to practice in an eclectic, creative and innovative manner, for the purpose of constructing theory that matters in practice and in the world of schooling"(2018, p.707).

It is in this space that the research reported on here rests, it looks to relate theory to meaningful practice in the biology classroom, and *vice versa*.

2. DBR is interventionist –

DBR strives to positively impact practice by bringing about transformation through the design and use of solutions to real problems. The theory of enquiry developed to underpin practical pedagogy informed the design and development of the practical innovation – the FTEA. Two purposes of DBR termed 'development studies' and 'validation studies' (Plomp, 2013), which encompass research *on* interventions and research *through* interventions respectively (McKenney and Reeves, 2012), were amalgamated by this research. The FTEA was first developed as a pedagogical tool for teachers to use, and its effect on teaching and learning was investigated to validate its use in the classroom. The intention here was to influence how practical work is taught by providing a viable, usable enquiry-specific alternative that is convincingly superior to recipe teaching. Compared to other research methodologies (e.g. Randomised Controlled Trials), with DBR, the findings from interventions have amplified ecological validity since they are measured in the naturalistic setting of the classroom (Bakker and van Eerde, 2013). In addition the theoretical products of DBR "..have the potential for rapid pay-off because they are filtered in advance for instrumental effect" (Cobb et al., 2003, p.11).

3. DBR is collaborative –

The active participation of collaborators increases the potential relevance of the intervention and its chance of successful implementation in its intended setting (Plomp, 2013). In this project, the initial problem identification stage was conducted in collaboration with teachers and students who gave access to their classrooms and provided interview evidence about their experience of practical work. The next stage of the research, the design stage, involved not just the input of teachers and students, but also pre-service teachers and a university biology research scientist (termed the RP; researcher practitioner). In this way the craft wisdom of research partners in other design research contexts are valued and incorporated into the research (McKenney and Reeves, 2012). Collaboration in this sense added validity to the research endeavour, where interventions were adapted in different ways by different people, and yet still met the same basic goals (Clarke and Dede, 2009).

4. DBR is iterative –

When there is no known solution to the problem under study, there may be more than one way to solve the problem, or the solution to the problem may ultimately be ideal but requires refinement to enable the intervention to evolve over time through multiple iterations of investigation, development, testing and refinement (McKenney and Reeves, 2018). While many research methodologies are iterative, what is particular to DBR is that changes can take place during an experiment as opposed to in between experiments (Bakker and van Eerde, 2015). In this study, the initial conjecture that finding a way to incorporate minds-on pedagogies into practical lessons would lead to improved learning was revised following initial investigation results, and ameliorated by an alternative conjecture based on an ontological innovation underpinned by scientific enquiry. The subsequent intervention was then tested in four different learning environments; a small scale laboratory experiment, a workshop for practitioners, a pre-service teacher practical biology teaching module (PBTM) in a university setting, and in the target setting, the classroom. Having multiple iterations of the same intervention in different environments is reminiscent of Barab's "braids of change" where "each experience can be talked about independently, yet, by weaving them together, one gets a better sense of the design as a whole"(Barab, 2008, p.329).

5. DBR is process oriented –

In comparison to research methodologies that require a black box model of input-output measurement, DBR focuses on understanding what makes the black box work (Latour, 1987). Therefore a comprehensive documentation of the research process is deemed essential to generate a thick description, undergirded by four quality criteria that are universally applicable to DBR interventions; relevancy, consistency, practicality and effectiveness. Each iteration of an intervention is assessed for these four criteria to ensure methodological rigour.

Kelly (2006) talks about how the commissive space of design is exploratory and ambitious. The goal of DBR is to understand and foster meaning making through an historical, cultural and social process. There is an acknowledgement with DBR that these factors cannot be 'randomised away' so instead DBR researchers engage, understand and influence them in collaboration with teachers, students and other stakeholders. Kelly articulates very well the ethos of DBR as:

> "….experimental but not an experiment. It is hypothesis generating and cultivating, rather than testing; it is motivated by emerging conjectures. It involves blueprinting, creation, intervention, trouble-shooting, patching, repair, reflection, retrospection, reformulation, and reintervention."
>
> (2006, p.114)

The context of DBR therefore, is that of discovery rather than of verification (Schikore and Steinle, 2002). Developing a novel theory of enquiry to meet the requirements of the Irish biology curriculum, while simultaneously acting as a lens for designing an usable enquiry-based intervention was a process of exploration and description; analogous to mapping and signposting the route for other adventurers.

6. DBR is utility oriented –

The process of conducting the research project along with the process of enacting the intervention must be described in sufficient detail for researchers and practitioners to understand and use the intervention in real world settings. Ann Brown's observation that academic research often does not translate into implementable practice in classrooms led her to the development of DBR as a research methodology to engineer innovative learning environments to bridge this research/practice divide by contributing simultaneously to a theory of learning and to practice (Brown, 1992).

Brown's (ibid.) methodological approach was influenced by engineering studies where the emphasis is placed on the design of an usable innovation through iterative prototyping underpinned by rigorous scientific principles. Rather than being confined to the parameters of any particular research paradigm, she advocated for a mixed methods approach which was adopted in this research project, by combining empirical measurements with rich descriptions of knowledge acquisitions. In her own words:

> "I attempt to engineer interventions that not only work by recognisable standards but are also based on theoretical descriptions that delineate why they work, and thus render them reliable and repeatable."
>
> (1992, p.143)

In terms of alternative research methodologies, Action Research (AR) was considered for this project because it has many characteristics that are suitable for intervention-based research. It is situated in a real educational context (Anderson and Shattuck, 2012), it has a pragmatic philosophical outlook (Jen et al., 2015) and its approach is an iterative cyclic process of design, evaluation and redesign (Dolmans and Tigelaar, 2012). Like DBR, its interventionist nature also involves collaboration among participants (Bakker and Van Eerde, 2015).

However, the focus of AR is on practical issues that have been identified by practitioners as problematic yet capable of being changed (Cohen et al, 2007). As this section has already outlined, the problem of practical pedagogy in biology is 'wicked', with pedagogical issues only recognised by practitioners on a surface level, while their deeper epistemological implications remained hidden. Teacher participants in this study knew that students were not learning from practical work but could not envisage an alternative way of teaching (Chapter 3).

The focus with AR is on on action and improvement of a situation, while the focus with DBR is on intertwining educational theory with the design of interventionist artefacts (Bakker and Van Eerde, 2015; Dolmans and Tigelaar, 2012). DBR is aimed at advancing theoretical knowledge as well as knowledge of instructional design (McKenney and Reeves, 2018), leading to ontological innovations, or new ways of knowing.

This specific situation required a theoretical agenda where the "theory must do real work" by providing detailed "guidance in organising instruction" (Cobb et al, 2003 p.10). For this reason, DBR was more appropriate because of its theory-oriented underpinnings. AR does not take the same approach to developing and using theory - or ontological innovation – to design educational artefacts.

Decolonising Interpretive Research (DIR) was also considered as a possible research methodology for this project. Grounded in the work of Freire, the ethos of this methodology is to bring about a deliberate and meaningful epistemological shift in the production of knowledge, and the ownership of knowledge (1970). DIR seeks to challenge and disrupt what Parashkeva (2011) terms "epistemicides" – that is, one-dimensional Eurocentric ways of knowing, prevalent in traditional notions of education, of which recipe-teaching is an example. The main focus of DIR is on the production of counter-hegemonic forms of thinking and reflecting on the world, with a view towards understanding the impact of current social, cultural and economic hierarchies of domination, and how those structures impact on marginalised people – that is, the production of new theories (Darder, 2015)

In common with Brown's (1992) approach to DBR, DIR makes no claims to neutrality, actively working to deconstruct and reconstruct conditions for transformative practice, by recognising how people can change their conditions by naming the reality, problematising it, and posing new possibilities for change (Darder, 2015). It is a community approach to effecting change in practices that traditionally marginalise one or more groups of people.

DIR has potential as worthwhile future exercise if it is recognised that LC teachers and students of biology are marginalised from a deeper understanding of the subject through rote learning and recall-based examination (Burns et al., 2018), but DBR remains the most methodologically sound choice for this project because of its pragmatic capacity to delve under the rhetorical layers of terminal-exam culpability that teachers and students within the educational community cannot see. The use of DBR in this project was essential to interrogate the problem with recipe teaching and for the development of an alternative epistemology *within* the current system, through an iterative process of design, development and evaluation. There are quality assured research tools appropriate for each stage of the research process, that support the process of bringing new theories and artefacts from their nascence towards full realisation in the classroom setting (Nieveen et al., 2013). This clear-cut process is more appropriate given the complex nature of the issue (Chapters 4 and 5). With DIR this process is not as transparent (Darder, 2015).

2.3 Research design: Interpretation of DBR for this Project?

McKenney and Reeves (2012, p.78) outline how, within an iterative research project, there can be different levels of iteration, macro-, meso- and micro-cycles. The overall research endeavour is viewed as a macro-cycle of research. The three main phases of this DBR project (needs and context analysis, design and development of the innovation, summative evaluation) are viewed as meso-cycles. Each meso-cycle in turn, consists of a series of micro-cycles of which there can be any/all of three stages; analysis and exploration, design and construction, evaluation and reflection. McKenney and Reeves explain that "each one of these micro-cycles constitutes its own cycle of action, with its own logical chain of reasoning" (ibid, p.78). The analysis and exploration phase and the evaluation and reflection phases are empirical, featuring data collection. The design and construction phase is viewed as different and McKenney and Reeves term it a "deliberative-generative cycle" (ibid, p.78). This means that while it is informed by the findings of preceding phases, such as the literature review and analysis of site observations, it is also open to creative input or 'craft wisdom' from expert practitioners and other stakeholders and, as a stand-alone micro-cycle it is not empirical, it is subject to the rigours of a sound, coherent process. The function of this micro-cycle is the creation, not testing, of a conceptual intervention. The emphasis here is on the interaction between conceptualisation and creation; hence the term 'deliberative-generative'. The outputs from this phase are potential design solutions to the problem reified through application of these solutions to the construction of a prototype.

Application of McKenney's and Reeves's macro/meso/micro model led to the adaptation of this research project around iterative micro-cycles. Figure 2.2, below, gives a summary overview of the entire macro-cycle, illustrating the methodological design of this project. It contains three meso-cycles, representing the different stages of DBR, each one subdivided into appropriate micro-cycles as described below.

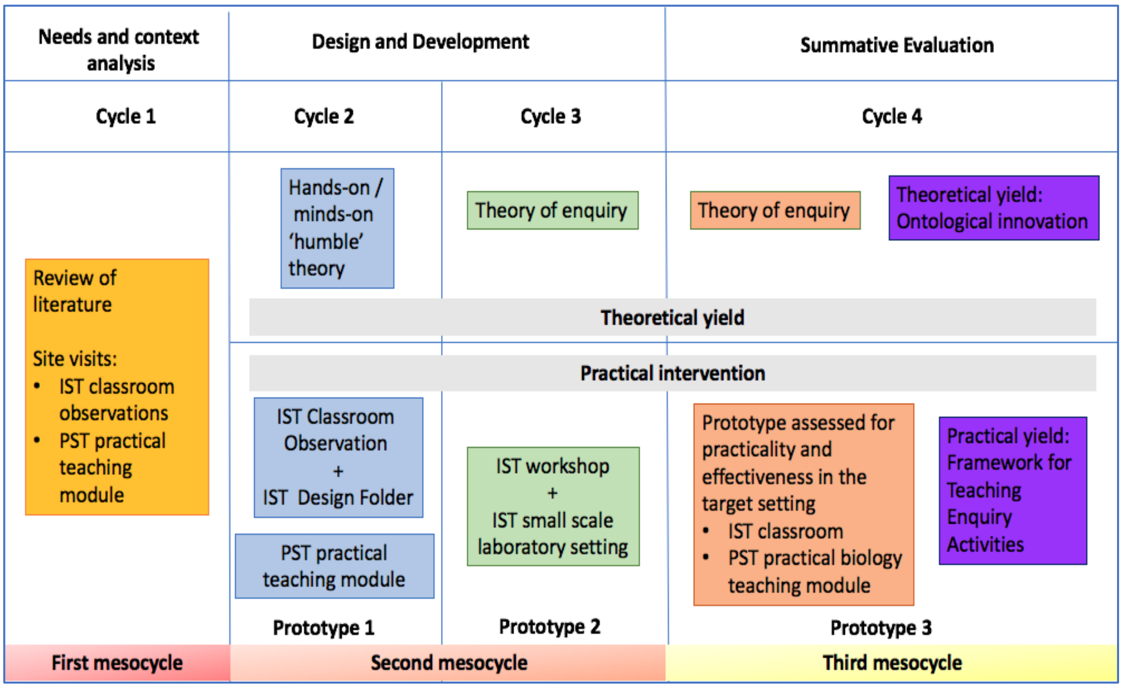

Figure 2.2: Macro-cycle overview of the project design.

2.3.1 First mesocycle – Needs and Content Analysis

The needs and content analysis cycle of the research is reported on in Chapter 3. This stage, termed Cycle 1, was viewed as a meso-cycle consisting of two micro-cycles of research;

1. Analysis and exploration which was subdivided into:

a. Review of the literature

b. Site visits – Inservice Teacher (IST) classrooms

2. Evaluation and reflection: the findings from this stage of the research were used to inform the second design and development meso-cycle (Chapter 3).

2.3.2 Second and Third Mesocycles – Design, Development, and Summative Evaluation

The evolution of the FTEA and the theoretical framework undergirding it is traced through two micro-cycles within the second meso-cycle, and one final summative-evaluative cycle. On paper these are reported as two separate stages in the DBR methodology, but in reality they often overlapped, hence they are described together in this section (Plomp, 2012).

In its nascence, DBR was subject to much methodological criticism regarding

- The lack of an argumentative grammar (Kelly, 2004)
- The superiority of methods such as Randomised Controlled Trials to demarcate between sound and unsound claims (ibid, 2004)
- The inability of DBR to simultaneously live up to the claim of design evaluation *and* theory building (Phillips and Dolle, 2006)
- The lack of methodological rigour or clear standards for DBR (Dede, 2004; Kelly, 2004; Shavelson et al., 2003).

Design Based Researchers have responded to questions of methodological rigour by developing research methods to ensure transparency and rigour. Nieveen and Folmer (2013), and Nieveen et al. (2012) designed an 'Evaluation Matchboard' that not only addresses issues of rigour and transparency, but also provides the researcher with a guide to evaluation techniques appropriate to the design and development, and summative evaluation of consecutive stages of an innovation.

Adopted here, the Evaluation Matchboard traced the development of the design intervention through two deliberative-generative micro-cycles and one summative-evaluative cycle; from the global design (prototype 1), through the partly detailed product (prototype 2), to the completed artefact (prototype 3). This meant that the design stage of each prototype was followed by reflection and evaluation of the innovation concurrently with the emergent theory. Figure 2.2 illustrates how the theoretical framework developed in tandem with the educational innovation.

Research methods appropriate to each stage were utilised to ensure methodological rigour and transparency throughout the second and third meso-cycles. Table 2.1, summarises how these meso-cycles are guided by the evaluation matchboard.

Table 2.1	Needs and content analysis	Design and Development Scoping prototype	Design and Development Walkthrough	Design and Development Microevaluation	Semi-summative Evaluation Tryout in third level setting	Semi-summative Evaluation Tryout in classroom setting
Descript-ion	• Comprehensive literature review and concept validation • Contextualise the problem with site visits	• Prototype lesson plan designed to incorporate hands and minds • Incorporation of laboratory skills into lesson plan	• Show teachers how to teach enquiry- based lessons using the framework	• The intervention is trialled in a laboratory setting with a small number of participants • (n=4; 2 students, 2 teachers) • 4 experiments adapted for the framework	The intervention is trialled in a revised university module with the framework for teaching through enquiry as the central tenet of the module (n=36).	Final prototype trialled in the target setting with target users
Research methods	• Observation (field notes, video and audio recording) of ISTs in classroom setting • Interview with ISTs and senior cycle students	• Screening (Nieveen & Vliegen) using checklist • Observation of pre-service teachers (PST) teaching an experiment using the prototype (n=28 – 6 experiments observed) • Focus group with in-service teachers (IST) (n=6) • One lesson observation (field notes, video and audio recording) • One lesson design using the prototype	• Audio recording of walkthrough with n=4 teachers • Interview with teachers after workshop (n=4)	• Video • Audio • Interview	• Questionnaire • Observation - audio • Interview • Evidence of student work	• Observation (field notes, audio and video recording) • Interview • Evidence of student work
Data analysis	• Template analysis using MAXQDA (King) • Enquiry analysis • PAAI analysis (Millar) • Questioning analysis (Bloom)	• Template analysis using MAXQDA • Artefact collection (PST lesson plans and IST lesson plan) • Enquiry analysis (IST) using SEOS • PAAI analysis (IST) • Questioning analysis (IST)	• Template analysis using MAXQDA • Artefact collection (Research team designed frameworks, n=4)	• Template analysis • Enquiry analysis • PAAI analysis • Questioning analysis • Artefact analysis – students' work	• Template analysis • Enquiry analysis • PAAI analysis • Questioning analysis • Artefact analysis – student work	• Template analysis • Enquiry analysis • PAAI analysis • Questioning analysis • Artefact analysis – student work -exam questions
Format-ive evaluat-ion	Students can work with their hands, but their minds are not engaged in what they are doing i.e. they know what they did but do not know why they did it	• PSTs were confused with the structure of the lesson plan but did understand the aim of the prototype lessons • There was no clear evidence of minds-on thinking in the lessons • Hands-on lab skills were taught very well • ISTs did not engage with the first prototype with the exception of one lesson design • The observed IST lesson showed no enquiry	3 goals of DBR are beginning to take shape 1. Professional development for teachers around enquiry teaching 2. Development of a sound theoretical framework 3. Development of an intervention grounded in theory	Professional development - Teachers gain more clarity on the nature of the intervention - they design and teach their own lesson using the framework Student gains in terms of understanding – they know what they are doing and why they are doing it.	Final design principles for the intervention consolidated before the implementation of the intervention in the target (classroom) setting.	Teachers become the curriculum makers in their own classrooms. Students have freedom of thought and action during practical lessons. Evidence that students understand the scientific principles underlying practical lessons. Students are able to apply principles in unfamiliar contexts.
Next step	• Incorporate minds on activities into practical lessons • Include lab skills specifically into lessons	• Develop a theoretical framework for teaching enquiry- based lessons (Dewey) • Redesign prototype to reflect theoretical stance • Keep the lab skill focus • Professional development of ISTs to engage with enquiry teaching	Further professional development for ISTs in small scale laboratory setting with n=2 students	• Use the revised intervention again with PSTs in the same college module as before- adopt the module to focus on the enquiry-based nature of practical lessons	• Classroom tryout – use of the intervention in the senior cycle setting.	Document design principles

Table 2.1: Structure of design and development meso-cycle adapted from Nieveen & Folmer (2013)

Prototype 1 (Scoping Prototype Micro-cycle)

The first set of micro-cycles in this mesocycle focused on incorporating the mind into practical lessons and was developed as a humble theory based on research by Abrahams and Millar (Abrahams, 2009, 2017; Abrahams and Millar, 2008; Millar, 2004, 2010; Millar and Abrahams, 2009). On Table 1 this refers to the scoping prototype, since it ensued from the scoping stage. There are three micro-cycles here:

1. Analysis and exploration – of the humble theory (Lobato, 2008)
2. Design and construction – of a preliminary framework for teaching practical work. This was the first deliberative-generative cycle within this micro-cycle.
3. Evaluation and reflection – between September and December 2019 evaluation of a Framework for Teaching Practical Activities (FTPA) occurred in two different settings; the school and the university. The FTPA was shared with In-service Teachers (ISTs), who were asked to use it to design a practical lesson and trial the lesson in their classrooms. It was also trialled during a Pre-Service Teacher (PST) Practical Biology Teaching Module (PBTM). This university module was aimed at teaching PSTs how to teach senior cycle practical work. PSTs were taught two FTPA-designed practical activities and were then asked to design and teach one of six other activities using the FTPA.

In both settings the innovation was evaluated through a screening process where a checklist of expected characteristics of the design was created and then compared to the actual lessons observed. Lesson observations were evaluated through field notes, video/audio analysis and artefacts produced (Nieveen et al.,2012).

Reflection on this stage revealed that the humble 'minds-on' theory was not sufficient to support 'minds-on' engagement with the framework and did not lead to enquiry-based teaching. At this point an 'enquiry vacuum' (Chapter 4) opens up revealing the 'wicked' nature of the problem. A complete revision of the prototype *and* the theoretical framework was undertaken, leading to a turn towards the theory of enquiry and an exploration of enquiry teaching.

Prototype 2 (Walkthrough and Micro-evaluation)

The second meso-cycle focused on the development of a theory of enquiry and a programme for professional development to underpin the revised innovation. Again three micro-cycles were conducted:

a. Analysis and exploration – a theory of enquiry was developed to undergird the ontological innovation that was subsequently designed (Cobb and Gravemeijer, 2008; diSessa and Cobb, 2004; Gravemeijer and Cobb, 2013; 2006). Chapter 5 outlines this stage.

b. Design and construction –the ontological innovation, a redesigned and renamed Framework for Teaching Enquiry Activities (FTEA), was trialled in two different settings (Walkthrough Workshop and Micro-evaluation). Hence there were two deliberative-generative micro-cycles for each design and construction phase trialled at this stage:

Walkthrough Workshop (WW)

The recognition that professional development should also become one of the research goals of the project (van den Akker, 2006), led to the development of a Community of Practice approach to the Walkthrough Workshop in February 2020, in the university laboratory, for ISTs to informally explore how the FTEA supported the development of enquiry-based lessons (Wenger 1998). A teacher practitioner (TP) and a research practitioner (RP) designed, developed and taught FTEA lessons for three practical activities from the senior cycle syllabus. The deliberative-generative aspect of this workshop is in the design and development of the workshop, and of three new FTEAs.

Micro-Evaluation

Ann Brown (1992), advocates for the mutually beneficial results of combining small scale laboratory experiments (to get to the crux of an idea) with large scale classroom experiments (to understand the artefact in the 'messiness' of a real world setting). Micro-evaluations of four FTEAs, with two teachers from the workshop and two volunteer 5th year senior cycle students, took place in a small-scale laboratory setting, over four weeks in August 2020. Three different FTEAs were designed, developed and taught by the TP, and the fourth FTEA was designed, developed and taught by the two teachers. Professional development comes to the fore here as the teachers became involved in the deliberative-generative micro-cycles of design and development. At the end of this micro-cycle, the two teachers had trialled 8 FTEAs (almost 40% of the total number of experiments on the senior cycle syllabus), and learned how to design their own FTEA.

c. Evaluation and reflection – Each setting was subject to its own evaluation and reflection phase, based on the evaluation matchboard (Nieveen and Folmer, 2013). The walkthrough workshop was evaluated using a screening checklist. In addition, interviews are conducted with all participants following the workshop and an audio recording of the workshop is made. The data analysis of this stage informs the micro-evaluation stage, which is evaluated through video, audio and interview analysis.

Prototype 3 (Tryout in the Target Setting)

This third meso-cycle had only one micro-cycle, evaluation and reflection of the effectiveness and versatility of FTEA in two target settings – the third level PBTM and the senior cycle classroom. Here the research moved away from theory building and towards relating theory to practice.

At third level, the TP and RP designed and delivered eight practical FTEA lessons over 12 weeks using the Walkthrough Workshop approach. At the end of the module, each PST was tasked with using the FTEA to design and develop their own experiment from the senior cycle biology syllabus (one they had not undertaken in the laboratory). The PBTM was evaluated through pre- and post-module questionnaires, audio recordings made during the laboratory classes and photographic evidence of students' work.

At second level, four practical lessons and one practical assessment are trialled in a senior cycle biology classroom. The two practitioners, who had been involved in successive design cycles in this mesocycle, undertook teaching practical lessons in their senior cycle classrooms, using the FTEA. Evaluation of this stage is conducted through observation, audio & video recording, interview, and evidence of students' work.

The events that were subject to evaluation and reflection from the design and construction stages of each micro-cycle are summarised in Figure 2.3, below. Nieveen and Plomp (2013) point out that there is the potential for overlap between the various cycles of design and development, where one design cycle may not be entirely complete before the next cycle begins or, in this case, where there are two parallel situations in which a design is being developed. The PBTM was developed concurrently with the Tryout in the target setting and thus it spans Cycle 3 and Cycle 4 in Figure 2.3.

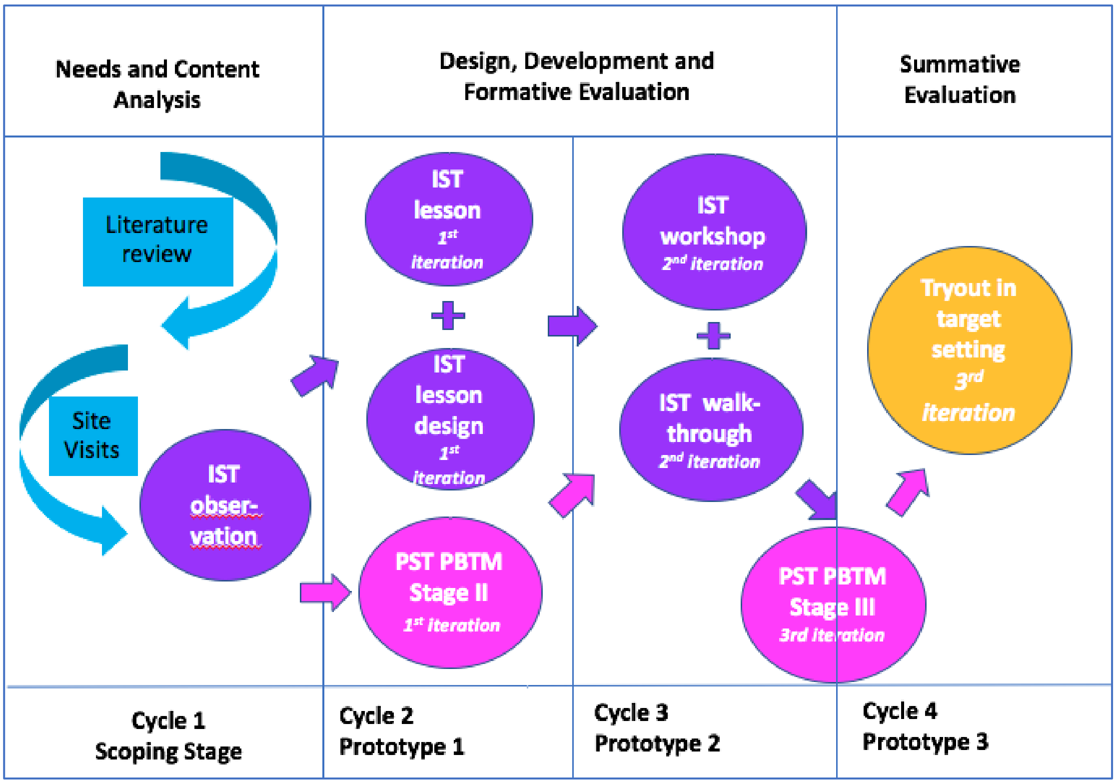

Figure 2.3: Summary of the activities undertaken to evaluate each micro-cycle of design and development.

2.4 The Evolution of the Sample Size

In the literature, the manner in which practical work is taught tends to be uniform in nature (Abrahams and Millar, 2008), indicating that a small sample studied in-depth would produce valuable data at all stages of the research, in terms of working collaboratively with teachers in various group settings, to develop a working innovation.

Mason's (1996) Theoretical Sampling best describes the type of sample appropriate to DBR because its focus is on choosing groups and categories that are relevant to the account that is being developed, meaning that the sample size is subject to change, depending on the research goals for each iteration of the research. This provides a sample that is “meaningful theoretically, because it builds in certain characteristics or criteria which helped to develop and test your theory and explanation” (Mason, 1996, p.93-94).

Members of each theoretical sample were drawn from four sources:

- The teacher design team (TDT) (Handelzalts, 2019) – comprised of a Teacher practitioner (TP), a biology teacher-turned-researcher with twenty years of experience at senior cycle, currently undertaking this PhD research, and a Research Practitioner (RP), a university biology lecturer-and-researcher. In later iterations of the innovation, ISTs joined the TDT as collaborators.
- ISTs - practicing biology teachers, who teach senior cycle biology students.
- PSTs - 3rd year university students who undertake a 12-week Biology Practical Teaching Module (PBTM)
- Secondary school senior cycle biology students

Samples were built specific to the needs of the study (Cohen et al., 2007). This facilitated a crossing over of ideas during the design and development research meso-cycle in particular, which enriched the prototype through successive designs, culminating in the final FTEA. Yin (2009) identifies the goal of this type of research as expansion and generalisation of theories - rather than enumeration of frequencies – in this case, of a theory of enquiry and development of an innovation, (the FTEA).

Four features of theoretical sampling are adopted here (Silverman, 2015):

1. Cases were chosen in terms of the theory (of enquiry) which were then used to represent the wider population. If the experiences of participants in practical classrooms are typical of the broader class of phenomena to which the theory refers and if the theory stands up in other ‘milieux’, such as the PBTM, then the research can be further validated (Bryman, 1988).
2. Cases that deviated from the innovation were chosen at the beginning of the prototyping design and development cycle which offered crucial insights into the design to test its effectiveness.

3. The sample size was adapted to accommodate the aims of each design cycle, which accorded with Mason's (1996) description of theoretical sampling, above.

4. The social situation in its entirety was studied in depth by including the actions of the teacher, interactions among students, student work, interviews with participants etc.. Gobo terms this view of the sample as the 'interactive unit' (2008, p.203). Section 2.4.2 explicates the four distinct interactive units in each design and development cycle.

2.4.1 The Recruitment Process

Recruiting ISTs

Reeves (2010) describes the delicate nature of gaining access through gatekeepers; people who have the power to grant or deny access to the research site. Through professional networking, access was gained to the schools in this study *via* gatekeepers, in some cases principals, in others, teachers. Following all ethical guidelines, secondary school biology students were given the option of partaking in the study by their teachers. Table 2.2 outlines the sample of teachers who took part in the research process.

Table 2.2: The sample of teachers that took part in each stage of the research

Name*	Years of Experience (up to 2018)	School	Cycle 1 Participation 2018		Cycle 2 Participation 2019		Cycle 3 Participation 2020		Cycle 4 Participation 2020
			Observ-ation	Inter-view	Focus group	Use of FTEA	Walk-through Work-shop	Micro-evalua-tion	Tryout
Ms. Brown	38	1		✓					
Mr. Kerwin	12	2	✓						
Ms. Rogan	15	3	✓	✓	✓		✓		
Mr. Donnell	4	4	✓	✓	✓		✓	✓	✓
Ms. Hollywell	5	4	✓		✓		✓	✓	✓
Mr. Jones	6	2	✓	✓					
Ms. Reilly	4	2	✓	✓					
Ms. Byrne	8	5		✓	✓	✓			
Ms. Power	9	5			✓				
Ms Smith	4	2			✓				
Ms. Hughes	5	5			✓	✓	✓		

*Pseudonym

Table 2.3 indicates the location and description of the schools that were involved in the sample size. The schools were varied in terms of their physical location and student population. All schools were mixed sex.

Table 2.3: Location and description of schools in the sample studied

School Number	Location	Description	Approximate No. Students
1	East Midlands	Urban	400 mixed
2	East Midlands	Rural	650 mixed
3	East Midlands	Urban	1200 mixed
4	South	Urban	1000 mixed
5	East	Urban	800 mixed
6	South East	Rural	400 mixed
7	South East	Rural	1000 mixed

Recruiting PSTs

In the university, during this doctoral research project, this TP taught and assessed the PBTM in collaboration with the RP. This laboratory-based module was designed for third year undergraduate PSTs to learn how to teach senior cycle biology experiments. All PSTs were given the option of partaking in the research. In 2019 27 PSTs participated in trialling the first prototype of the FTPA. The FTEA developed during the 2020 module involved 36 PSTs.

2.4.2 Interactive Units

A description of each interactive unit is presented in this section according to four design cycles (Gobo, 2008)

Cycle 1: Needs and content analysis

During September and October 2018, eleven teachers agreed to take part in the study. Ten lessons in total were observed between September and December 2018. Six interviews with teachers and four interviews with groups of students were also completed during this phase. Table 2.4 outlines the sample sizes and the data collected during this scoping stage.

Table 2.4: Interactive unit for cycle 1

ISTs: n=11

Table 2.4(i): Sample size for ISTs showing 10 audio and video observations with 6 teachers, and 6 interviews

Title of experiment observed	Teacher	School	Video data	Interview data	Student audio
Prepare and examine microscopically a T.S of a dicotyledonous stem	Ms. Rogan	3	✓	✓	✓
Investigate the effect of water, oxygen and temperature on germination	Mr. Kerwin	2	✓		✓
Investigate the effect of IAA growth regulator on plant tissue			✓		✓
Dissect and display a sheep' heart	Mr. Donnell	4	✓	✓	✓
Test for alcohol using iodoform			✓		✓
Production of alcohol by yeast	Ms. Hollywell	4	✓		✓
Investigate the effect of light intensity on the rate of photosynthesis	Mr Jones	2	✓	✓	✓
Investigate the effect of temperature on the rate of enzyme activity	Ms. Reilly	2	✓	✓	✓
Investigate the effect of pH on the rate of enzyme activity			✓		✓
Prepare one enzyme immobilization and examine its application			✓		✓
n/a	Ms. Brown	1		✓	
n/a	Ms. Byrne	5		✓	

Students in IST classrooms
n=103

Table 2.4(ii): Student interview sample

School	Group	No of students interviewed
School 2	Student interview 1	3
	Student interview 2	2
School 4	Student interview 3	5
	Student interview 4	6

Cycle 2: Design and Development of initial prototype

During September 2019, a meeting was held with 7 teachers to outline the first prototype of the FTEA. Teachers were asked to adapt the FTEA for use in their own practical lessons. One teacher successfully designed a microscopy FTEA and another teacher trialled a lesson that was designed by the TDT (DNA extraction).

Between September and December 2019, the prototype FTPA was introduced to PSTs during the PBTM. Two enquiry-based experiments were modelled by the TDT, using the prototype of the FTPA. PSTs were then tasked with using the FTPA to design and teach a different practical activity from the LC syllabus. Table 2.5 identifies the sample sizes and the data collected during this design cycle.

Table 2.5: Interactive unit for cycle 2 (design and development: scoping prototype)

Cycle 2: September – December 2019

ISTs n=7
Focus Group attendees
Ms. Byrne, Ms. Power, Ms. Hughes, Ms. Smith, Mr. Donnell, Ms. Hollywell, Ms. Rogan

Table 2.5(i): Data collected from cycle 2 ISTs

Teacher	School	Lesson title	Data collected
Ms. Hughes	2	Use of a light microscope to examine prepared plant cells	Lesson Plan with associated powerpoints and worksheets
Ms. Byrne	2	To isolate DNA from plant tissue **n=15 students**	Field notes Video recording Audio recording

PSTs n=27
PBTM Strand 2
Table 2.5(ii): Data collected from cycle 2 PSTs

Exemplar experiments taught	PST experiments taught (n=27)	Data collected from student experiments
Growth of leaf yeasts using agar plates (TP) DNA extraction (RP)	Effect of IAA on plant tissue (n=5) Effect of pH on the rate of enzyme activity (n=5) Effect of temperature on the rate of enzyme activity (n=5) Preparation and production of alcohol by yeast (n=5) Effect of light intensity on the rate of photosynthesis (n=4) Preparation of one enzyme immobilization and examination of its application (n=3)	Field notes Samples of students' use of the framework Audio of student-student interactions Survey

Cycle 3: Design and development of the FTEA

There are two separate settings that ISTs participated in during this cycle - the Walkthrough Workshop and the Micro-evaluations.

1. Walkthrough Workshop

In February 2019, the TDT designed and delivered a professional development workshop, to assist teachers to engage with enquiry teaching. The TDT tailored experiments, selected by ISTs as relevant to their upcoming schemes of work, to the FTEA. The workshop generated a space for teachers to informally develop their understanding of enquiry and improve their practical teaching skills in a laboratory setting, away from their own classrooms.

It should be noted that at this point in the research, Covid-19 was beginning to have an impact on the participants' personal situations, and only 4 out of 11 teachers could attend the workshop.

2. Micro-evaluations: Small scale laboratory setting

During March and April 2020 schools were closed due to a national lockdown as a result of the impact of Covid-19. As soon as it was permissible to gather a small number of people (n=5) in an indoor space together, a small-scale laboratory setting was developed by the TP, with two teachers and two senior cycle biology students, to trial the revised FTEA over the course of 4 weeks. One FTEA lesson was taught each week. Three of the activities were designed by the TP and RP, with the fourth (microscopy) designed collaboratively by the two ISTs. Table 2.6 indicates the sample sizes and data collected during this cycle.

Table 2.6: interactive unit for cycle 3 (design and development: walkthrough, micro-evaluation, try-out)

Cycle 3: February -December 2020

Walkthrough Workshop – small scale laboratory setting
February 2020

ISTs
n=4
3 FTEAs

Table 2.6(i): Walkthrough workshop sample

Teacher participants	Experiments conducted	Data collected
Mr. Donnell Ms. Hollywell Ms. Rogan Ms. Hughes	1. Investigate the effect of IAA on plant tissue 2.Investigate leaf yeast using agar plates 3.Use of starch or skimmed milk agar plates to show digestive activity during germination	Interview with all teachers Audio recording of workshop

Micro-evaluation – small scale laboratory setting
July-August 2020

ISTsn=2 **Students n=2 (2 x 5th year students from schools 6 and 7 respectively)**
4 FTEAs

Table 2.6(ii): Micro-evaluation sample

Week no.	Title of experiment	Participants	Data collected
Week 1	Dissection and display of a sheep's heart	TP Mr Donnell Ms Hollywell Mary Ava	Video and audio recording of l (including informal conversations) Records of students' work 1 lesson designed by Mr Donnell a Hollywell using the framework
Week 2	Investigate leaf yeast using agar plates		
Week 3	Use of a light microscope to examine prepared plant cells		
Week 4	Investigation of the factors affecting enzyme activity		

Cycle 4: Tryout in the target setting

Finally, the prototype of the framework for enquiry was brought to two target settings between October and December 2020 (Table 2.7). In the second level biology classroom, five lessons were observed during this time. Interviews were conducted with Mr Donnell, Ms Hollywell and four of their students.

Between September and December 2020, the redesigned PBTM was delivered to third year undergraduate PSTs. The module was significantly altered from the previous two strands, with the TDT modelling eight FTEA designed lessons. The usability of the FTEA was developed iteratively over the course of the module, following reflection on each lesson by the TDT. Students were then asked to design a FTEA for one other senior cycle experiment. Table 2.7 documents the lessons modelled by the TDT, designed by students, and the data collected.

Table 2.7: Interactive unit for cycle 4 (design and development: try-out in target setting)

<table>
<tr><td colspan="2">Cycle 4: October -December 2020</td></tr>
<tr><td>ISTs – Try-out
n=2
Table 2.7(i): Sample size for classroom try-out
<table>
<tr><td>Teacher</td><td>Experiment</td><td>Data Collected</td></tr>
<tr><td>Mr Donnell</td><td>Microscopy</td><td rowspan="5">Video & audio recordings

Examples of student work

Interviews</td></tr>
<tr><td>Ms Hollywell</td><td>Factors affecting the rate of enzyme activity</td></tr>
<tr><td>Mr Donnell</td><td>Factors affecting the rate of enzyme activity</td></tr>
<tr><td>Mr Donnell</td><td>Factors affecting the rate of enzyme activity</td></tr>
<tr><td>Mr Donnell</td><td>Practical assessment</td></tr>
</table>
</td><td>Students
n= 48

2 interviews with 4 students

Interview 1: Joe & Lia

Interview 2: Katie & Carol</td></tr>
</table>

PSTs – Try-out
September – December 2020
n=36
Table 2.7(ii): Try-out sample size

Sample size	FTEAs modelled by the TP and RP	Each PST designs one FTEA from the list below	Data collected
n=36 PSTs	1.Ecology field trip 2.Effect of light intensity on the rate of photosynthesis 3.Investigate leaf yeast using agar plates 4.Use of a light microscope to examine prepared plant cells 5.Dissection and display of a sheep's heart 6.Investigation of the factors affecting enzyme activity 7.Preparation of one enzyme immobilization and examination of its application 8.Preparation and production of alcohol by yeast	1. To test food for the presence of fat, protein, sugar, starch 2. Demonstration of osmosis 3. Investigate the effect of water, oxygen and temperature on germination	Initial survey Final Survey Records of students work, including lesson design Audio of laboratory lessons

2.5 Research Instruments and methods

Table 2.1 indicates the three main research instruments utilised to collect data; interview, observation and questionnaire. Each section elucidates:

1. How the instruments were adapted for use in this project
2. The method by which the data collected by the instrument was analysed
3. How quality was achieved in the collection and analysis of data

The following sections detail how each instrument was adapted for this study:

2.5.1 Interview

Kvale defines the interview as, "an inter-view, an interchange of views between two persons conversing about a theme of common interest" (2011, p.6). As such, the interview is neither objective nor subjective, it is intersubjective (Cohen et al., 2007). Baker and Johnson describe the interview as "a particular medium for enacting people's knowledge of cultural forms, as questions, far from being neutral, are couched in the cultural repertoires of all participants, indicating how people make sense of their social world and of each other" (1998, p.230). The intersubjectivity of the interviews increased over the course of three years working with the research participants, as the TP established a rationale of personal involvement with the teachers in the study, leading to a less hierarchically delineated relationship, which in turn optimised interview data-gathering goals (Oakley, 1984).

Interviews were also employed here to test hypotheses and to suggest new ones (Cohen, 2007). Additionally, at the beginning and end of the research process, alternative answers to the same questions tracked the transformation in thinking that took place among research participants. This approach blends seamlessly with the DBR methodology, which is transformative by nature.

Semi-structured interviews were designed following Mason's guidelines for planning interview questions, since they provide researchers with flexibility to examine relevant topics in greater depth while also allowing unforeseen topics to be explored (Mason, 2017):

1. Work out the 'big' questions that the interview should answer. For example, one big question taken from reports in the literature and the scoping stage observations is: 'Do the syllabus requirements and classroom enactment of the syllabus align?' (Abrahams and Reiss, 2012; Government of Ireland, 2003, Government of Ireland, 2002; Government of Ireland, 2001; Grunwald and Hartman, 2010; Hofstein et al., 2005; Kind et al, 2011; Lunetta et al., 2007; Llewellyn, 2013; National Research Council, 2012).
2. Break each big question into a series of 'mini-questions' to delve deeper into a theme. For example, pertaining to whether syllabus requirements and classroom enactment align were questions around whether specific aspects of scientific enquiry were present; observation, formulating hypotheses, data interpretation etc. (Grunwald and Hartman, 2010; Llewellyn, 2013; Hofstein et al., 2005; National Research Council, 2012).
3. Work out what each mini question is endeavouring to uncover. Here the mini questions were derived from themes which had been identified through a comprehensive review of the literature, from syllabus documents, from classroom observations and from audio of student conversations. Appendix 2.1 lists the themes incorporated into student and teacher interviews and indicates the origin of each theme, along with general mini questions that were derived from each theme.

4. Cross reference so that each big question has a set of mini questions and each mini question has a set of ideas about interview topics. The connection between themes and questions is outlined in Appendix 2.1.

5. Develop a loose format for interviews. Each mini question acted as a separate topic to be explored in as much, or as little, depth as was deemed necessary as evidenced in the interview transcripts.

6. Work out if there are any standardised sections. One standard question was asked of all students and teachers; Why do we teach practical work? This allowed a comparison with the syllabus view on why practical lessons should be taught (Government of Ireland, 2003, Government of Ireland, 2002; Government of Ireland, 2001), and with classroom observations, to investigate whether the reasons given for teaching practical work were evident in the enactment of practical work.

2.5.1.1 Data Analysis of Interviews using Template Analysis

Template analysis (TA) has its origins in the work of Crabtree and Miller (1999), who devised a method of creating a coding scheme as a descriptive/interpretive tool for qualitative data that bridges the gap between top-down deductive data analysis and bottom-up inductive data analysis. It is described in Brooks et al. as "…a form of thematic analysis which emphasises the use of hierarchical coding but balances a relatively high degree of structure in the process of analysing textual data with the flexibility to adapt it to the needs of a particular study." (2015, p.203).

To be classed as 'theme' a piece of data must recur several times in the data set and it is defined as a feature of a participant's account "characterising particular perceptions and/or experiences that the researcher sees as relevant to the research question" while 'coding' refers to "the process of identifying themes in accounts and attaching labels (codes) to them" (King, 2004). The template created based on a subset of data (e.g., six interviews) is then applied to further data, revised and refined in an iterative fashion.

TA can be applied to various data collection procedures including interview transcripts (Brooks et al., 2015), focus groups (Brooks, 2014), and open- ended questionnaires (Kent, 2000). It has previously been used in an educational research setting (Au, 2007), and it has a spectrum of adaptability ranging from a single autobiographical case (King, 2008) to a large- scale study with over 80 interviews (Donnelly, 2008).

In common with DBR, TA's iterative nature means that it is necessary to revise and refine templates until the data is unquestionably accounted for under the selected themes. King provides a description of the process in numerous books chapters (Brooks et al, 2015; King, 2012; King, 2004), journal articles (Brooks and King, 2012; King et al., 2002; McCluskey et al., 2011) and also through the University of Huddersfield website (King, 2004). King's process is applied to this research using MAXQDA software as the coding tool. Figure 2.4 provides an example of the scoping stage final template used to analyse teacher interview data.

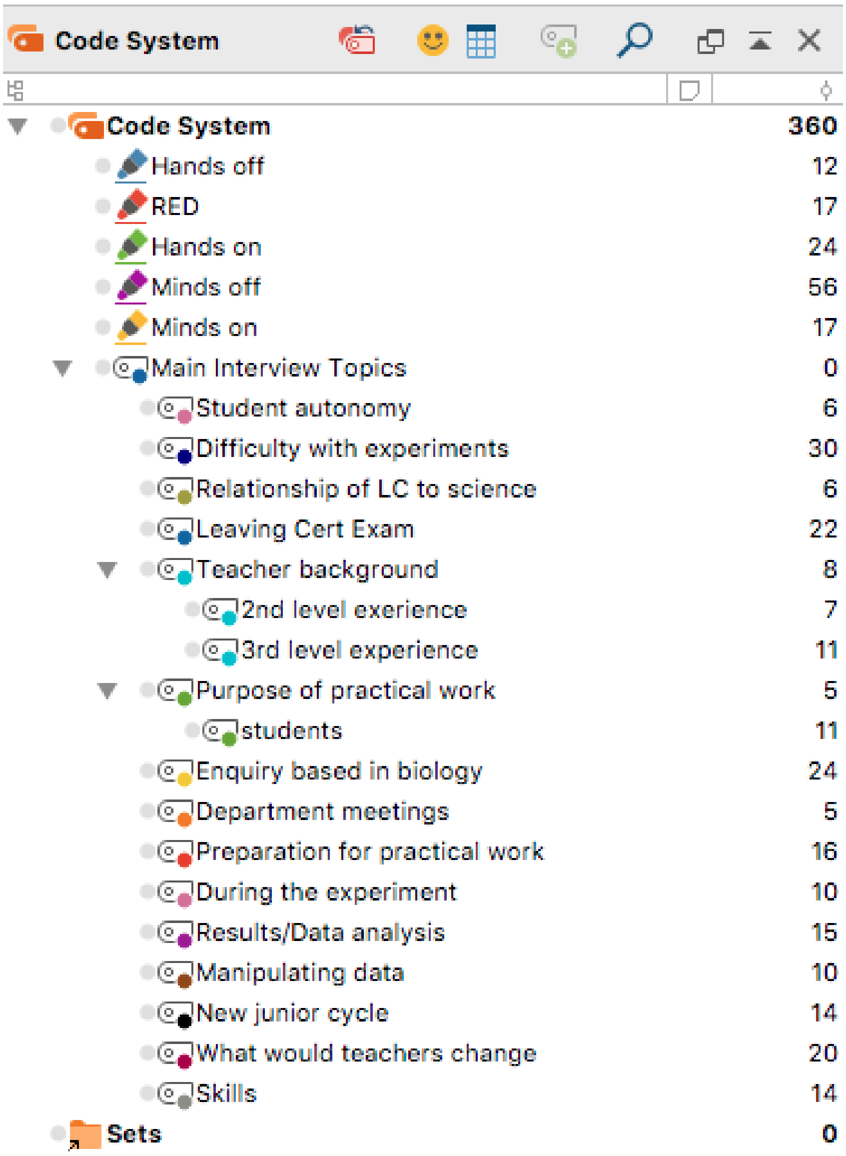

Figure 2.4: Coding system for teacher interviews

TA was entirely appropriate as a data analysis technique here, in the sense that there was both an inductive and deductive aspect to the data analysis, which is in keeping with the spirit of DBR (McKenney and Reeves, 2012), compared to Grounded Theory (Corbin and Strauss, 2008) or Interpretive Phenomenological Analysis (Smith and Shinebourne, 2009) which are inductive only, or Framework Analysis (Pope et al., 2000) which is purely deductive. Five reasons are outlined below that establish why TA is the most suitable method of data analysis for this project.

1. Use of *a priori* themes

TA occupies a position that bridges inductive and deductive analysis techniques, meaning 2-3 higher level themes could be defined *a priori* which were used tentatively in the initial template while themes could also be created from interview transcripts (King, 2012). King (ibid.) advocates for the use of *a priori* themes as an acknowledgement that the researcher has undertaken the data analysis with issues in mind that warrant an investigation and it is better to be upfront about this than to pretend that a theme has been 'discovered'. In the case of this research project, these themes were selected from the initial interviews, which asked specific questions to get answers to issues raised in the literature review.

Notwithstanding, the main part of the process was to conduct a bottom up reading through the text and code all relevant areas of interest to ensure nothing was overlooked. Codes at the top of the hierarchy covered broad themes and have nested within them more defined, narrow themes.

2. Flexibility of the coding structure

Unlike Thematic Analysis (Braun and Clarke, 2006), the hierarchical structure of the coding was not restricted to three levels of coding; four or five levels of hierarchical themes were possible, allowing an exploration of the research question in greater depth, and simultaneously capturing at a broader level, other areas of interest. For example, during initial interviews it emerged that teachers had no pre-service or in-service professional development specific to teaching practical work through enquiry. This lack of enquiry training was assigned as a theme and data relating to it was coded as such. The highly flexible nature of TA meant that subsequent templates can be easily modified following on from the initial template (Androitis, 2010).

3. Suitable for studies with applied concerns

This study was not merely about depicting the problem with practical teaching, it also had an applied aspect that required analysis and interpretation before the next cycle of research could resume. TA's flexibility enabled its use as a research tool throughout the project which ensured continuity and enhanced the reliability of the interpretation (Brooks and King, 2012). Successive iterations of the DBR cycle were analysed here using modified versions of the original template.

4. Useful across cases

An aim of TA was to look for similarities in themes across cases (King, 2012). Following McCluskey et al. (2011) - who analysed data from two different groups (people suffering with back pain and their significant others) to gain insight into different perspectives of the same phenomenon - teacher experiences of practical teaching were coded and then the student experience was mapped onto this data. A rich account of the experience of practical work from two diverse viewpoints is produced allowing commonalities and differences to be captured (King et al., 2002).

5. Epistemological flexibility

In Brooks et al. (2015), TA is not identified with any particular epistemological position; therefore it is important that the researcher is explicit about their particular epistemological assumptions. Here both the methodology and philosophical underpinnings were grounded in pragmatism; specifically, the work of Dewey regarding enquiry teaching (see Chapter 5). Following Madill et al. (2000), TA was used in a pragmatic way to search for research-based meaning rather than absolute facts. It was acknowledged that the final template in each research cycle was but one of a number of ways of interpreting these data.

2.5.1.2 Ensuring Quality in Collection and Analysis of Interview Data

The term 'quality' is used here, drawing from Roulston's (2010) and Kvale's (2011) interpretations of ensuring quality condensed into four facets below.

Roulston (ibid, p.202) outlines four interrelated facets of quality in interviews

1. The use of interview data was justified here as an appropriate means to inform the research questions posed, because questioning teachers and students about practical work enabled an in-depth examination of the reasons for the prevalence of

recipe teaching and its effects on learning, which could not be captured by any other method.

2. The interviewer and the interviewees must adequately understand one another's meanings. The TP's experience as a biology teacher assured this understanding.

3. Quality must be addressed in the research design. Kvale's (2011) uses the concept of validity to refer to the correctness and the strength of a statement. He outlines two general approaches to validating an interview:

   a. The craftsmanship of the interviewer ensures that the interview answers the research question. It is underpinned by a theoretical conception of what is investigated to ascertain whether the interview investigates what it intends to investigate. Grounding interview questions in the academic literature, along with conducting interviews before and after the research process helped to meet this requirement.

   b. Communicative and pragmatic validity

      "Communicative validity means testing the validity of knowledge claims in a conversation" (Kvale, 2011, p.124). Initial scoping interviews tested claims made in the research literature, and subsequent interviews tested claims made in each design cycle. Pragmatic validation "relates to the users' responses to an interpretation, and in a strong form it concerns the issue of whether interventions based on the researcher's knowledge may instigate actual changes in behaviour" (ibid., p.125). Again, the interviews demonstrated how the interventions of the researcher changed the behaviour of students and teachers.

4. The methods and strategies used to demonstrate the quality of interpretations and representations of data should be consistent with the theoretical underpinnings for the study. In agreement with Mishler (1986, p.112) and with the pragmatic lens of this research project, what was sought here is not absolute truth but rather the assessment of the relative plausibility of an interpretation when compared with other potentially plausible interpretations. Hence, the consistency in the replies of interviewees, triangulated with lesson observations and student conversations, served as a plausible interpretation here. It is then incumbent upon other researchers

to critically evaluate whether the transfer value of this situational knowledge has other applications.

Overall, the quality of the work was tested in dialogue with others, and in terms of resulting actions producing desired results. Hence, if the nature of how practical work is taught was changed through DBR and explicated through the interviews, this demonstrated one way of ensuring quality.

Roulson writes that central to demonstrating quality in interviews is "that researchers have worked to communicate with research participants and audiences and have been successful in fostering productive dialogue and action … contributing to educational transformation goals" (2010, p.221). The chapters that follow clearly outline how the above definition of quality was embedded in the collection of interview data.

In terms of the analysis of interview data using TA, the loss of "holistic understanding" of individual accounts (Brooks et al., 2015) that can occur across a range of interviews was mitigated by the small number of interviews in each design cycle, combined with the fact that all of the data collection, transcription and analysis was undertaken by the TP, providing an inherent familiarity with all of the cases. The TP also had a holistic understanding of the experiences of teachers and students, evidenced by her two decades of experience as a biology teacher.

King's (2012) caution that an emphasis on the coding structure may lead to an overemphasis on the construction of template itself was counteracted by the evaluation and reflection stage built into every DBR cycle, which ensured the emphasis was on interpretation of the template (not construction), since the results of each cycle of the research must be interpreted to inform subsequent cycles. Finally, when a high degree of reflexivity in acquiring and processing data is required (as in this study), TA makes that process apparent and overcomes the risk of pre-judgement on the part of the researcher about meanings contained in participants responses by grounding the results in the data (Stratton et al., 2006).

2.5.2 Observation

Observation allows direct access to the functioning of a practical lesson available from no other source (Evertson and Holley, 1981). In an educational setting, Weintraub (1989) calls this identification of the “ghosts behind the blackboard”. Observation here is given Tilstone’s ‘working definition’ as “the systematic, and as accurate as possible collection of usually visual evidence, leading to informed judgments and to necessary changes to accepted practices” (1998, p.6). This resonated with the DBR methodology because it included the notion of observation to effect transformation in practice. Its use as an inductive and a deductive instrument accorded with the methodology and the underpinning theoretical framework of enquiry. In addition, observation provided access to the social situation of the biology classroom that other instruments could not capture, and it allowed for the TP to “see the familiar as strange” by applying the lens of enquiry to biology lessons (Simpson and Tuson, 2003).

2.5.2.1 Inductive Observation

Using inductive unstructured observation, the researcher can observe the environment with some general idea of what might be important (from the literature review), but not with any specific or pre-determined categories (Hornoff, 2008). The data were selectively derived from key issues that arose from the situation itself (Cohen et al., 2007, p.398). The aim of this type of observation was to gain further insights into how different research participants perceive and interpret events during a practical lesson (Simpson and Tuson, 2003). The recording of data was descriptive to allow a broad and flexible log of the sequence of events in the practical lesson (ibid., 2003). This data was used to inform hypothesis generation during the first meso-cycle in the IST classroom and the PBTM1.

Field notes were used to document data in the inductive stage. Written in the third person to reduce the effect of the “the researcher’s professional and personal worldview”, concentrated the observation on what others were doing (Mulhall, 2003, p.310).

Following Spradley’s guidelines (1980), the field notes include:

- A record of the physical space – a map of each classroom visited was drawn to include where students were seated

- Actions, activities and events in the situation – this was recorded as a chronological time stamped log of what people were doing at different moments throughout the lesson.
- A record of the materials used

In addition:

- Appropriate dialogue was recorded
- It was noted where the students display signs of uncertainty or confusion about the work they were tasked with.

In this study unstructured observational evidence generated the hypotheses that were then tested deductively against three structured observation tools which as described in the next section. Video and audio evidence of the lesson examining dialogue and non-verbal behaviours of research participants was utilised during the first and second meso-cycles, as it collected a permanent record of a transient situation that was be later analysed from multiple perspectives, inductively and deductively, qualitatively and quantitatively, creating a more in-depth picture of the entire lesson (Baker and Lee, 2011).

2.5.2.2 Deductive Observation

This study was contingent on the use of observational data as a 'transformative tool' to drive pedagogical change towards enquiry-based instruction *via* professional development (Lawson, 2011). The ethos of DBR aligns with effective transformation, and deductive observation helped to quantify how this change was brought about within the biology classroom.

Silverman (2015) used the work of Whyte to illustrate how powerful data can be generated when quantitative structured coding instruments are developed after less structured qualitative observation. Prezlik (1994) cites the work of Dunn (1998) who utilised unstructured observation in a family setting, while also measuring children's actions and words in a structured way. Following this idea, hypotheses were generated inductively using less structured methods and then tested deductively in a more structured manner, which drove the design and development of the FTEA.

The observational data from this phase was generated from video recordings of the lessons. Cevin-McNally advises that analysing teaching "requires a systematic and evidence-based structure in order to be effective" (2016, p.476), therefore, each video-recorded lesson was subject to three structured observational tools which tested the hypotheses generated in the inductive observation phase:

- Event Sampling
- Structured Enquiry Observation Schedule (SEOS)
- Practical Activity Analysis Inventory (PAAI) (Millar, 2009)

Field notes, taken during lesson observations, were utilised to generate hypotheses about the nature of practical lessons. The methods of deductively testing those hypotheses are designed or adapted from existing policy or academic literature (Table 2.8).

Table 2.8: Inductive hypotheses generated and the method of deductive hypotheses testing.

Inductive hypothesis	Method of deductive testing
Teachers are asking 'lower order' questions only and as a result, students' understanding of scientific concepts underpinning the practical work they do is limited. Teachers only ask questions before and after an experiment, not during.	Event sampling based using a questioning analysis based on Bloom's Taxonomy (1956)
Student thinking is absent from practical work - there is no evidence of enquiry or of the use of the scientific method to do practical work.	Structured Enquiry Observation Schedule (SEOS) adapted from Irish Policy Documents
The lessons were not effective at promoting student understanding. Students follow the recipe by doing the 'hands-on' work, but the 'minds-on' work remains in the teacher's domain.	PAAI (Millar, 2009)

The use of each structured observational tool is described below:

1. Event Sampling

Simpson and Tuson (2003) describe event sampling as a tally of how often a certain behaviour takes place. Three Irish research studies have recently employed event sampling to measure the cognitive level of questions asked in Leaving Certificate examination papers using variations of Bloom's taxonomy (Burns et al., 2018;Cullinane and Liston, 2016;Letmon et al., 2021). Similarly, this study employed Bloom's (1956) taxonomy to measure the cognitive level of the questions asked by teachers during lessons. The number of questions asked by teachers during each lesson was counted and classified according to Bloom's taxonomy. It was also noted whether the student to whom the question was asked could answer it correctly. This tool was applied to all research cycles where lesson observations were conducted.

2. Application of Document Analysis using the Structured Enquiry Observation Schedule (SEOS)

The three syllabus documents available to biology teachers are:

1. Biology Syllabus (Government of Ireland [GOI], 2001)
2. Biology Support Materials: Laboratory Handbook for Teachers (GOI, 2003)
3. Biology: Guidelines for Teachers (GOI, 2002)

The Structured Enquiry Observation Schedule (SEOS) was developed specifically for the purpose of interrogating the extent to which practical skills required of students in the written curriculum, were evident in the enacted curriculum at different stages of the research.

Following Lankshear and Knobel (2004), the SEOS was tightly planned, detailed and included a checklist of scientific skills to be graded according to a rating scale. This checklist of skills was adapted from the syllabus document recommendations for aspects of practical activities that should be evident in practical lessons. They are listed in the left-hand column of the SEOS (Table 2.9). Fradd et al. (2001) developed a science enquiry matrix for classifying the level of enquiry in a practical lesson, by documenting whether the teacher or the student carried out the main elements of enquiry teaching (questioning, planning, implementing, concluding, reporting, applying). A similar rating scale was developed here to determine the extent to which the teacher/student was engaged in the different skills listed in Table 2.9:

0 = This skill is a feature of the syllabus recommendations but not evident in this lesson

1 = Teacher completes this skill with no input from students (>95% teacher input)

2 = Teacher mostly completes this skill with a little input from students (>75% teacher input)

3 = Most students complete this skill with some assistance from teacher (50% each)

4 = Most students complete this skill with a little assistance from teacher (>75% student input)

5 = Most students complete this skill without assistance from teacher (>95%student input)

The SEOS can accommodate up to 10 lesson observations. Table 2.9, below, is an example of the SEOS for one lesson in the final iteration of the FTEA in the target classroom.

Table 2.9: The SEOS for the Microscopy lesson observed during the final iteration of the research in the target senior cycle classroom

Skills as outlined in the syllabus document	Breakdown of syllabus skills	Microscopy
Following instructions	Follow instructions step by step	4
	Listen carefully to the teachers instructions	5
Correct manipulation of apparatus	Labelling solutions and equipment	0
	Using given apparatus in the correct manner	5
	Correct preparation of solutions and mixtures	4
	Using and/or measuring time as a variable	n/a
	Correct use of a measuring instrument	5
	Take an accurate reading	5
Observation	Accurate observation (using equipment)	4
	Appropriate observation of the phenomenon under study – (was the correct aspect of the phenomenon observed)	3
	Complete observation of the phenomenon under study (producing the correct phenomenon)	3
Recording	Careful recording of data	5
	Write up the procedure	5
	Perform calculations as required	n/a
	Tabulate results	n/a
	Draw diagrams or graphs to represent data collection	n/a
Interpretation	Draw reasonable conclusions from your observations and results	4
	Conclusions should ensue from hypothesis being tested	4
	Coherent final interpretation that explains how results are reached	2
Application	Awareness of any other application of what was learned	1
	Consider the results in a wider context	2
	Identify an activity that serves as a model for further investigation	4
Practical enquiry	Consideration of ambiguous results	3
	Repetition of activity if necessary	5
	Design of a new activity	4

Use of the scientific method as outlined in the syllabus documents	Making initial observations Forming a hypotheses Designing a controlled experiment Reporting and publishing results Appreciation of errors Use of controls to reduce errors Collecting data- *see observation / recording above* Interpreting data & reaching conclusions - *see interpretation above* Placing conclusions in the context of existing knowledge & development of theory and principal – *see application above*	4 4 3 4 4 5
Average score		3.74

If the SEOS presented ratings of mainly 0 or 1, then the lesson was not considered to be enquiry based, since the student was not conducting any of the enquiry skills required by the syllabus. SEOS ratings comprising majority scores of 4 or 5 indicate the converse. From Table 2.9, an average score of 3.74 indicates that more than half of the enquiry skills are carried out by students in the lesson, therefore the lesson can be considered to include some level of scientific enquiry.

3. Measuring the Effectiveness of the Lessons using Millar's Practical Activity Analysis Inventory (PAAI)

The PAAI (Millar, 2009) was used to assess 10 lessons simultaneously for effectiveness by measuring the presence or absence of clearly defined aspects of 'hands-on' and 'minds-on' activities (Millar, 2004; Abrahams and Millar, 2008). It also accounted for the way in which the purpose of an activity was communicated and explained to students, the type of whole class discussion that took place before and after the activity, and how students were asked to present their findings. Overall, it enabled a comprehensive examination of the nature of practical activities. If both 'hands-on' and 'minds-on' activities have been attended to during a lesson, the lesson was considered both enquiry-based and effective.

Supplementing the use of the PAAI with the newly designed SEOS tool above, provided a comprehensive measure of the enquiry-based nature of the observed lessons.

See Appendix 3.1 and 4.8 for PAAIs for each lesson observed during the research.

2.5.2.3 Ensuring Quality in Collection and Analysis of Observational Data

Two main issues that may affect the quality of observational data gathered are addressed below:

1. Researcher bias

The most concerning limitation of classroom observations is that observers provide just one perspective on classroom events which is never completely objective (Wilkinson 2000, Moyles, 2002, Robson, 2002, Shaughnessy et al, 2003). Fawcett summarises the issue as, “we have a tendency to see what we are looking for and to look for only what we know about” (Fawcett in O’Leary, 2016, p.63). Unstructured observation is particularly subject to judgement bias if the observer has already made premature judgements based on a review of the literature or may have pre-conceived personal bias based on personal interests and experience (Baker and Lee, 2011). In addition, only highly visible events and overt behaviours are captured with observational research. To mitigate researcher bias, a number of measures were taken to enhance the quality of the data gathered here (Cohen et al., 2007):

a. Hypotheses were generated not only from the literature but also from inductive observations: For example, inductive observations revealed that teachers have a pattern of lower order questioning before and after each practical lesson.
b. Lessons were video/audio recorded to enable re-analysis from multiple perspectives (structured/ unstructured, questioning, hands-on/minds-on) which counteracts any attention deficit on the part of the researcher.
c. Audio recordings of student conversations provide insight into less overt behaviours such as what students are talking and thinking about.
d. Unstructured observational data was triangulated against interview data from students and teachers, and audio transcripts of student conversations; each of which formed the assemblage of the entire situation.
e. Structured observations reduce selective entry of interpretations affected by judgements and preferences of the researcher and substantiate inductive hypothesis generation. There is the assumption that the criteria for collecting structured data are transparent, explicit and can be applied objectively by any person observing (O’Leary, 2016).

2. The Hawthorne Effect

This refers to the positive effect of the presence of an observer in the classroom on the behaviour of the research participants. Ann Brown, dogged by claims that the success of her DBR research was "*only* a Hawthorne effect", responded with the following:

> "… my major defence is that a "Hawthorne effect" is what I want: improved cognitive productivity under the control of learners……. and with a theoretical rationale for why things work"
>
> (ibid., p.167)

As this study was an interventionist one, involving cycles of design and development of an intervention through collaboration between research participants, there was a deliberate effort to change the participants behaviour, and to measure how that behaviour changed, using triangulated data collection instruments, including observation.

2.5.3 Questionnaire

Proving the FTEA works in an alternative setting (the PBTM) adds methodological rigour and experimental validity to it (Barab et al., 2008). A questionnaire can be filled out rapidly by a large number of research participants, which has the added advantage of generating a greater uptake with research participants and of collecting a broader account of the PST experience compared to an interview. PSTs completed the questionnaire before and after undertaking the PBTM in the target setting (n=22/36 respondents), to allow for a comparison of their prior experience of practical work with their experience of practical work during the module.

The questionnaire was divided into two sections, based on two distinct aims:

> Section 1: Their experience as secondary school students (before module), and of the PBTM (after the module)
>
> Section 2: Their beliefs about the purpose and structure of practical lessons

Section 1 comprised an appropriate set of statements which mirrored the questions asked of ISTs and students during interviews for comparative purposes. Adapted from the SEOS, each statement was accompanied by six possible responses (Table 2.10).

Respondents chose the most appropriate response to each statement from six standard responses listed here:

- Never
- My teacher usually did this part without input from students
- My teacher mostly completed this part with some input from students
- Students completed this part with some assistance from the teacher
- Students completed this part with a little assistance from the teacher
- Most students completed this part with no assistance from the teacher

Table 2.10: List of statements in Section 1 of the PST questionnaire

Statement no.	Statement
1	During LC practical work students learned to follow instructions step by step
2	During LC practical work students learned new laboratory skills e.g. aseptic technique, preparation of solutions, measurement skills
3	During LC practical work the students learned to make accurate observations e.g. when using measuring equipment
4	During LC practical work students observed experimental phenomena i.e saw what was meant to happen. Single choice.
5	During LC practical work students were encouraged to ask a question and to formulate a hypothesis regarding the answer to this question
6	During LC practical work students collected data
7	During LC practical work students recorded data appropriately e.g. in table form, diagrams, photos etc.
8	During LC practical work students analysed collected data in order to draw conclusions
9	During LC practical work students presented the findings of experiments in graph form or otherwise
10	During LC practical work students applied experimental findings to new experiments
11	During LC practical work students wrote an experimental report
12	During LC practical work students got to design their own experiment

The advantage of this method is that it gave the respondent a flexible concrete choice, while allowing the researcher the opportunity to utilise quantitative measures of analysis. These can be fused with opinion by triangulating with observation and interview to ensure quality. The disadvantages of this method and how they are minimised are outlined here:

1. There is no guarantee that the respondent is telling the truth, however this applies to any other form of questioning
2. There can be a tendency for respondents to opt for the middle of the scale, which was overcome by using an even number of choices
3. Respondents pick the same response for each statement, which was overcome by looking at patterns of replies and eliminating 'response sets' from the analysis (Baker, 1994)
4. There is no way of knowing if the respondent may have something else to add, hence, the inclusion of an open-ended question at the end of Section 1; 'please sum up your experience of LC practical work in secondary school here'

Section 2 was designed around open-ended questions to allow the respondents to share their beliefs about how practical work should be taught. These questions were adapted from the transformative interviews and serve the same purpose (tracking the change in beliefs about practice). Open-ended questions contain information that can be authentic, rich and honest in a way that a closed question cannot capture. While they can be difficult to compare across cases, the qualitative aspect of this type of question implies a search for meaning rather than numerical data. Table 2.11 indicates the open-ended questions that were asked in Section 2 of the survey.

Table 2.11: Questions from Section 2 of the PST Questionnaire

Question no.	Question
14	What are you hoping to learn by doing this BI317 module?.
15	What, do you think, is the purpose of practical lessons or why do we teach practical work?
16	Have you ever taught a practical lesson at junior or senior cycle level?. Yes No
17	If you answered yes to the previous question, how did you find the experience?
18	What factors do you think are important to consider from a teacher's perspective when planning and preparing a Leaving Certificate practical lesson?.
19	What factors do you think are important to consider when teaching a LC practical lesson (i.e. during the lesson itself).
20	What factors do you think are important to consider after a LC practical lesson is complete?
21	How long do you think is appropriate to spend planning and preparing a practical lesson for LC biology?
22	What do you understand by the term "enquiry based learning" as it applies to practical work?
23	How much of your experience of practical work to date at second and third level has been "enquiry based"? (Give a percentage for each).

2.5.3.1 Data analysis of the questionnaire

Data from Section 1 of the questionnaire was analysed in the same manner as the observational data from the SEOS. This enables a straightforward comparison of the extent of enquiry in the lessons before and after the module. The data gathered from Section 2 was subject to Template Analysis in order to compare pre- and post-module responses of PSTs.

2.5.3.2 Ensuring quality in the use of the questionnaire

Cohen et al. (2008) specify three phases in the development of a questionnaire:

1. The general purpose of the questionnaire is clarified and translated into two concrete aims as follows:

- To obtain an accurate account of PSTs' experience and beliefs about practical work from their experience as students in secondary school and as PSTs in secondary school.
- To map the transformation in experience and beliefs after taking part in the PBTM.

2. Subsidiary topics, relating to these aims were already identified and itemised through the SEOS and the interview protocol.
3. Similarly, formulating specific information requirements relating to each subsidiary topic was pre-empted by adapting the SEOS and interview questions to the questionnaire.

The questionnaire was peer-reviewed by the RP, who checked for clarity of instructions, accessible layout, appearance, style of questioning and suitability to the group of respondents. Data obtained using this instrument was triangulated with audio data of PST conversations, with lesson plans developed by PSTs and with photographic evidence of the PBTM – all of which endorse the quality of the method.

2.6 Ethical considerations

The first ethical issue to be considered was that of my identity in the field. Atkinson and Hammersley's (1998, p.249) guidelines around identity determine that:

1. I was known to all research participants as a teacher-turned-researcher, a teacher practitioner (TP)
2. All research participants (ISTs, PSTs, students, parents of students and school principals) were given a letter explaining the purpose of the research which asked for signed, informed consent – see Appendix 2.2 for copies of these letters. All research participants had the right not to take part in the study, to step out of the research study at any stage during the project and to have their data removed from the study, should they so wish. Ethical approval for this study was granted by the Maynooth University Ethics Committee.
3. In the classroom situation, during scoping observations, I did not engage in any activity or discourse with students, teachers or PSTs during their lessons. The camera was set up in the centre at the back of the room, allowing areas for students to sit to the left or right of the camera (Simpson and Tuson, 2003). During the second design

and development cycle, as students ventured into my vicinity during practical activities, I asked them questions about the nature of the practical work they were engaged in. There were two reasons for this:

a. Students were familiar with my presence in the classroom and were willing to answer questions as they went about their work.
b. Not all students were doing the exact same activities. The least intrusive way to find out what students were doing was to ask them quietly when they were in my vicinity.

4. My orientation was that of observer as participant regarding the students, since I had less extensive contact with this group and my prime interest was in gathering detailed information about the situation (Cohen et al., 2007). With teachers, my orientation is best described as collaborative participant as observer (ibid.), particularly in the second and third mesocycles when ISTs joined the TDT as collaborators.

The second ethical issue considered was nature of the power dynamic between the research participants and me (the TP) during observations and interviews. Underpinning observation with a Community of Practice approach to collaboration, fostered a less hierarchically delineated relationship between observer and observed because it was "…..driven by a desire to nurture pedagogical knowledge and skills rather than simply passing judgement on the professional competence of the observed on the basis of isolated observation" (O'Leary, 2013, p.69). Cockburn (2005) supports this statement by noting how the move towards observation from a developmental perspective casts the observer as a "supportive facilitator", which reduces the power differential. Bratich suggests that observation should "create zones of contact between insiders and outsiders" (2018, p.534). Amalgamating the three perspectives sees observation used here as a way to work collaboratively with teachers as a "culture-broker", using insider and outsider knowledge to build a collaborative, transformative, creative FTEA built on a mutual drive to improve practical biology instruction (Angrosino, 2005; Angrosino and Rosenberg, 2011).

Using video recordings of observations allowed lessons to be analysed outside of the 'now' moment, thereby removing the teacher from the situation emotionally, making it easier to enact conscious interventions and hypothesis testing (Cockburn, 2005).

Ethical interviews were assured by avoiding deeply personal or sensitive questions and by guaranteeing confidentiality and anonymity to all research participants by changing the names of interview respondents (Mason, 2017). Group interviews were conducted with children (participants under 18) as a useful way of gaining insight, where a group of people have been working together for some time (Watts and Ebbutt, 1987). Group interviews can also throw up opinions that can be cross-checked, leading to a complete and reliable record (Cohen et al., 2007). In addition, a sense of security exists with group interviews that is more appropriate for student research participants. (Kvale, 2011). The interviewer was consciously aware that some individuals may be reticent in front of others, or the interview may produce a 'group think', where individuals with a different view do not speak out (Arksey and Knight, 1999) and every effort was made to avoid this.

In addition, the interviewer maintains the privilege of interpretation and reporting of interview data which may lead some interviewees to withhold information or talk around a subject (Silverman, 2015). The Community of Practice approach taken in this study led to a flattening of the any hierarchies that promoted equal voice between all of the research participants.

The final ethical issue arising is the question of "whose beneficence?", whom does the research serve? In time, and with considered dissemination, it is envisaged that the research will reach the wider science teaching community and benefit future students and teachers of science.

2.7 Conclusion

This chapter set out to explain the nature of DBR as a research methodology and why it is suited to this particular research project. Following the needs and content analysis (which is developed further in the next chapter), it is also outlined here how iterative cycles of design and development were adapted to suit the needs of this particular research project leading to a two-fold research output; a Framework for Enquiry supplemented by a solid Theory of Enquiry for teaching practical lessons at senior cycle.

The changing nature of the sample size was directly related to each micro-cycle of research and development, which is a feature of DBR. Some situations, such as the PBTM, required a larger sample size while others, such as the small-scale laboratory setting, comprised only four participants. The main research instruments utilised here were observation, interview and survey. Some of the data analysis tools were designed specifically for this study (the SEOS) and others were adapted from the research literature (TA and the PAAI).

The next chapters use the methodological tools developed here to interpret and report on the research findings of this study. The first mesocycle of research is reported in Chapter three, a needs and content analysis that identifies the nature of practical activities in the upper secondary biology classroom. It begins with a review of the international literature around practical work and then turns to a scoping analysis of the Irish context carried out through site visits to senior cycle biology classrooms. The second mesocycle of design and development is documented in the next three chapters. Chapter four describes the first design and development research cycle, as an initial prototype FTPA is developed for teachers to use in the classroom. Evaluation and reflection of this research cycle leads to two further design cycles and two more outputs of DBR: development of a theory of enquiry to underpin the refinement and use of the artefact (Chapter 5), and development of a programme for professional development grounded in literature around a Community of Practice approach to learning (Chapter 6). A summative evaluation of the research process is provided in Chapter 7 as the artefact is trialled in two target settings, a university pre-service teaching module and secondary school biology classroom. Chapter 8 provides an overview of the three research outputs of this study.

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Chapter 3

Needs and Content Analysis of Practical Teaching in Biology

3.1 Introduction

Design Based Research (DBR) projects usually begin with a Needs and Content Analysis (NCA). This NCA is divided into two sections: the first presents a review of the international literature around school-based practical science activities, while the second examines the enactment of practical biology activities in the Irish upper secondary classroom. The international literature review identifies recipe-based activities as a common form of practical work at both upper and lower secondary levels; where students conduct "hands-on" activities without "minds-on" cognitive engagement (Abrahams and Millar, 2008). Mirroring the literature, a scoping investigation into the enactment of practical work in the Irish classroom reveals a picture of recipe-based practical activities that leads to "minds-off" disengagement in biology lessons. The chapter concludes by identifying what needs to change in order for students to experience minds-on activities during school based practical biology lessons.

The research questions for this design cycle are:

> How is practical work currently experienced by teachers and students in the Irish biology classroom? How does this experience compare with written curriculum intentions for biology students?

3.2 Literature Review

3.2.1 Practical Activities

In the literature the term “practical activity” is used interchangeably with “practical work” and refers to “any type of science teaching and learning activity in which students, working either individually or in small groups, are involved in manipulating and/or observing real objects and materials” (Abrahams and Reiss, 2012, p.1).

Practical work is characterised by what is undertaken as opposed to where it is undertaken, therefore it can include field activities in addition to laboratory experiences: “Practical work in this sense is a broad category that includes, for example, experiments, investigations, discovery and ‘recipe’ (Clackson and Wright, 1992) style tasks.” (Abrahams et al., 2014, p.265).

In terms of upper secondary practical activities, Millar’s (2004, p.2) definition of practical work is appropriate to describe the type of activity that this study is concerned with “any teaching and learning activity which at some point involves the students in observing or manipulating the objects and materials they are studying”. He also states that he does not use the term “experiment”, “as this is often used to mean the testing of a prior hypothesis. Whilst some practical work is of this form, other examples are not” (ibid., p.2). Similarly, “laboratory work” is not suitable since it implies a more open-ended type of investigation which is not evident in secondary school science education (Kind et al., 2011). In the context of this paper, the term “practical work” is used interchangeably with “practical activities”.

3.2.2 Policy for Practical Work

Practical work is seen internationally as an integral component of teaching and learning science. Teachers themselves see practical work as an essential part of what it means to be a science teacher (Abrahams and Fotou, 2018). Wellington (1998) posits three aims for practical work which Lunetta et al. (2007) attest are universal:

1 Cognitive development of scientific knowledge by enabling students to affirm the underpinning theory

2. Affective motivation which generates enthusiasm and assists learners to remember its purpose

3. Development of manipulative laboratory skills and skills required for scientific enquiry.

They propose this may be why practical work has been so prominent in science curricula for over 100 years. Osborne (2015) cites two reasons why practical work should be taught in schools; it provides opportunities for students to experience phenomena for themselves and, when taught effectively, practical work provides students the opportunity to experience the activity of enquiry. Millar, also supports the idea that practical work enables students to experience phenomena in the laboratory that they may never witness in sufficient detail in their everyday lives, calling it 'essential and irreplaceable' in this context (2004, p.9). In addition, practical work is an effective tool for challenging students "incorrect expectations about matters of fact" (ibid., p.11). Dillon's (2008) review of practical work identifies that many of the perceived advantages to doing practical work come from policy makers. For example the Science and Technology Committee in England (House of Lords, 2006), identify three aims of practical work; it is essential to effective science teaching, it allows students to participate in (rather than be subject to) science education, and it supports students to further study science at third level.

Irish policy is set out in three main documents that teachers use to guide their practice.

1. The Biology Syllabus sets out the aims of the Leaving Certificate biology course which include "to contribute to students' general education through their involvement in the process of scientific investigation" and "to encourage in students an attitude of scientific enquiry" (Government of Ireland (GOI), 2001, p.2).

2. The Biology Support Materials Handbook (GOI, 2003) describes how to set up and carry out the 22 mandatory experiments on the Leaving Certificate syllabus, and also sets out the original intentions for practical work in biology. According to this handbook, the rationale for doing practical investigations is because -"the study of biology is incomplete without the study and application of the scientific method", thus -"practical activity forms an essential and mandatory part of this course"(ibid, p.3). As in the international context, practical work is seen as integral to learning biology. In addition -"the main focus of these activities for students is the attainment of practical skills. The emphasis is on the process rather than on product attainment alone" (ibid, p.2). The handbook specifies the practical skills to be developed as: "manipulation of apparatus, following instructions, observation, recording,

interpretation and observation of results, practical enquiry and application of results" (ibid, p.4).

The purposes of practical activity for students are listed as follows:

> "[It] Introduces them to a scientific method of investigation, allows for greater development of affective and psychomotor forms of learning, encourages accurate observation and careful recording, promotes simple, common sense scientific methods of thought, develops manipulative skills, gives training in problem solving, elucidates the theoretical work so as to aid comprehension, verifies facts and principles already taught, arouses and maintains interest in biology, makes biological, chemical, and physical phenomena more real through actual experience"
>
> (ibid, p.3)

3. The Guidelines for Teachers document (GOI, 2002) also endorses practical activities as a way to develop skills and contains suggestions for non-mandatory activities that may enhance learning. It encourages teachers "to allow the teaching of the course to be syllabus led rather than textbook led" (p.3).

As can be seen from these government syllabus documents there is a clear emphasis on the process of scientific enquiry, the application of the scientific method and on learning practical laboratory skills. In line with international aspirations for science curricula, there is a cognitive, affective and skills focus within the Irish biology syllabus.

3.2.3 Translation of Policy into Practice

Millar begins the process of pulling apart the reality of practical work, with the observation that the two aims of "improving students' scientific knowledge and their knowledge of science as a form of enquiry" (2004, p.3) are combined and integrated in many science curricula. This means that practical work should serve two distinct purposes – learning scientific knowledge and learning about the processes scientists use to discover new knowledge. This places a large burden on practical tasks because there is a lack of explicit indication that different kinds of practical tasks may be better suited to each separate aim (ibid., 2004). For example, it is difficult for students to learn about the microscopic structure of plant cells (scientific knowledge) if they are not familiar with the use of the microscope (a process used to access scientific knowledge). The learning that teachers expect to occur during practical work is often implicit and not immediately accessible to students (Abrahams and Reiss, 2012). For example, when viewing plant cells using a light microscope, it is implied that students will recognise the parts of the plant cell under the microscope from the diagram in the textbook, when this may not be the case.

Millar goes on to say: “there are no obvious examples, anywhere in the world, of a form of science education like … [the aims outlined above]… being successfully implemented in a national education system”(2004, p.6). Later sections in this chapter support Millar’s claim that, in the Irish context enquiry-based policy intentions for science education are not successfully implemented in the biology classroom as enquiry-based practical lessons.

Policy makers internationally, have endeavoured to reform science curricula to reflect a more enquiry-based ethos, yet teachers still persist with recipe-style pedagogy (NRC, 2012; Kidman, 2012). This led Capps et al, (2013) to call into question the impact of these reform-based policy documents, specifically because there is no comprehensive consensus of what enquiry is and what it looks like. In their study, some of the ‘best’ science teachers they could find believed they were teaching science as enquiry when they were not.

In the Irish context, the misalignment between policy and practice is even more pronounced at upper secondary level. Enquiry is emphasised in the policy documents as the preferred pedagogical approach, yet there is no agreed definition of enquiry, nor is there a recommended pedagogical approach to enquiry for teachers to utilise. Priestly and Minty (2013) argue that content and pedagogy should be underpinned by an appropriate learning theory if a course of study is to be successful, yet there is no learning theory underpinning Irish practical activities.

Almost 40 years ago Hacking (1983) criticised practical work in science education as having been reduced to a process of following instructions to produce the phenomenon. Other academics have spoken out about how practical work, as it is currently taught, is ineffective in producing any meaningful learning because it has become a matter of following a ‘recipe’, where students follow a set of instructions to generate a predetermined result (Abrahams and Reiss, 2012; Clackson and Wright, 1992; Kirschner, 1992; Tobin, 1986).

Dillon suggests the lack of context within recipe-style tasks leads to lower quality learning than if the tasks were connected to students' everyday lives (2008). With recipe tasks, students practice lower-level skills with "little evidence of any enduring conceptual understanding that could be clearly attributed to a specific practical task" (Abrahams and Reiss, 2012, p. 1050).

In an effort to drill down into the nature of the problem, Abrahams and Millar (2008) developed a hands-on/minds-on framework for assessing the effectiveness of practical work on two levels; the intended level compared to the enacted level. The framework examined what students have to do with materials and objects compared to what they actually do (hands-on domain), and the teachers intended learning objectives for the lesson compared with what the students actually learned (minds-on domain).They found that students were not able to make productive links between the objects and materials they use (hands-on) to conduct an investigation, and the observables and ideas (minds-on) that were the intended learning goals of the teacher. In all of the lessons observed, the teachers' focus was solely on the substantive science content. There was no discussion of specific points about scientific enquiry such as data analysis and interpretation, nor of the nature of science, *even though* there were opportunities to so. The lessons occupied the hands-on domain only and were classed as recipe-style where the sole aim of the lesson was that "students do with objects and materials provided what the teacher intended them to do and generate the kind of data the teacher intended", which significantly diminished the effectiveness of practical work as a learning tool (ibid, p. 1949).

The scholarship around practical work in science education widely reports that this is predominantly how students are taught practical science in schools (Hofstein and Lunetta, 2004; Kind et al., 2011; Lunetta et al., 2007; Millar, 2004; Sharpe and Abrahams, 2020).

Practical work is widely considered to be an essential part of the learning experience of science students, yet many researchers have questioned its role and effectiveness as a learning tool, in light of the plenteous evidence that it is ineffective at equipping students with the skills and cognitive abilities that it was originally intended to cater for (Abrahams and Millar, 2008; Bybee,'99; Hodson, 1991, 2001; Hofstein and Lunetta,'04; Lunetta, '98; Osborne, 2015; Wellington, 2002). Clackson and Wright (1992, p.40) provide an insight into the problem with practical work with their observation –"Although practical work is commonly considered to be invaluable in science teaching, research shows that it is not necessarily so valuable in science learning."

3.2.4 The Enduring Nature of the Recipe

Teachers attribute their use of recipe-style practical work to the short nature of most practical lessons, which does not allow sufficient time for enquiry-based tasks (Cheung, 2008; Hofstein and Lunetta, 2004). In addition, open-ended tasks are seen as a greater pedagogical challenge to teachers (Abrahams and Reiss, 2012), relegating practical work to didactically delivering information to get through the required content (Dillon 2008; Krajick, 2001; Lunetta, 2007).

Research suggests that teachers often expect that explanatory ideas will 'emerge' from observation, as long as students can produce the phenomenon, but this simply is not the case (Abrahams and Millar, 2008, Abrahams and Reiss, 2012; Lunetta, 2007). The cognitive challenge of learning in the minds-on domain is seriously underestimated with recipe tasks.

Teachers do not seem to understand that many scientific ideas do not simply follow from observing natural phenomena and that the teaching of conceptual structures and reasoning needs to be as much a part of practical work as manipulating objects and materials (Duschl and Gitomer, 1997; Fotou and Abrahams, 2018; Millar, 2004). The difficulty in integrating the minds-on domain into practical work is confounded by discrepancies between what teachers identify as their learning outcomes and the outcomes that students perceive (Abrahams and Millar, 2004; Abrahams and Reiss, 2012; Goodlad, 1983; Hodson, 1993,2001; Kesidou and Roseman, 2002; Lunetta et al, 2007; Tamir and Lunetta, 1981; Wilkenson and Ward, 1997). Referring back to Millar's point above, students are expected to learn scientific concepts through practical work without the teacher explicitly developing the ideas behind the practical tasks, yet "there is no direct route from data to explanation" (2004, p.4)

It is no surprise then that students perform school-based science practical work with very different purposes in mind than those articulated by teachers (Lunetta et al., 2007). For students the principle aim of practical work is producing the correct phenomenon while for teachers the goals of practical work are conceptual and procedural understanding (ibid, 2007).

The conflation of learning, with enjoyment of practical work, also needs to be considered. A study by Cerini et al. (2003) found that 71% of student respondents found practical work enjoyable (because they do not have to write or think), while within the same cohort, only 38% found it useful. Students' preference for and enjoyment of practical work is taken as a motivating factor by teachers to continue its practice, however few students see it as a better way of learning about or understanding scientific concepts and ideas (Abrahams, 2009; Blumenfeld and Meece, 1988). Practical work was found to be memorable only when students saw "flashes, bangs and pops" (Abrahams and Reiss, 2012). Later research suggests that as students move towards high stakes assessment in upper secondary, their preference for practical work diminishes as it is seen as a more frivolous waste of time (Sharpe and Abrahams, 2020).

Another factor that determines how practical science is taught internationally is the method of summative assessment (Donnelly, 1996).

> "It has long been recognised that summative assessment drives what is taught to the extent that teachers' preferences for using different types of practical work are influenced by their consideration of curriculum targets and methods of summative assessment"
>
> (Abrahams et al., 2013, p.210)

Abrahams (2013) is identifying the "washback effect", which has been used to describe the influence of the terminal Leaving Certificate examination on classroom practices (Hyland, 2011). In the Irish context, Burns et. al (2018) conducted an analysis of Leaving Certificate examination papers, across 23 subjects assessing the type of questions asked and categorising them based on Bloom's taxonomy. Of the 23 subjects analysed, Biology had the highest percentage of questions asked at the two lowest levels of thinking – 93.9% of questions were at the level of recall and comprehension. This manifests in the classroom when memorisation of factual knowledge is prioritised above understanding of scientific concepts (Cullinane and Liston, 2011). Comments by subject specialist reviewers of biology also reported an under-development of scientific thinking, reasoning and creativity in biology examination papers, with students relying heavily on memorisation techniques to achieve exam success (Baird et. al, 2014).

Wellington's (1998) three aims for practical work (cognitive, affective, skills) are written into the syllabus documents for biology but are not assessed in the terminal examination.

As a result, the terminal assessment becomes "a process in which students learn to gain high marks for summative exams as opposed to being taught about having opportunities to develop their practical skills" (Abrahams et al, 2013, p.244). Classroom practice has aligned itself with the method of assessment of practical work but neither of these two is aligned with policy intentions.

3.2.5 Recommendations for Engaging the Mind in Practical Activities

Academics have suggested ways to overcome this mismatch between teacher intention and student experience. Firstly, the learning outcomes for practical work must include goals for learning alongside goals for specific tasks to be accomplished. Students need to learn to use materials in the laboratory to manipulate ideas. If teachers want students to talk about scientific ideas, then unfamiliar scientific terminology needs to be explained (Fotou and Abrahams, 2018). Olsen (2004) proposes a case for using a 'pre-lab' to familiarise students with new equipment and materials in advance of a practical activity to shift the focus onto conceptual ideas *during* the practical lesson.

Secondly, attention should be paid to the Nature of Science, how scientists work and the scientific method of enquiry (Capps and Crawford, 2013; Duschl, 1987). The lack of focus on the Nature of Science, the *process* of enquiry, in the biology curriculum has been detrimental to the learning of skills and ways of thinking that are so important to students of biology (Lunetta et al, 2007). This cannot be developed as a by-product of engaging in other learning activities, instead it requires explicit teaching to counteract the "notion that scientific understanding and acceptable explanations of phenomena and events will emerge in a straightforward way from simple engagement in hands-on activities", (Hodson, 2014, p.2535).

In the same way that teachers cannot expect that scientific ideas will emerge from data without explicitly teaching for understanding of those ideas, teachers should also not expect that students will tacitly understand what it means to plan and conduct enquiry scientifically by doing simple hands-on practical activities (Donnelly et al.,1996; Hodson, 2014).

This first research cycle set out to investigate the nature of practical activities at upper senior cycle biology in the Irish context. In light of the misalignment between policy and practice reported in the international literature, this scoping stage was conducted to investigate whether this also applied to the Irish lessons observed. The contribution of practical work to student learning was also examined to assess whether students understood the scientific concepts underpinning the practical work they were doing.

Two overarching themes were chosen for the purposes of this analysis. The first theme, 'Syllabus Ideal vs Classroom Reality', was chosen to compare Irish policy guidelines with how the syllabus is enacted in the classroom. The second theme, 'The Separation of Hands from Minds' was chosen to determine the effectiveness of practical lessons (Millar, 2009). The next section outlines these two themes through a description of practical activities at upper secondary biology.

3.3 Policy Vs Practice in Practical Biology Teaching

In this section, policy intentions for practical work are compared to the reality of practical work in the Irish biology classroom. Video recordings of ten practical lessons were subjected to Structured Enquiry Observation Schedule (SEOS) analysis, to determine to what extent skills listed in policy documents were included in practical lessons (Table 3.1). Supporting data from student (n=16) and teacher (n=6) interviews provided qualitative data, evaluating how well practical work aligned with policy intentions from the perspective of those who participated in it. Data gathered was analysed using Template Analysis via MAXQDA software (King, 2012). All participants were allocated pseudonyms, with student comments preceded by Christian names and teacher comments preceded by surnames in interview extracts. Figure 3.1

signposts two parts to this section, both of which provide evidence of a mismatch between the original enquiry-based intentions and the recipe-style enactment of practical work in the classroom - the first part outlines the difference between the perceived value of practical work compared to the actual value of it, and the second section utilises the SEOS to query the extent to which practical skills are a part of the student and teacher experience of practical work.

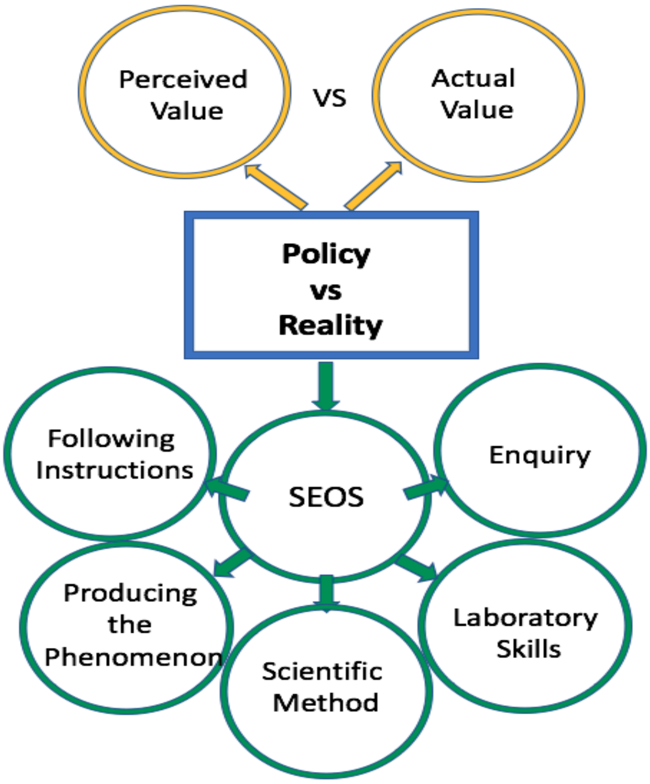

Figure 3.1: Outline of the analysis comparing policy with practice in the practical classroom

3.3.1. The Perceived Value of practical Work Vs the Actual Value of Practical Work

During interviews, students and teachers were asked about what they believed the purpose of practical work to be. Both cohorts perceived practical activities as aligning with the syllabus ideal; that practical work teaches skills, enables students to connect phenomena to underpinning scientific principles, and to 'learn by doing'. The view that practical work enabled students to learn skills that may benefit them when they go into the workplace was common among both cohorts:

> Maybe like if you're doing a job, like, if you go into a job with, that you need biology like, it'll give you a feel of what you actually have to do and what it's going to be like.
> *(Dan, student interview 3)*

The teacher below was cognisant that the students see practical work as a break but also believed that they were learning practical skills and the skills needed to follow instructions:

> They get a break. Now they also get, I suppose they gain skills as well in terms of measuring and using equipment and following instructions, you know, you have like a recipe to a degree and they get in to that, into the mode of following the instructions and you know, it is, certainly it is a break and they do like the idea of doing practical work.
> *(Interview with Ms. Brown)*

Both cohorts reported that practical work helped students to connect with the theory they were learning. The student below explained how practical work, helped with his understanding of what he reads in a book:

> So you actually see for yourself like, if you're reading something from a book then you can actually see it, like in place, like you can see how it works and the process and the results rather than just reading it from a book, like A,B,C
> *(Andy, student interview 3)*

When asked why practical work might be important for student learning, there was also a common view that practical work was an amalgamation of theory with practice to reinforce understanding:

> Well I think basically it improves our spatial awareness and our visual, our understanding of the world because unless you see something in action, its theory based and a theory is just an idea so unless you see it in action, unless you compare it to different things then it's just an idea out there, it's like reading a fairy story in a book.
> *(Ms. Rogan)*

Students also reported that they learn best by 'doing'. However, the way students describe being active here uncovered two contrasting viewpoints; one student believed that she was learning by doing, while the other student preferred doing *rather* than learning. It will become clear that the latter's preference reflected the reality of the classroom while the former reflected the syllabus ideal:

Dan: I kind of learn by doing it and I think it kind of suits me better when we're doing practical stuff than just sitting and reading it out of a book like
Researcher: Ok, yeah, would you agree with that L?
Liam: Yeah I'd be more practical now to be honest, than doing theory. Doing, more than learning
(Student interview 3)

The remainder of this section elucidates how Liam's (above) preference for doing rather than learning was reflected in the reality of the classroom, while Dan's preference reflected the syllabus ideal.

Teachers had an awareness that a large portion of the practical work that they conducted served no other purpose than to act as a diversion from the normal routine of lessons (Abrahams, 2009; Cerini et al., 2003; Blumenfeld and Meece, 1988).

Researcher: So, what's the main reason do you think that they (students) like practical work so much?
Teacher: It's a diversion from listening and learning and taking down notes. It passes the time quicker and it can be fun
(*Ms. Rogan*)

For students, practical work in the classroom setting was seen as a break from learning theory, they liked the hands-on aspect of it, and they liked the atmosphere in the practical class where they could chat with their friends without any disciplinary repercussions (Abrahams, 2009). Students did not see practical work as valuable in itself; they saw it as providing a preferable distraction from reading out of the book (Blumenfeld and Meece, 1988).

More than anything, it was the social aspect of practical work that appeals to students:

Researcher: So, what is, if you were to think of something positive about doing experiments, what is good about them?
Sue: Doing it with your friends. It's like, it's great fun
Jim: Yeah, like, we have so much fun. I know we're supposed to be not laughing but, like, we just have to sometimes *(laughter)*
Ann: Like, normally we just sit in class and just listen to the teacher, and just like, you're not allowed to talk or anything, but here you're allowed to, like, talk to others

(Student interview 2)

It was striking that the student comments above revealed their experience of education as being restricted by silence, when education by its very nature is a social enterprise (Dewey, 1916/2011; Wenger 1988). Field notes revealed that students talked to each other while they were doing the experiment, but not before or afterwards, which is when the teacher was talking. Ms Rogan, quoted above, believed that experiments were a diversion from 'listening and learning', equating listening (which requires silence) with learning. Dewey strongly advocates against silence as evidence of learning, as students "still have to find their intellectual way out" (Dewey, 1916/2011, p.166).

This scoping exercise found obvious discrepancies between the perceived value and the actual value of practical work in terms of student learning. Teachers and students believed the purpose of practical work was for students to learn by 'doing'. In addition, practical work was viewed as a means to connect experimental observations with scientific explanations. This opinion accords with the findings of Lunetta et al. (2007), Abrahams and Millar (2008), Abrahams and Reiss (2012) and Hodson (2014). They all found that teachers expected that explanatory ideas would 'emerge' from observation made during the course of an experiment. The natural disposition of students to talk to each other has long been recognised by proponents of social learning (Wenger, 1988; Vygotsky, 1978; Dewey, 1938/2015). However, teachers did not harness this inclination for students to engage in discourse, to facilitate thinking about the scientific concepts underpinning each practical activity.

3.3.2 Practical Skills are Not a Part of Practical Work

The ten practical lessons observed were scored using a Likert scale in order to compare actual classroom lessons with the intentions of the syllabus. Table 3.1 summarises the results of this comparison. The column on the left lists the syllabus skills for practical activity and teaching the scientific method (GOI, 2003), while the column on the right indicates the degree to which each skill was undertaken by the teacher/student.

Table 3.1: The compatibility of the requirements of the syllabus documents with practical activities in the biology classroom

Skills as outlined in the syllabus document		Expt 1	Expt 2	Expt 3	Expt 4	Expt 5	Expt 6	Expt 7	Expt 8	Expt 9	Expt 10
Following instructions	Follow instructions step by step	4	4	3	4	3	3	4	4	4	3
	Listen carefully to the teachers instructions	5	5	5	5	5	4	5	5	5	5
Correct manipulation of apparatus	Labelling solutions and equipment	5	5	0	n/a	3	1	n/a	n/a	n/a	3
	Using given apparatus in the correct manner	4	4	3	4	4	1	2	2	0	1
	Correct preparation of solutions and mixtures	1	1	3	4	3	1	2	2	n/a	n/a
	Using and/or measuring time as a variable	0	0	1	n/a	n/a	n/a	n/a	n/a	0	n/a
	Correct use of a measuring instrument	5	5	2	n/a	0	n/a	2	2	0	n/a
	Take an accurate reading	0	0	2	n/a	0	n/a	n/a	n/a	0	n/a
Observation	Accurate observation (using equipment)	5	5	2	5	0	0	4	0	0	3
	Appropriate observation of the phenomenon under study – (was the correct aspect of the phenomenon observed)	5	5	2	4	0	0	4	4	2	3
	Complete observation of the phenomenon under study (producing the correct phenomenon)	0	0	0	5	0	0	n/a	0	0	3
Recording	Careful recording of data	5	5	2	0	0	n/a	n/a	0	0	3
	Write up the procedure	3	3	5	4	0	n/a	5	4	3	5
	Perform calculations as required	5	5	n/a	n/a	0	n/a	n/a	n/a	2*	n/a
	Tabulate results	5	5	0	n/a	1*	n/a	n/a	n/a	1*	0
	Draw diagrams or graphs to represent data collection	1	1	0	4	0	n/a	n/a	5	0	4
Interpretation	Draw reasonable conclusions from your observations and results	1	1	1	4	1		1	1	1	3
	Conclusions should ensue from hypothesis being tested	0	0	0	0	0		0	0	0	0
	Coherent final interpretation that explains how results are reached	1	1	1	1	1		1	1	1	1
Application	Awareness of any other application of what was learned	0	0	1	2	1		4	0	0	0
	Consider the results in a wider context	0	0	0	1	0		1	0	0	0
	Identify an activity that serves as a model for further investigation	0	0	0	2	0		2	0	0	0
Practical enquiry	Consideration of ambiguous results	1	1	n/a	n/a	0		n/a	1	1	0
	Repetition of activity if necessary	0	0	n/a	4	0		n/a	0	0	0
	Design of a new activity	0	0	0	4	0		0	0	0	0

Use of the scientific method as outlined in the syllabus documents	Making initial observations	0	0	0	0	0		0	0	0	0
	Forming a hypotheses	0	0	0	0	0		0	0	0	0
	Designing a controlled experiment	0	0	0	0	0		0	0	0	0
	Reporting and publishing results	0	0	0	0	0		0	0	0	0
	Appreciation of errors	0	1	0	n/a	1		n/a	1	1	n/a
	Use of controls to reduce errors	3	4	1	0	1		1	0	0	n/a
	Collecting data- *see observation / recording above*										
	Interpreting data & reaching conclusions - *see interpretation above*										
	Placing conclusions in the context of existing knowledge & development of theory and principal – *see application above*										
Notes on Experiments	Experiment 1: To investigate the effect of pH on the rate of enzyme activity – Optimum pH from doing experiment inconclusive. Teacher told students what they should have observed. No mention or measurement of the rate of enzyme activity Experiment 2: To investigate the effect of temperature on the rate of enzyme activity – Incorrect phenomenon observed due to errors in experimental procedure. No mention or measurement of the rate of enzyme activity Experiment 3: To Carry out one enzyme immobilisation and investigate any application if it- Partial phenomenon observed – turbidity omitted. Students only did the first part in their groups.The second part was done at the top of the room by demonstration. Experiment 4: To examine the structure of a dicot plant - This lesson was partly taught through Irish. 3 students in the class. Relaxed atmosphere. Teacher gave students freedom to conduct further investigations into plant structure when they had finished the main experiment. Experiment 5: Investigation of the effect of IAA on root and shoot growth in radish seed- No phenomenon observed – seeds did not grow. Data set was not given to students to analyse or to draw a graph. Teacher showed students the graph. Some of the interpretation of the graph was misleading. Experiment 6: To investigate the conditions necessary for germination - Only the set- up of this experiment was observed Experiment 7: To investigate the production of alcohol from yeast – first part of the experiment. Experiment 8: To test product of yeast fermentation for alcohol - The iodoform test is not sensitive for alcohol at the %v/v of alcohol produced by yeast in this experiment., therefore no phenomenon observed Experiment 9: To investigate the factors that affect the rate of photosynthesis - No phenomenon observed – teacher gave students a data set results. No explanation of how the rate is measured Experiment 10: Dissection and display of a sheep’s heart - Some aspects of the heart dissection omitted e.g. location of the coronary artery										

Key: 0 = recommended by syllabus documents but not a feature of this experiment 1 = Teacher completes this part with no input from students 2 = Teacher mostly completes this part with a little input from students 3 = Most students complete this part with some assistance from teacher 4 = Most students complete this part with a little assistance from teacher 5 = Most students complete this part without assistance from teacher
* Teacher showed a data set to class

The sections that follow provide a commentary on the provision of these skills in the biology practical classroom

Following instructions:

The main skill emphasised by teachers during the observed lessons was to follow instructions. All except one practical class observed followed the same routine whereby students entered the classroom, the teacher explained what was intended for them to do during the practical lesson and the students then followed step by step instructions in order to produce a pre-determined phenomenon. From Table 3.1, students were not able to follow instructions completely independently.

It was not always clear to the students how they should execute the instructions given to them by the teacher. Mr. Jones was cognisant of his students' uncertainty and he found it frustrating that having explained the step by step instructions, students still had difficulty following the instructions. He was inclined to attribute the students' inability to follow instructions to 'information overload' rather than anything else:

> Teacher: Yeah, I can put up on the board the steps on how to do it and they take it down and then you say, "right, let's do the experiment" and they sit there blankly. They wouldn't even know to get two beakers. So there is, at times there's a mismatch and it does depend on the group sometimes as well
> Researcher: Yeah, why is that?
> Teacher: It's hard to know. Maybe its information overload like? Sometimes when I give the experiment, "right this is step one, this is step two this is step three", they will do it that way. If I put up step one on the board, they all do step one but what are they learning from that? They're learning to follow orders more than anything, like.
> *(Mr. Jones)*

However, for students to learn science there should be some connection with their everyday experience (Dewey, 1938/2015). It seems anathema that the teacher would "start with knowledge already organised and proceed to ladle it out in doses" (ibid., p.82), but this is exactly the format that was used in the observed classroom experiments. Mr. Jones could see the difficulty students had with following the instructions they were given but he could not understand it. Generally this difficulty is underestimated by teachers, who do not consider their students' unfamiliarity with the materials and procedures given to them (Olsen, 2004), leading to cognitive overload (Sweller, 2011):

> Sue: Yeah, there was a lot to do today
> Jim: Yeah
> Sue: I think that's what it was. There was a lot of different components to mix
> Ann: Yeah, new stuff
> Sue: New stuff, like stuff we've never used. Like I've never used sodium alginate before
> Jim: Yeah. I've never heard of it *(laughs)*
> *(Student interview 2)*

Producing the phenomenon:

All of the observed experiments (with the exception of one lesson taught through the Irish language to a class of 3 students) were taught using a recipe method. The difficulty with this style of teaching was that students could not 'see' the phenomenon in the same way the teacher 'sees' it (Ogborn et. al., 1996; Pardo and Parker, 2010). Therefore, to students, a successful experiment was one that produced the phenomenon, rather than any deeper learning intention such as connecting the phenomenon with the underlying scientific principle:

> Researcher: Orla what is a successful experiment, how do you know it has been successful?
> Orla: Em, like when you read the experiment and like, when you actually perform it and it comes out like, the way it's ….*(pause)*
> Researcher: The way you read it?
> Orla: Ok
> *(Student interview 4)*

Table 3.1 shows that producing the correct phenomenon in the observed practical lessons proved difficult for six of the experiments. When the teacher failed to produce the phenomenon, the learning was seen to be impeded because the 'learning' focused on the end-product rather than the process of scientific investigation. Nott (1996) outlined three ways that teachers compensate for this failure to produce the phenomenon:

1. Students are told what should have happened, which leads to a curious situation where students can give an accurate account of an experimental phenomenon that they never actually witnessed – this was observed in 6 lessons

2. Teachers 'rig' the experiment by applying their subject or pedagogic knowledge to make the practical work – this was not observed in any observed lesson.

3. Teachers 'conjure' the correct phenomenon by deceiving the students into believing a phenomenon was produced – this was not observed but is alluded to below by Mr. Donnell who talked about 'spiking' an experiment:

> Teacher: …. sometimes even if their results aren't achieved or they get a result that potentially isn't for the exam, they're told what to put in the exam. For the alcohol experiment with respiration, it never works and it's just a matter of, "This is what you should see", or potentially you have to go in and spike it with concentrated ethanol and make up the results for them.
> *(Mr. Donnell)*

Recipe-style teaching has been criticised for its false expectation that that scientific concepts follow on from simply observing natural phenomena (Lunetta et. al, 2007; Millar, 2004). The excerpt below illustrates how utterly confusing and frustrating it was for students to blindly follow instructions without observing any phenomenon at all:

> Researcher: What are the, at the moment with practical work, what are the major barriers to your learning?
> Emma: We don't really understand it (practical work) in the first place to actually understand what's going on as we're doing it like
> Olive: That it doesn't really work as well, like maybe if it worked we'd understand why it worked. Whereas when it doesn't work you're just like " alright, it didn't work" and we don't know why it didn't work or how we could change it to make it work
> Emma: And it's not even like, say like, ours didn't work but somebody else's worked, that did, so you could compare, like, it's just, nobody's did.
> Olive: Yeah
> Emma: So we don't actually know what's supposed to happen
> *(Student interview 1)*

From the notes at the bottom of Table 3.1, it can be seen that teachers omitted important aspects of many of the practical activities. Following Kang et al. (2013), the evidence presented above and in Table 3.1, provides evidence that teachers' lack of content knowledge affected their ability to teach through enquiry.

Teaching laboratory skills:

Each experiment in the Laboratory Handbook for Teachers (GOI, 2003) is furnished with a list of scientific skills students should acquire by completing the experiment using the scientific method of enquiry. These include manipulation of apparatus, observational skills, recording skills, interpretation and application skills (See Table 3.1). The excerpts below indicate that teaching laboratory skills was not prioritised for two reasons; lack of time and perceived lack of relevance to the examination:

> Yes, you can be extremely accurate and precise in your measurements but who's going to give you anything for that like? 'Do you know what the result is?'
> *(Interview with Mr. Donnell)*

> I think that there's just so much in the course that we don't get a chance to do anything else but the bare minimum
> *(Interview with Ms. Reilly)*

This contradicted the belief held by some teachers and students, that students were learning laboratory skills that may benefit them going forward. Gatsby (2012) found that practical skill levels had declined over a five year period in third level students, and a factor in the dearth of practical skills was the "limited exposure to practical skills at school" (Grant, 2011, p.2). At no point in any of the lesson observations was any emphasis placed on basic laboratory skills:

> Researcher: Like are there measurement skills they learn?
> Teacher: Yeah, I think so. I do think it's funny even still looking at some of them using graduated cylinders, it's kind of off the wall in terms of their use of equipment… but yeah, I think there's scope for it but I think it's still not something that we're focusing on.
> *(Mr. Donnell)*

Table 3.1 indicates that, in general practical skills such as interpretation, data recording and application, were generally absent or, if they were present, were conducted by the teacher.

The Scientific Method:

The scientific method involves, making initial observations, forming hypotheses, designing controlled experiments, collecting and interpreting data, presenting findings to confirm or refute the hypotheses. An examination of Table 3.1 shows that there was no evidence of the use of the scientific method in any of the observed lessons. The teachers and students were aware that the practical lessons did not incorporate aspects of the scientific method:

> Researcher: Every experiment was supposed to incorporate the scientific method. Would you say that happens?
> Teacher: No
> Researcher: Ever?
> Teacher: Definitely not, no.
> *(Mr. Jones)*

Ironically the students were familiar with the scientific method as a means of conducting experiments, but only as a theory chapter in the book, since it was never actually applied in real classroom situations. The students below did not understand that the scientific method they learn about in class is relevant to Leaving Certificate biology practical work:

> Researcher: Ok. You've studied the scientific method?
> Both: Yeah
> Researcher: Ok. Do you ever use the scientific method to do an experiment? So do you ever pose a hypothesis? Do you ever ask a question? Do you ever collect data and analyse your data?
> Emma: We should be
> Olive: But we're not
> Researcher: Is that a part of Leaving Cert biology?
> Both : No
> *(Student interview 1)*

The type of language that teachers used when talking about why they do not use the scientific method or an enquiry-oriented approach in their practical teaching is significant:

> I **wouldn't have time** for anything **out of the ordinary** like that
> (Ms. Reilly)

> I was getting quite academic people and they don't want to be bothered with all that kind of **nonsense**. They want to get the learning done
> *(Ms. Rogan)*

The scientific method of enquiry was rendered "nonsense" in favour of a system that has been proven *not* to lead to thinking or learning in any meaningful sense. Enquiry was considered a waste of time and 'out of the ordinary' or in Dewey's words "intellectually suspect" (1916/2011, p.13)

Scientific Enquiry:

Table 3.1 indicates a dearth of scientific enquiry used by students, even though this is a syllabus requirement. The observed practical activities demanded that students only follow instructions, observe and conform.

One reason given by teachers for not incorporating enquiry-oriented work into their teaching is the belief that doing enquiry based practical work and achieving high grades were mutually exclusive. Ms. Rogan, below, recognised that enquiry-oriented teaching was actually superior in terms of student understanding but did not believe that it was suited to senior cycle biology and designated it as a "hobby":

> Teacher: Teachers are afraid that it will take up too much time and they'll miss out on the theory and the kids will – even though they'll understand more – they won't get high grades. So that's basically points
> Researcher: So it boils down to points?
> Teacher: ……..So going into enquiry based learning is great if it's a hobby but no good if you want the points [required to gain entry to third level]
> *(Ms. Rogan)*

Mr. Jones believed it was too great a risk to employ enquiry methods as a newly qualified teacher:

> Teacher: So I just had to learn the course again, first time doing experiments, so there definitely is scope for enquiry based but as a new teacher coming out, it's a big risk, it's a risk for you like-
> Researcher: Yeah
> Teacher: -trying enquiry based methods if you're learning the ropes yourself like-
> Researcher: Ok
> *(Mr. Jones)*

Ms. Brown, a teacher with 38 years of experience, made an attempt at conducting an enquiry-oriented lesson – she had her class investigate factors required to cause rust on iron nails, by introducing unusual variables such as methylated spirits and saltwater. She found that 'it kind of complicated it for them' and it was not relatable to the type of exam question they would be asked to answer so she did not try it again:

> Teacher: ……. and then ask for an experiment to describe testing something for oxygen, testing the conditions needed for rusting and that, and they giving back something about methylated spirits and things and all that; they're nothing at all to do with it but I just got them to do it to see what effect, would any of these things have an effect, putting acids in and all different things in and it was grand except that they weren't able to bring it down to what they needed from an exam point of view
> Researcher: Ok, yeah, that's a good point
> Teacher: Do you know? So that would kind of tell you to, teach you to mind your own business in future and do what's on the course, you know?
> *(Ms. Brown)*

Perhaps a more salient reason for the dearth of enquiry-based practical work is related to the type of school, university and professional development experiences that teachers have. All of the teachers interviewed, (excluding one who couldn't remember doing practical work) reported a lack of enquiry-based practical experience as second level students themselves:

> …it was very much recipe based, it was very much, we would normally go in, the teacher would have set up a demonstration at the top of the room, she would demonstrate, we would do the experiment, we'd write up the results and then she would often give us like a photocopy of what we should write into, like, our experiment book so it was very, very much recipe based
> *(Ms. Byrne)*

As third level students, their experience in the laboratory was not much different to their second level experience:

> Teacher: Yeah, just get the job done. I didn't have much of an understanding, I suppose chemistry in particular, like it was just 'mix these two things together and away you go.
> Researcher: So, enquiry based then?
> Teacher: Not a whole heap at all, no. It was 'how well can you read the instructions' and go at it.
> *(Mr. Donnell)*

What came through in the interviews very clearly was that there was not enough emphasis placed on how to teach laboratory-based practical lessons through enquiry during initial teacher education. Two of the teachers interviewed referred to modules they had done in college where they learned how to teach the Leaving Certificate biology experiments using the recipe-style method.

For those teachers who had been taught about enquiry-based learning, when they looked back on their experience as student teachers, they could see a disconnect between the enquiry-based nature of what they were taught in their education lectures and the subject specific recipe-based laboratory work they undertook. This finding accords with that of Wei and Li (2017), who reported that there was no enquiry-based training at all during initial teacher education, or the training that teachers received was perceived as separate from practical laboratory experience. The lack of opportunities to engage in professional development courses aimed at teaching enquiry-based practical activities was echoed by all of the teachers interviewed here (Dillon, 2008). This resonates with a report from the Biosciences Federation that,

> "newly qualified science teachers are entering the profession ill-prepared to deliver lessons with practical work or field experiences as they themselves are not receiving the training in the delivery of these important aspects of science teaching."
>
> (House of Lords, 2006, p. 66).

Research has found that in general, science teaching remains relatively didactic and focused on delivering information because teachers are not skilled in enquiry teaching methods (Capps et al, 2013; Lunetta et al., 2007).

3.3.3 Summary

The observational work carried out in this phase of the research and summarised in Table 3.1 indicated that students have some level of competence in following instructions, manipulating apparatus, making observations and recording results; the 'hands-on' skills. However, the 'minds-on' thinking skills – data interpretation, application and practical enquiry – eluded senior-cycle students. The vast amount of research that supports the importance of enquiry-based learning in science has had no impact within the sphere of the Irish biology classroom.

Biesta (2015) asks the question of whether the messages we convey are actually the ones we deem desirable for the education of our students, which is a pertinent question to ask of the recipe approach to teaching biology. When there is a contradiction between what we say and what we do (as there is between the aims of practical activities as set out in syllabus documents and the enactment of practical activities in the classroom), students tend to focus more on how we do than on what we say (ibid., 2015). Teachers encourage students to rote learn as much as they can, to do well in their exams, and as a result, students have become discerning in what they learn, focusing specifically on exam-based material (Smith, Banks and Calvert, 2011). Consequently, educational effectiveness is measured with very narrow criteria for success in mind. This has led to the current situation where the enquiry-based syllabus intentions are ignored in favour of phenomenon oriented recipe-based instruction. This method of teaching practical science has become culturally ingrained at upper secondary level, regardless of what the syllabus requirements are and regardless of teacher awareness of other more effective options that can help students develop real thinking skills (Coil et al., 2010; D'Costa and Schleuter, 2013; Fotou and Abrahams, 2015; Philip and Taber, 2016). Teaching students to learn through enquiry and preparing students for the Leaving Certificate exam were seen as mutually exclusive by the teachers in this study.

3.4 Engaging the Mind in Practical Biology

This section concerns the initial observations and interviews that were conducted as part of the scoping phase of the project. Six teachers in four secondary schools participating in 10 biology practical lessons were observed. In addition to video recording each lesson, a Dictaphone was placed on one desk during each observation, to record student conversations throughout the practical class. Interview evidence from students and teachers was used again during this section to support observational claims made here

Video observations were re-visited after the interviews

1. To assess the 'effectiveness' of the practical activities using Millar's (2009) PAAI
2. To assess the level of questioning (Cullinane and Liston, 2016)

All participants were allocated pseudonyms, with student comments preceded by Christian names and teacher comments preceded by surnames in interview extracts. Where dialogue was taken from tape recorded lessons, the teacher is denoted as 'T' and the student is denoted with 'S'. If there is more than one student recorded during a lesson, they are allocated 'S1', 'S2' and so on.

Millar and Abrahams (2008) describe the effect recipe-style teaching has on students' comprehension of scientific concepts underpinning practical work. Following Tiberghien (2000), they separated practical activities into two domains – the domain of observables and the domain of ideas. The former concerns what students do with equipment and materials (the hands-on domain) while the latter concerns what students do with ideas (the minds-on domain). Their findings suggest that students are generally capable of working somewhat effectively within the hands-on domain but not in the minds-on domain. Millar's (2009) Practical Activities Analysis Inventory (PAAI), a structured observational tool, was used here to assess the level of hands-on and minds-on activity in the ten observed lessons, from which the effectiveness of each practical lesson was determined (for full PAAI, see Appendix 3.1). Each section in the analysis that follows, is based on a different aspect of the PAAI.

Abrahams and Millar (2008) obtained evidence for the degree of learning that occurred in each domain from student interviews, where they found that students could recall *what* they had done (hands-on), but did not understand *why* they had done it (minds-on). In this section, to supplement the data collated in the PAAI, interview and student dialogue is used in a similar manner to explore the separation of 'doing' and 'thinking' in the observed biology practical lessons.

The interview and dialogue findings were coded into themes which are presented in Figure 3.2. Each section (before, during and after practical work) is addressed in turn here.

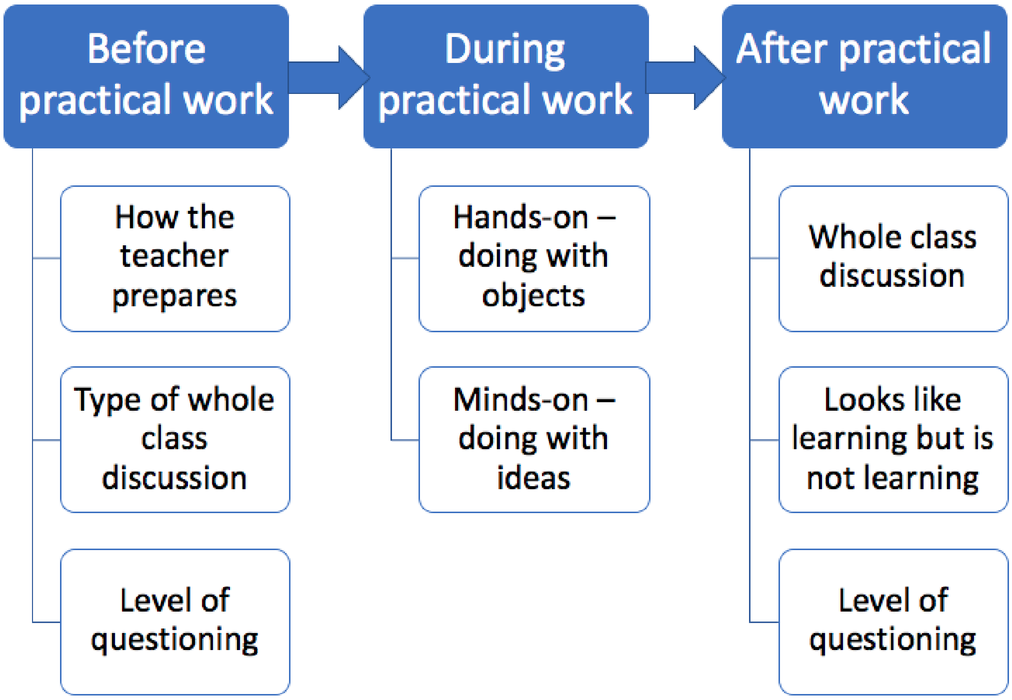

Figure 3.2: Outline of the presentation of findings before, during and after practical work.

3.4.1 Before Practical Work

This piece looks at how teachers prepare for practical lessons, the type of discussion before an activity and the level of questioning before an activity.

Preparation:

Teaching through scientific enquiry requires advanced planning – teachers need to plan for what students are to do and for what they are think about, i.e., learning objectives have to be established and planned for. In all of the observed lessons the students were not explicitly told what the learning objectives were for their practical lessons. Generally, the objectives of the lessons had to be inferred by the researcher following classroom observations and video analysis. These inferred learning objectives focused on using equipment and following a standard procedure (Table 3.2).

Table 3.2: The learning objective for each practical lesson - From Millar's PAAI (2009)

2 Learning objective(s) (or intended learning outcome(s))

Activity number →		1	2	3	4	5	6	7	8	9	10
1.1 Objective (in general terms) *(Enter '1' for the* ***main objective****; '2' if necessary for a* ***subsidiary objective****.)*											
A: By doing this activity, students should develop their knowledge and understanding of the natural world					1				X		x
B: By doing this activity, students should learn how to use a piece of laboratory equipment or follow a standard practical procedure		X	X	X	2	X	X	X		X	X
C: By doing this activity, students should develop their understanding of the scientific approach to enquiry											
1.2 Learning objective (more specifically) *(Tick ✓ one box in each group for which you have entered a number above)*											
A1	Students can recall an observable feature of an object, or material, or event										X
A2	Students can recall a 'pattern' in observations (e.g. a similarity, difference, trend, relationship)				X	X		X			
A3	Students have a better understanding of a scientific idea, or concept, or explanation, or model, or theory								X		
B1	Students can use a piece of equipment, or follow a practical procedure, that they have not previously met	X	X	X		X				X	X
B2	Students are better at using a piece of equipment, or following a practical procedure, that they have previously met				X		X				
C1	Students have a better *general understanding* of scientific enquiry										
C2	Students have a better *understanding of some specific aspects* of scientific enquiry										

For C2, rather than simply ticking ✓ the box, enter letters to indicate the *specific aspects* being taught, as follows:

a	How to identify a good investigation question	e	How to analyse data to reveal or display patterns
b	How to plan a strategy for collecting data to address a question	f	How to draw and present conclusions based on evidence
c	How to choose equipment for an investigation	g	How to assess how confident you can be that a conclusion is correct
d	How to present data clearly		

Practical lessons could only be described as closed (Table 3.3) since the method for each practical activity was given to the students by the teacher:

> Researcher: Do you ever sit and plan what you're going to do or anything like that?
> Sue: No, we're always just given the method and we just copy the method, whereas we never, like, discuss "oh we could do it this way or that way"
> *(Student interview 2)*

Table 3.3: The openness/closure of each lesson – from Millar's PAAI (2009)

Activity number	1	2	3	4	5	6	7	8	9	10
2.1 Openness/closure (Tick one box)										
No question given, and detailed instructions on procedure		X	X		X		X	X	X	X
Question given, and outline guidance on procedure; some choices left to students				X						
Question given, but students choose how to proceed										
Students decide the question and how to proceed										

Teachers' preparation for practical activities revolved around organising equipment and ensuring students had read and understood the instructions. None of the teachers questioned prepared for what they wanted students to think about during the experiment (Abrahams and Reiss, 2012; Fotou and Abrahams, 2018). The preparation itself was hands-on rather than minds-on:

> Researcher: Ok and does your prep mostly revolve around equipment then? So, would it ever revolve around, 'what I want them to think about' or 'how I'm going to' -
> Teacher: -My prep would involve equipment
> *(Ms. Brown)*

From the students' perspective, their preparation involved reading the experiment and writing down the steps of the procedure (Table 3.4):

> J: Well normally like, beforehand we would actually like, we'd have it taken down the class before, he'd tell us like and we'd take down all the instructions and stuff
> *(John, student interview 3)*

> R: So, say you're coming into class, you know you're doing an experiment. How does it generally go? What happens?
> S: We read over it for about 10 hours *(exaggerating) (laughter)*
> *(Sue, student interview 2)*

The paucity of minds-on planning led to one dimensional lesson objectives that focused mainly on using equipment and following instructions to produce a phenomenon. It is hard to rationalise how students were expected to operate in the minds-on domain when teachers themselves did not prepare for how students could occupy said domain (National Research Council, 2000, 2012; Osborne, 2015).

> Researcher: When you come in to do an experiment what preparation have you done?
> Emma: He puts like, the boxes [PowerPoint presentation] up on the board with the instructions on what to do
> Researcher: But say before you come into class even, what have you done in preparation for your experiment?
> Emma: We don't even know there's an experiment going on like
> Olive: It's just we go in there "put on your lab coats"

(Student interview 1)

Discussion:

In seven out of ten lessons, the activity was proposed by the teacher without any links made to previous work (Table 3.4). Dewey (1938/2015) believes that the crux of enquiry teaching is linking topics together along an experiential continuum. With recipe teaching, students cannot make their own connections to ideas in order to make sense of scientific concepts because the self, "the tool of tools", "**the** means in all use of means" is excluded (Dewey, 1925/1958, p.247). They have no previous experience from which to draw upon.

To explain the activity to students, teachers generally focused on *what* students were to do with materials and objects, rather than *why* they were to do it. There was a general format that most practical lessons took, captured perfectly by Mr. Donnell below:

> Yeah so I suppose in the class previous we go through what we're going to do. We might look at a video if there's one available on the procedure, we come in that morning, we go through the procedure again, might ask them a couple of questions to see what we're going to do, put it open to them then maybe the equipment that we're using and what safety precautions they might have to come up with and then I tend to let them off and see can they follow the instructions……..And then I suppose making sure that they get the results and take down the results, good clean up and then our results and our conclusion then afterwards in their workbook and do the write up then
> *(Mr. Donnell)*

In terms of whole class discussion preceding the activity, it is also important to define what is meant by a discussion in this scenario; namely "the activity in which people talk about something and tell each other their ideas or opinions"(Cambridge International Dictionary of English, 1995). From observations and interviews, it cannot be said that what occurred in biology classrooms was a discussion, since there was no exchange of ideas - the beginning of the lesson was dominated by the teacher explaining to students what to do with materials and equipment (Table 3.4).

Table 3.4: The explanation of the purpose of each activity and how the activity is explained to students – from Millar's PAAI (2009)

Activity number	1	2	3	4	5	6	7	8	9	10
3.1 How is the purpose, or rationale, communicated to students? (Tick one box)										
Activity is proposed by teacher; no explicit links made to previous work	X	X	X		X	X	X			X
Purpose of activity explained by teacher, and explicitly linked to preceding work				X				X	X	
Teacher uses class discussion to help students see how the activity can help answer a question of interest										
Purpose of activity readily apparent to the students; clearly follows from previous work										
Activity is proposed and specified by the students, following discussion										
3.2 How is the activity explained to students? (Tick all that apply)										
Orally by the teacher	X	X	X	X	X	X	X	X	X	X
Written instructions on OHP or data projector	X	X	X		X	X	X	X	X	
Worksheet								X		
(All or part of) procedure demonstrated by teacher beforehand								X		
3.3 Whole class discussion before the practical activity begins? (Tick all that apply)										
None										
About equipment and procedures to be used		X	X	X	X	X	X	X	X	X
About ideas, concepts, theories, and models that are relevant to the activity									X	
About aspects of scientific enquiry that relate to the activity										

Questioning:

The bulk of any discourse that took place with students before a lesson took the form of questions, asked by the teacher and answered by the student. Bloom (1956) developed a hierarchical taxonomy that classifies the level of thinking behind an educational objective. Following Cullinane and Liston (2016), who classified the Leaving Certificate biology exam paper questions into the different categories in Bloom's Taxonomy (*recall, comprehension, application, analysis, synthesis* and *evaluation*), this study examined the type of question that teachers asked before and after practical lessons and categorised them in a similar manner (Figure 3.3). It was also noted whether students could answer each question asked correctly on their first attempt.

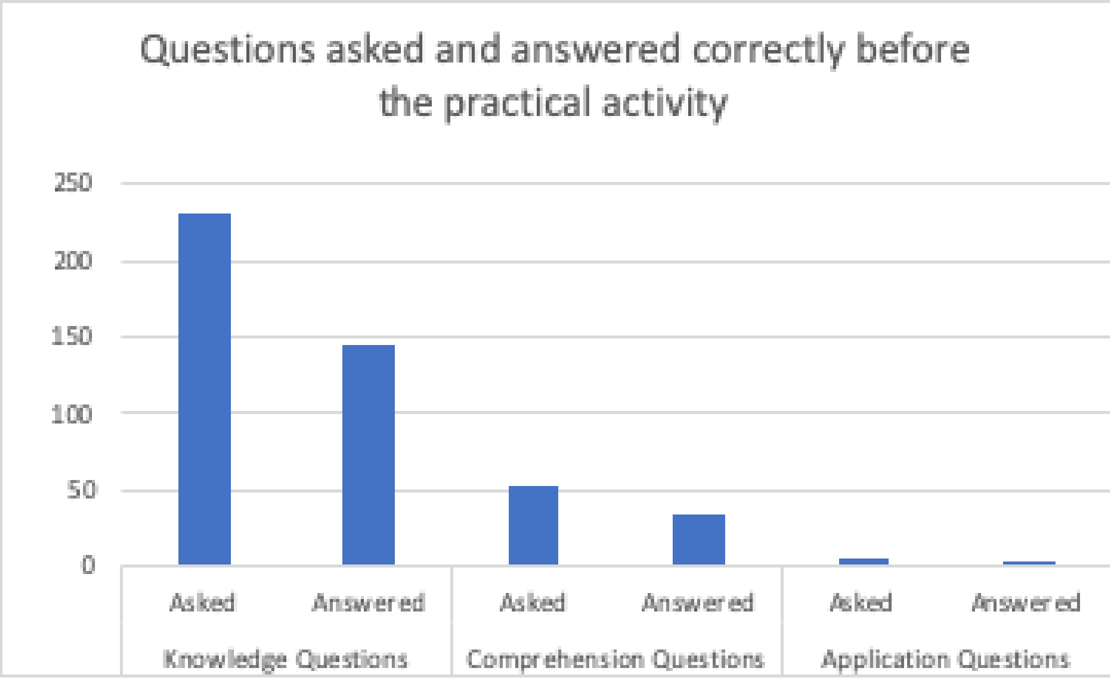

Figure 3.3: Bloom's taxonomy classification depicting the type of questions asked and answered correctly before the practical activity

In total, 290 questions were asked by teachers, before practical lessons. When the questions were classified according to Bloom's Taxonomy, 231 (79.7%) were at the level of *recall* which represents the lowest level of cognition, 53 (18.2%) were one level up at *comprehension* and only 6 questions were asked at the level of *application*. All of these questions are considered to be lower order questions. No question was asked at any of the three higher levels of thinking: *analysis, synthesis and evaluation*.

The hierarchical nature of Blooms Taxonomy means that a student can only learn at a higher level once they have attained prerequisite familiarity and skills from the lower levels of the taxonomy (Orlich et al., 2004). In this study, the students' cognitive level was stifled by the restricted nature of questioning which was confined mainly to the two lower levels of Bloom's Taxonomy. While the level of questioning in the classroom was aligned with the level of questioning on the terminal exam paper (Cullinane and Liston, 2016), the level of questioning in the classroom was mis-aligned with the cognitive level required to conduct scientific enquiry. Enquiry requires that students operate at higher cognitive levels, using synthesis, application and evaluation to design experiments and interpret results to form conclusions that can be applied in further experimental situations (Dewey, 1938/2015).

3.4.2 During practical work

This section evidences students' lack of scientific literacy and practical skills by outlining the nature of hands-on and minds-on work incorporated into the observed practical lessons.

The excerpt below revealed how students understand what they were doing but not why they were doing it:

> Researcher: How often do you come out of doing a practical and you'll go, "I definitely know what that was about" and how often would you come out and go," I have no idea what that was about? What do you think O? Which is more likely?
> O: coming out saying I know what it was about, yeah
> R: You're more likely to know what you were doing?
> O: Yeah
> R: Physically. How likely are you know what you were supposed to understand? To make the connection between the practical work and the theory?
> O: Less likely. I dunno cause sometimes I just get, I get really confused about what's going on with the practical and how it relates to what we're doing
> *(Student interview 4)*

Below, students were engaged in observing a phenomenon and recording data. While it is understood that students speak to each other using their own colloquialisms, learning to read a measuring cylinder is an essential skill in experimental science that makes universal communication possible. Student 1 below did not understand that she should be reading 20 ml on the graduated cylinder, mistaking the 10ml graduations as "rounds":

> S2: Ok what's the volume?
> *Student reads volume on graduated cylinder*
> S1: Like 2 is it? …… 2 rounds
> *(Tape recording at 37.19 mins during Enzyme & Temperature experiment)*

Students tended to superficially follow the instructions, without giving due thought to what they were actually doing. The lack of attention to accuracy or correct procedure in the excerpt below, highlighted how the student was thinking about the experiment; there was a sense of uncertainty with following the instructions:

> S1: Right here which one am I putting this in? I need something to stir it with. *(Laughter)*…….. Just take it, just put it in. Come on give me the stirring yoke. I don't think we're supposed to use it – no we're not supposed to use this .Right so, I'm just going to throw this in and hope for the best. What do I do? Stir?
> *(Tape recording at 28.11. mins, during Enzyme Immobilisation experiment)*

The lack of attention to laboratory skills or scientific literacy, resulted in a reduction in students scientific communication skills.

'Hands-on' - Doing with objects and materials:

Table 3.5 indicates what students did with objects and materials in the lessons that were observed. A closer examination of student discussions recorded during experiments revealed that students were focused solely on using equipment and following instructions.

Table 3.5: A record of what students "do" with materials – From Millar's PAAI (2009)

Activity number	1	2	3	4	5	6	7	8	9	10
2.4 What students have to do with objects and materials (Tick all that apply)										
Use an observing or measuring instrument	X	X	X	X	X					X
Follow a standard practical procedure	X	X	X	X	X	X	X	X	X	X
Present or display an object or material				X				X		
Make an object										
Make a sample of a material or substance			X	X	X				X	
Make an event happen (produce a phenomenon)	X	X	X		X	X	X		X	
Observe an aspect or property of an object, material, or event	X	X	X	X				X	X	X
Measure a quantity	X	X	X		X		X			X

Enzymes were chosen as the main topic to examine in depth as more than 25% of mandatory experiments in the Leaving Certificate syllabus are based on enzyme activity. For example, in the enzyme immobilisation experiment students were required to do the following:

a. Use an observing or measuring instrument / measure a quantity

In the class the students were given the opportunity to use an electronic balance to weigh out a very small amount of yeast. The student below understood how to use it and was heard correcting a mistake made by another student:

> S1: Just for clarification, I'm putting this in here amn't I? (*laughter)* …… That's way too much, it's supposed to be 0.4 and you put in 10 *(laughter)*…… You're supposed to put it on zero and then weigh it out.
> *(Tape recording at 29.42 mins during enzyme immobilisation experiment)*

b. Follow a standard procedure

Students followed the procedure to the point where they immobilised (trapped) yeast inside gel beads. The second part of this experiment was to examine any application of an immobilised enzyme. The teacher performed this part as a demonstration.

c. Make a sample of a substance (producing the gel beads),

Making the beads or 'balls' was the most memorable part of the experiment for the students, which aligns with Millar and Abrahams (2008) observation that students can recall experiments when there is some unusual aspect to them. At one point there was a group observed handling and laughing over a giant bead they had made, but they had no understanding of how the gel beads were formed from the materials they were working with:

> Like, how does, like, two, like, just two, like, liquids suddenly form, like, these little balls, like (laughs). I just don't get that
> *(Sue, student interview 2)*

The following excerpt, taken from a different enzyme experiment (Production of Alcohol), outlines how making gel beads was so memorable that Student 4, below, thought he was supposed to be making them again:

> S4: Do something like!
> S3: Here right *(puts fermentation lock on conical flask and looks around to see if other groups are doing same)*
> S4: This lad goes in here. Is there bubbles coming out of yours?
> S5: We need limewater now
> S3: So, what do we want? We want carbon dioxide to come out of this
> S4: I thought we were making the little balls *(referring to the enzyme immobilisation experiment)*

Tape recording at 39.59: production of alcohol experiment

Incidentally, the teacher missed an opportunity to connect the experiment above with the enzyme immobilisation experiment, as both experiments use yeast as the source of enzyme(s).

d. Produce the phenomenon

The students spent 30 minutes immobilising enzymes in gel beads and then did not perform an application with the immobilised enzymes. For the last 15 minutes of the lesson, they stood around one desk while the teacher demonstrated the diagnostic test to check for the production of glucose. The class ended before the students were able to observe the intended phenomenon.

e. Observe a property of an object

A second phenomenon that students should have observed in this experiment was the turbidity of the free yeast solution compared to the immobilised yeast. However, the demonstration of the phenomenon neglected to examine for turbidity. As outlined in the next section, students did not understand the scientific concept underpinning the experiment.

‘Minds-on’ - Doing with ideas:

Table 3.6 details what students had to ‘do’ with ideas. A comparative glance at Table 3.4 reveals how students had less to do with ideas compared to what they do with materials.

Table 3.6: A record of what students "do" with ideas – from Millar's PAAI (2009)

Activity number	1	2	3	4	5	6	7	8	9	10
2.5 What students have to 'do' with ideas (Tick all that apply)										
Report observations using scientific terminology				X				X		
Identify a similarity or difference (between objects, or materials, or events)			X							
Explore the effect on an outcome of a specific change (e.g. of using a different object, or material, or procedure)									X	
Explore how an outcome variable changes with time			X							
Explore how an outcome variable changes when the value of a continuous independent variable changes	X	X					X			
Explore how an outcome variable changes when each of two (or more) independent variables changes						X				X
Design a measurement or observation procedure										
Obtain a value of a derived quantity (i.e. one that cannot be directly measured)										
Make and/or test a prediction										
Decide if a given explanation applies to the particular situation observed										
Decide which of two (or more) given explanations best fits the data										X

In the enzyme immobilisation experiment (activity 3 in Table 3.6), there are two areas identified where students have to 'do' with ideas:

a. Identify a similarity or difference - between free yeast and immobilised yeast.
b. Explore how an outcome variable changes with time – the length of time it takes immobilised yeast/free yeast to produce glucose

Students should have understood that the enzyme reaction proceeds quicker when using the free yeast because the sucrose needs more time to access the enzyme source (yeast) in the gel bead before it can be converted to glucose. They also needed to understand that the product produced by free yeast is more turbid than the product produced by immobilised yeast.

From the comments below, students did not learn either of these two aspects during the lesson. The teacher asked the students to predict what would happen before she tested the two solutions for glucose. Initially, the students thought only the immobilised enzyme would produce glucose, not understanding that that both reactions (free and immobilised enzymes) would produce glucose:

T: What do you think is going to happen. Which one is going to get out our product?
S4: The beads
T: The beads, yeah, very good. What are our products that are going to come out here?
S7: Glucose
T: So it would be?
S7: Glucose
T: Glucose and ....fructose. So, the way we are going to test for that is we have these strips here *(holds up container of glucose strips)*. So we're going to place that underneath. You have a table there at the back of your book so we're going to do that glucose test strip. Ok. We're going to repeat it every 2 minutes until the glucose appears in both.
Tape recording at 48.35 mins: enzyme immobilisation experiment

When the teacher asked if there is enzyme in the free yeast reaction, students then thought there was none:

T: Is the enzyme in this still? *(pointing at free yeast solution)*
S1: *(whispers)* No
T: Yeah
(Tape recording at 58.12 mins: enzyme immobilisation experiment)

When students were then asked to answer questions from their textbook about the experiment, they struggled to do so (it is worth noting that the name of the enzyme being assayed for –sucrase- was never mentioned in this lesson):

S2: Name the enzyme that was immobilised? Which was it? Yeast? Yeast?
S1: No, it was sodium alginate
S2: Name the material that immobilised the enzyme
S1: Sodium alginate
S2: I thought that got immobilised?
S1: It was yeast
S2: Yeast
(Tape recording at 1.06.20: enzyme immobilisation experiment)

It may seem that to choose just one lesson to explore in detail may lead to bias, however all students (16 students from 2 different schools taught by 4 different teachers) interviewed were asked about this particular experiment. All of them could remember making the ‘beads’ or ‘balls’. Even more interesting is that in three of the interviews, students said they learned that the beads could be re-used, which is true, but not something that they learned by doing the experiment.

> Researcher: What was the point of that experiment?
> *Pause*
> Andy: Em, enzymes can be reused, like if they're immobilised
> Researcher: How did the experiment tell you that?
> *Long pause – no answer*
> Researcher: It's gone? That's ok, it's fine.
> *(Student interview 3)*

At the end of the lesson, the teacher asked two students what they had learned. They told her they did not know. She tells them the reason why they do not know was because they were not listening. But there may be more to this than what the teacher sees as inattentiveness.

> T: Does everyone now understand immobilised enzymes?(name of student) Why do we immobilise enzymes? Why are they good? From what we discovered today?
> S3: I dunno
> T: What were we doing with the immobilised beads that we couldn't do with the free yeast?
> S3: I actually don't know
> T: *(asks another student)*
> S4: I dunno
> T: You're not listening
> *(Tape recording at 1.10.15: enzyme immobilisation experiment)*

Here it seems that the student was being unfairly accused of not listening, because there was an element of cognitive overload in this activity (Sweller, 2011), where the students' focus was on producing the gel beads, rather than on the scientific concepts underpinning the activity. In addition, the above exchange between teacher and student encapsulates the problem identified in the literature that teachers expect that scientific ideas will 'emerge' from merely observing a phenomenon (Abrahams and Millar, 2008). In the teacher's eyes, the failure of the student to answer is proof that he was at fault. When the responsibility is transferred from the teacher to the student in this way, the material does not have to show that it fulfils any particular need because that responsibility is placed on the student (Dewey, 1916/2011). Recipe-style teaching can then continue unquestioned.

3.4.3. After Practical Work

Every experiment conducted in the classroom included some form of data analysis and interpretation, which fell into three distinct categories (outlined below) – whole class discussion, learning and questioning.

Whole class discussion:

Part of the whole class discussion following an experimental activity involved data analysis. In Table 3.7 it can be seen that the discussion revolved around confirming ‘what we have seen’, whether students actually saw it or not. There was no repetition of the activity, no explanation of observations or concepts, and no scientific enquiry mentioned. As with the discussion before the practical activity, it was questionable whether what occurred could be called a discussion since the teacher dominated the conversation and there was no sharing of ideas.

Table 3.7: Type of discussion before and after the activity- from Millar’s PAAI (2009)

Activity number	1	2	3	4	5	6	7	8	9	10
3.4 Whole class discussion following the practical activity? (Tick ✓ all that apply)										
None						n/a				X
About confirming ‘what we have seen’	X	X	X	X	X	n/a	X	X	X	
Centred around a demonstration in which the teacher repeats the practical activity						n/a				
About how to explain observations, and to develop conceptual ideas that relate to the task						n/a				
About aspects of investigation design, quality of data, confidence in conclusions, etc.						n/a				

In the case of one experiment which did not ‘work’, the teacher showed the class a pre-prepared graph which he interpreted himself, missing the opportunity to let his students attempt the interpretation. The teacher mentioned on a few occasions during the practical lesson that the solution they were using was carcinogenic. The question asked by the student at the end gives an insight into what she was thinking and how it is not connected to what the teacher was saying:

> T: You should have seen basically -this is high concentrations of eh, IAA, and this is the concentration going down. So basically there should have been no

growth at all for the high concentrations of indole acetic acid and as you go down, you know, to the medium you get a little bit of growth and as you get to the really low concentrations you should have had a good bit of growth …….. That's what I've found most years and I'm not sure what happened that time, I'll get some nice photos from previous years..... but basically lower concentrations are very good for growing with IAA and higher concentrations can actually inhibit growth. What did I say IAA could be used for?
S1: Weedkiller
T: Yeah, exactly. It can actually be used to promote growth or to stop growth altogether. It can be used for weed killer depending on the concentration
S2: So is it more carcinogenic or less carcinogenic at high doses?
Tape recording at 25.23mins: IAA experiment

Following the explanation of the graph, the teacher put up a data set for the experiment, which, again, he interpreted himself, rather than allowing the students to use the data to draw a graph and then interpret the graph themselves. During his explanation, video evidence corroborated that all students were facing the board and quietly listening to him talking; essentially it appeared as though they were paying attention. However, the two students interviewed below did not understand the concept that underpinned the practical lesson; in fact, they were left utterly confused by the experience to the point where they believe that the teacher did not explain it afterwards:

Researcher: Ok, ah so, what did you learn from it or what were you supposed to learn, do you remember?
Olive: Em, I'm assuming one of them was supposed to germinate, but like-
Emma: Like better than the others
Olive: Yeah, because it was stronger or something
Researcher: Do you know which one?
Both: No
Emma: ……… we kind of guessed it was supposed to grow and some weren't going to grow but he never said afterwards like
(Student interview 1)

Looks like learning but is not learning:

The second common theme relating to data analysis that came through clearly during classroom observations and tape recorded lessons was that students were told by teachers that they had learned a phenomenon, even though in this study 60% of the experiments did not result in the production of a phenomenon (Table 3.1). See for example the enzyme immobilisation experiment, already discussed. Another example relates to the production of alcohol by yeast experiment, where the students believed the experiment worked because their teacher told them that it did, even though they did not witness the phenomenon themselves by doing the experiment:

> Researcher: It’s totally fine. Yeah. Did that experiment work?
> Andy: It did
> Researcher: How do you know it worked?
> Liam: Mr D says (laughter)
> Karen: Good answer
> *(Student interview 3)*

The excerpt below outlines how practical work superficially revolved around ensuring that students know what the phenomenon should be, regardless of whether they had seen it or not. The lesson was not concerned with teaching for understanding, the focus was on reproducing the correct answer. There was a poignant question asked at the end of the exchange below, where a student was trying to form an understanding of ‘yellow crystals’ that he had not seen:

> T: And in the presence of ethanol or alcohol what should happen if we put that in a hot bath at 60 degrees?
> All S: Yellow crystals
> T: You should get yellow crystals. And what was the name of that test?
> All S: Iodoform test
> T: Iodoform test…….
> S: Sir are the crystals big?
> *Tape recording at 28.46 mins: production of alcohol experiment*

Mr. Donnell, below, was fully aware of this contradiction with practical work whereby students were told what to write because they need to be able to recall this information for exam purposes:

> Researcher: How do your students know then if one of their experiments has been a success?
> Teacher: I would get them to, I suppose, to compare it to what’s given as a result in the book or I’d give them verbal feedback on it, “Yeah, that’s what you’re supposed to get” or “No that actually is not what you’re supposed to get but here’s the answer you’re going to write down”.

Researcher: Ok so there's no focus on the process, it's just on the end result?
Teacher: Yeah
(Interview with Mr. Donnell)

What may appear as learning on the surface is not actually learning when it is examined at a deeper level.

Using questioning in the discussion:

The third theme to emerge in data analysis revolved around questioning. Often to consolidate a lesson the teacher asked a series of questions in a similar manner to that which occurred at the beginning of a lesson (Figure 3.4). 87% of questions asked after an experiment were at the level of recall. The main purpose of these questions was around 'confirming what we have seen' (Table 3.7).

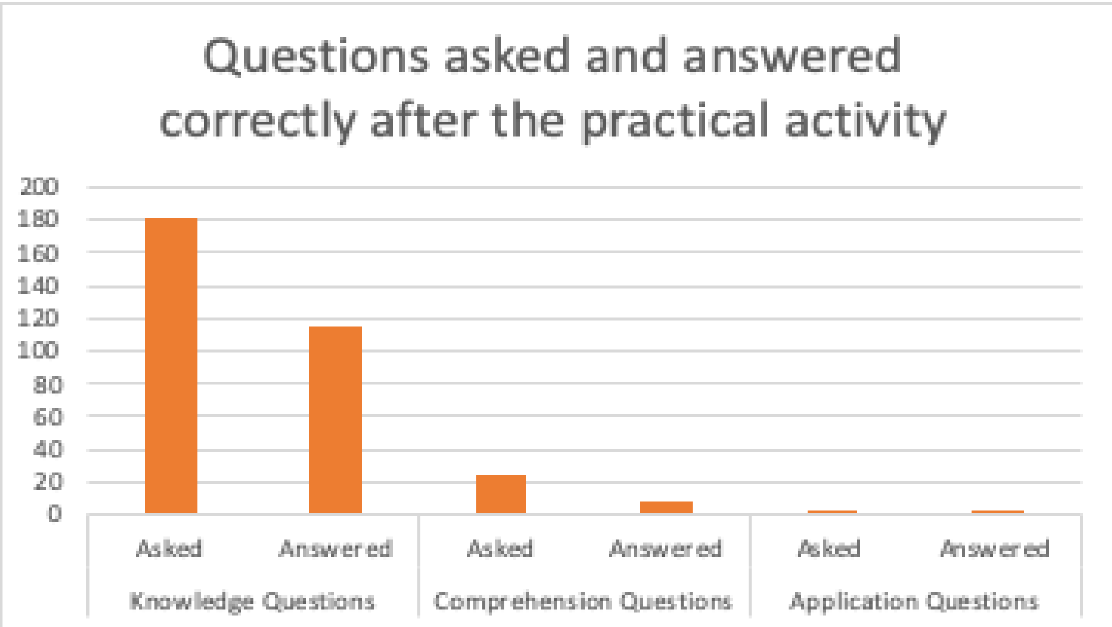

Figure 3.4: Bloom's taxonomy classification depicting the type of questions asked and answered correctly after the practical activity

It is worth noticing that while students could answer roughly the same number of knowledge questions before an experiment (62.3%) as after (63.5%), the proportion of comprehension questions answered correctly before (64%) and after (36%) showed a significant decrease in student understanding following the practical activity.

3.4.4 Summary

Dewey has long recognised the dualism between body and mind and the view of knowledge that accompanies it. When practical activities are presented as complete (as they are with the recipe method), the knowledge is already *had* and there is no need to *know* it. When there is no knowledge to search for, there is nothing further to think about, excluding the mind from learning. Experiments taught as isolated topics, with no connection to past experience and no vision towards future ideas, "makes a division where none exists and resorts to artifice to restore the connection that has been wilfully destroyed"(Dewey, 1925/1958, p.283). The result is that the student merely "observes ready-made models and patterns, and unquestioningly follows procedures antecedently established" (ibid., p.213). The result of this kind of teaching on student learning is outlined in this section. Students may know what they are doing but they do not know why they are doing it, or how what they witness is related to its scientific underpinnings.

3.5 Planning for Design

This small-scale study, in line with international literature, has found that the focus of practical work for teachers and students in biology practical classes was on materials, equipment and producing the phenomenon (Abrahams, 2005; Hodson, 1996, 2001; Hofstein and Lunetta, 2004; Lunetta et al., 2007). Keeping in mind that the syllabus objective is for students to conduct practical work through enquiry using the scientific method and to learn scientific skills, the challenge is to encourage teachers to use enquiry in their classrooms to carry out practical work to a standard that does not disadvantage students who are sitting state exams, or to take up an excessive amount of time compared to recipe learning. Enquiry skills such as defining a research problem, formulating a hypotheses, planning an experiment, collecting data, answering and modifying the original question and communicating the results were not observed in this study but need to be addressed when teaching practical work (Coil et al, 2010; Farenga et al, 2002; Grunwald and Hartman, 2010; Lunetta and Tamir, 1981; National Research Council, 2000; National Research Council, 2012; Wilke and Straits, 2005).

These skills cannot be developed as a by-product of engaging in practical work. Hodson (2014) explains the importance of explicitly teaching enquiry skills in order to develop scientific understanding. To teach using scientific enquiry means that teachers must also recognise that explanatory ideas do not simply emerge from observation or data no matter how carefully the students follow the recipe (Millar, 2004).

There is also a need to examine how data is generated, analysed and interpreted in Irish classrooms. As far back as 1987, Pickering wrote, "Never are the students forced to reconcile results or confronted with challenge to what is naively predictable" (p.522). The challenge for teachers will be to see merit in using data to answer questions to problems that the students pose and to analyse it in such a way that it leads to further experimentation.

The lessons were not effective in the 'minds-on' domain, since students could not think about the task using ideas and vocabulary to link their observations with the correct scientific theory (Abrahams and Millar, 2008). Students enjoyed practical classes, but they did not learn to think critically from them in the manner intended by the syllabus:

> Researcher: You know like, are you learning by doing experiments? What do you think?
> Emma: I wouldn't say so, no
> Olive: No
> Researcher: Ok. So, remind me again why you like experiments so much?
> Olive: Because it's not sitting, theory, it's not sitting down like.
> *(Student interview group 4)*

The student in the classroom situation described here became what Dewey (1916/2011) calls a "spectator", one who absorbs other people's knowledge directly. This concept of the student separates thinking from activity, and allows words to be mistaken for ideas. This occurred on six out of ten occasions where the teacher told the students the outcomes of experiments they never witnessed. There is no learning for students when a genuine learning experience is substituted with a 'half-perception' of an experience:

> "The substitution is the more subtle because some meaning is recognised. But we are very easily trained to be content with a minimum of meaning, and to fail to note how restricted is our perception of the relations which confer significance. We get so thoroughly used to a kind of pseudo-idea, a half perception, that we are not aware how half-dead our mental action is, and how much keener and more extensive our observations and ideas would be if we formed them under conditions of a vital experience which required us to use judgement: to hunt for the connections of the thing dealt with"
> (Dewey, 1916/2011 p.80)

This study highlights some design principles that need to be incorporated into practical lessons:

1. Plan meaningful questions

The cognitive challenge of making the link between the domain of observables (hands-on) and the domain of ideas (minds-on) is underestimated by teachers (Abrahams and Millar, 2008). It is important that teachers plan what they want students to 'do' with ideas and how to get students to use scientific ideas to make sense of their own observations and data (ibid.). Donnelly (1996) recommends that teachers focus on specific points about scientific enquiry and not simply on the substantive science content. Perhaps a worthwhile starting point to involve students in their own learning would be to ask questions that stimulate higher order thinking (Driver, 1995). Blooms Taxonomy can act as a guide to assist teachers to ask thought provoking questions, or to encourage students to develop their own questions and convert these into hypotheses (Bloom, 1956).

2. Carry out more than one iteration of each practical activity

Research has shown that when students are using materials and equipment for the first time, their attention is on the new materials and not on the conceptual ideas behind the experiments (Olsen and Clough, 2001; Olsen, 2004). All of the students interviewed in this study could recall making the 'little balls' or 'beads' (immobilised enzymes fixed in a gel bead) but could not remember the purpose of the immobilised enzyme activity. Factoring in an initial activity to familiarise students with materials and equipment first, before allowing them to focus on underpinning scientific concepts in a later iteration, would reduce the cognitive load on students and encourage fluency in terms of laboratory skills (Sweller, 2011).

3. Scaffold practical lessons for 'minds-on' thinking

Bachtold (2013) argues that scientific concepts have to be explicitly introduced by the teacher so that they can be integrated by the students into their former conceptual system.

The teacher 'sees' a phenomenon from the point of view of one who already knows the route and can follow it in a linear fashion, whereas the student 'sees' it through the eyes of a novice, who finds himself in unfamiliar territory. However, when teachers assist students to connect one educative experience with prior familiar experiences, they develop students' cognitive tools to understand a new unfamiliar experience, leading to what Dewey terms an "experiential continuum" (1938/2015). Similarly, Vygotsky theorised that: "if one changes the tools of thinking available to a child, his mind will have a radically different structure" (1978, p.126).

Both Vygotsky and Dewey refer to the spiral nature of learning, which is complemented by using scientific enquiry as a pedagogical tool. What makes enquiry so attractive is that it focuses learning on scientific skills, on the nature of science and on building scientific knowledge; none of which are currently used as a part of practical work in biology. Wood, Bruner and Ross (1976) used Vygotsky's work to develop the idea of scaffolding as a tool to promote learning at higher cognitive levels. For example, familiarising students with an experimental technique first followed by the provision of a situation in which the students must use that technique to solve a problem. Bruner's (1975) original statement about scaffolding referred to how a mother assists her young child to master new tasks, but it is equally relevant to the work that teachers must do in practical lessons to "support the child in achieving an intended outcome entering only to assist or reciprocate or 'scaffold' the action" (1975, p.12). This applies to the (currently) absent components of practical activities such as hypothesis formation and data collection, recording, analysis and presentation. The student should become consciously involved in their own work, maintaining control of the language and experience, supported by the teacher who acts in response to the student by "holding the lesson steady" while the student tries to extract something from it (Searle, 1984).

4. Use productive classroom discussion

Wass et al. (2011) found that relationships are crucial to the process of using scaffolding to improve critical thinking skills. Students rely on each other for emotional support and rely on their teachers for guidance. Vygotsky also believed that learning occurs in the interaction between the individual and the social environment (Vygotsky, 1978). He reasoned that that intelligent action, as seen through the use of tools, is dependent on speech. To integrate the mind into practical work, speech combined with action can introduce new forms of behaviour so that students can make sense of what they are doing and why they are doing it. Vygotsky (1978, p.25) found that “speech not only accompanies practical activity but also plays a specific role in carrying it out”. One of the most enjoyable aspects of practical classes for students is the opportunity to talk to their peers, so it makes sense to harness this willingness to talk into something productive.

Research has shown that when teachers devote lesson time to introducing students to appropriate terminology and to their understanding of the terminology, students can then talk and think appropriately about the task (Abrahams and Millar, 2008). In addition, using discussion to encourage student involvement in making decisions around experimental design that incorporate enquiry-based learning, has the dual advantage of improving the conceptual skills and the social skills of students (Erduran and Dagher 2014; Osborne 2011, 2015; Stroupe, 2015).

The next chapter sees the beginning of the design phase of this DBR project, where a prototype for a Framework for Teaching Practical Activities was designed and shared with two cohorts of teachers, in-service teachers and pre-service teachers. The chapter reports on the learning that occurred when both cohorts were asked to trial the Framework in their own learning environments.

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Chapter 4

Second Design Cycle: Design and Development of the Prototype Framework for Teaching Practical Activities

4.1 Introduction

This chapter marks the beginning of the design and development cycle, where the design of prototype Framework for Teaching Practical Activities (FTPA), was documented and evaluated for relevance, consistency and expected practicality in the biology classroom (Nieveen et al, 2012). Figure 4.1 summarises the events that took place during this second research cycle. Having identified the research question, design guidelines from the previous scoping cycle were adapted into design principles, and the development of a humble theory from the work of Millar and Abrahams (2008, 2009) was integrated with these principles to produce the prototype FTPA. The expected outcomes of the FTPA were identified before subjecting it to formative evaluation with two distinct groups of users (in-service teachers and pre-service teachers). A final appraisal identified actual outcomes for this design cycle which determined the design principles of the next research cycle:

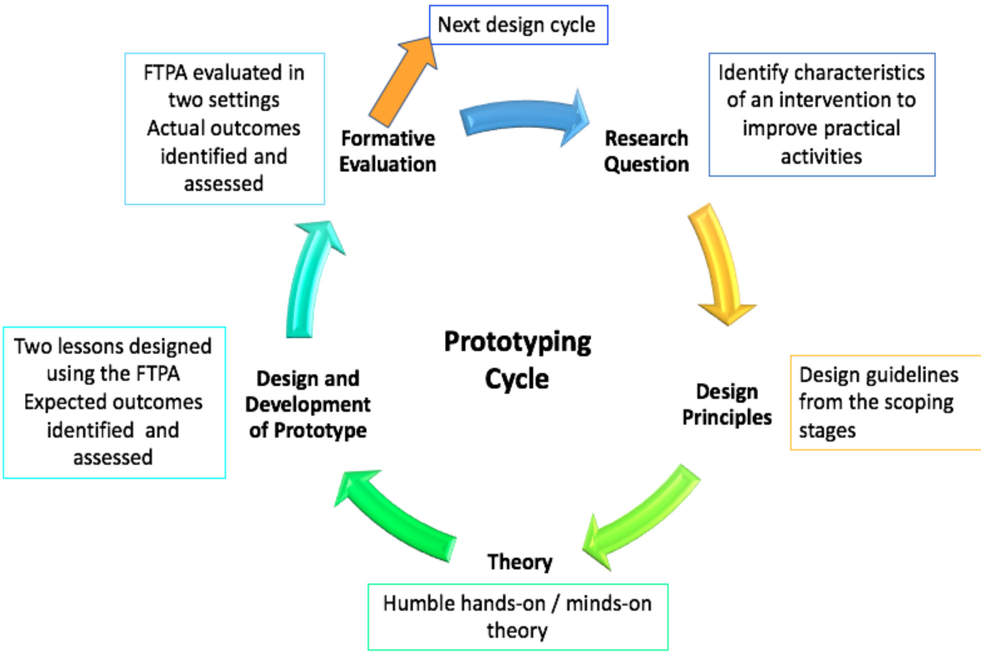

Figure 4.1: Structure of the prototyping research cycle

The research question for this phase is:

What are the characteristics of a framework for teaching practical activities that will enable teachers to transition from recipe-style experiments towards a more hands-on/minds-on approach to teaching practical activities in upper secondary biology classrooms?

4.2 Design Guidelines

The first prototype was informed by guidelines from the scoping cycle, which were delineated in the preceding chapter. Table 4.1 outlines how these guidelines were converted into design principles for a new educational innovation that teachers could use to plan and conduct practical activities. The following two sections (4.3 and 4.4) document how they were embedded as design principles within the design of the FTPA.

Table 4.1: Design principles adapted from recommendations of the scoping stage observations.

Design Guidelines for Improvement of Practical Lessons
Lessons should be pedagogically scaffolded in advance for *thinking* rather than *doing* in order to make them more effective in the minds-on domain. Minds-on activities should be specified on the FTPA
Teaching needs to facilitate minds-on work in tandem with hands-on work
Enquiry needs to be evident in practical lessons
The scientific method needs to be evident in practical lessons
Questioning is core to enquiry and needs to be planned by teachers
Teachers need professional development to teach through enquiry – develop exemplar lessons
Teachers need to develop their content knowledge beyond the prescribed experiment
Data analysis, interpretation and presentation should be completed by students, not teachers
Students should have an opportunity to familiarise themselves with the equipment, materials and laboratory technique first to reduce the cognitive load
Teachers should explicitly teach a lab skill each time they organise an experiment
Students should be afforded opportunities to engage in discussion before, during and after the practical activity

4.3 The Humble Theory

A humble theory is one that occupies the middle ground between practice and theory by targeting domain specific learning processes (Svihla, 2014). It addresses *how* rather than *why* questions (Noyes, 2008). With DBR, the use of humble theory is a common tool for the development of educational interventions, because of the need for theories that are context specific that have practical implications for *how* to implement new learning designs (Anderson and Shattuck, 2012; Bakker and Smit, 2017; Gravemeijer and Prediger, 2019). Millar and Abrahams present a humble theory that examines the effectiveness of practical activities in two distinct domains - the 'hands-on' domain of objects and observables and the 'minds-on' domain of ideas (Millar and Abrahams, 2009). It underpins the first prototype of the FTPA. The hands-on domain, is concerned with what the teacher intends for the students to do with materials and equipment while the minds-on domain constitutes what the teacher intends for the students to understand by doing the practical work.

Figure 2, shows Millar and Abrahams' (2009) process for developing and evaluating a practical lesson. The links between the two domains can be seen where A and D relate to minds-on activities and B and C relate to hands-on activities. Millar and Abrahams (2009) observed that the majority of the time in a lesson was apportioned to hands-on work. The scoping work carried out for this research (Chapter 3) also confirmed that no time is allocated to minds-on practical activities in the Irish biology classrooms. Using Abraham's and Millar's theory to assist with the design of lessons requires that the minds-on aspect of preparing for practical activities can be identified, considered and implemented in the classroom. It begins at A where the teacher must think about the concept that she intends for the students to learn in the minds-on domain (effectiveness at level 2) which must then be complemented by pedagogical hands-on practices that foster understanding of the scientific concept underpinning the experiment, seen in B (effectiveness at level 1). C and D, appraise what the students actually do and what they actually learn respectively, and are used to evaluate the lesson through interviews, observation and artefact collection.

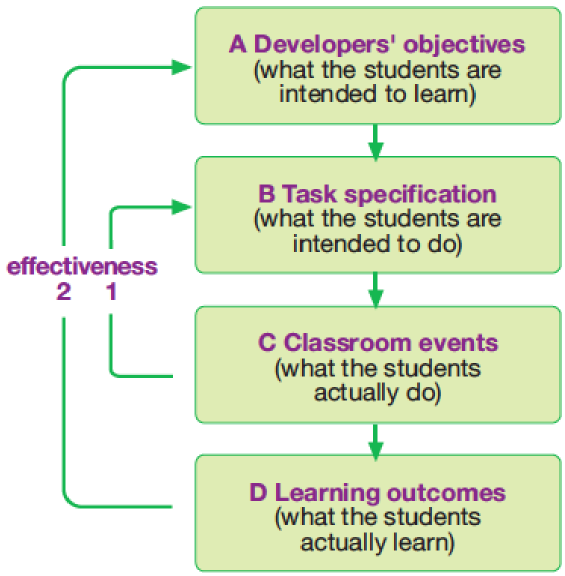

Figure 4.2: Stages in the development and evaluation of a teaching and learning activity – and their relationship to two senses of 'effectiveness' (from Millar and Abrahams, 2009)

The first prototype FTPA presented here was designed so that teachers specifically think about where practical activities can incorporate minds-on work (and hands-on work) to make practical activities more meaningful for students. This change in approach, amalgamated with the design guidelines from Table 1, formed the basis of the prototype FTPA.

4.4 Design and Development of the Prototype FTPA

The first prototype is always a 'global design' that will be refined through subsequent research cycles (Nieveen and Folmer, 2012). Table 4.2 divides the lesson into sections; each section related to the design guidelines. The hands-on (where students are *doing* something) and minds-on (where students are *thinking about* something) aspects of the lesson are clearly identified in the left-hand margin. The teacher allocates these two terms (as they deem appropriate) to aspects of the lesson that the student will conduct; the context, the procedural teaching methodology, the data collection, data presentation, data analysis and real world application sections. To reduce the cognitive load for students, a double experiment approach has been adopted where students learn an experimental technique, a laboratory skill and produce a phenomenon during the first experiment (Sweller et al., 2011). In the second experiment the focus shifts towards the scientific method of enquiry, with a clear focus on data handling and the inclusion of a real world application, which requires *students* to ask a question, develop a hypotheses, carry out their own investigation (using the experimental technique they learned in the first experiment), collect data, interpret data and present data.

Table 4.2: Design of the first Prototype FTPA

Context:	
Procedural (hands-on)	What students are expected to 'do' during the practical activity
Informational (minds-on)	What students are expected to 'learn' by doing the practical activity

Preparation for Experiment	Teachers must think about the materials and equipment they need to prepare *and* the ideas they are preparing students to understand (Abrahams and Millar, 2008)
Laboratory skill attainment	Identify the skill that the student will learn Include any laboratory skills the teacher should know
Risk assessment	A mandatory part of any laboratory endeavour (Department of Education and Science, 1996a; 1996b)
List of equipment needed	List the material and objects required for the initial experiment and the extension experiment.
Procedural teaching methodology: Hands-on Minds- on **Minds-on**	Distinguish between hands-on work and minds-on work in a double experiment First experiment - specify the laboratory technique or skill that students will use to observe the phenomenon Include worksheets or other pedagogical devices that require students to work collaboratively, and make decisions about the experiment as they encounter each step in the procedure. Second experiment - students pose a question and propose a hypotheses. They then apply the experimental technique learned to design a second experiment to answer their hypothesis
Data collection: Minds-on	First experiment - Qualitative data collection identifies the phenomenon Second experiment - Quantitative Data Collection takes place in the second investigation, where the student confirms or refutes their hypothesis using evidence from data collected
Data analysis: Minds-on	This requires students to examine and interpret their data, and to form a conclusion. Suggested methods: graph, bar chart, photo-story etc
Data presentation: Minds-on	Students create a poster or a report using the following headings: Title, Question, Hypothesis, Procedure, Data Collected, Data presentation, Analysis of data, Conclusion
Real World Application: **Minds-on**	Second experiment only - students apply the technique/skill learned in the first experiment to the second experiment by asking a question, developing a hypothesis and conducting an investigation to confirm or refute the hypothesis. It is important to anticipate what hypothesis students will formulate– in order to prepare materials that will assist students to devise investigable questions. Not all students will ask the same question – prepare for a variety of questions or re-route student thinking towards a more realistic investigation
Evaluation	Teacher evaluates the lesson by answering these questions: What worked? What needs improvement? What will I do differently next time? Student presentation is evaluated by the teacher.
LC exam questions relating to Leaf Yeast	List relevant exam questions as a form of summative assessment.

4.5 Design of exemplar lessons using first prototype FTPA

The design team for this prototyping stage was comprised of the Teacher Practitioner (TP), a science teacher and educational researcher, and the Research Practitioner (RP), a professional scientist and university educator. The TP developed the FTPA for Leaf Yeast and then worked with the RP to design the DNA FTPA.

4.5.1 Leaf Yeast FTPA

A mandatory practical activity from the LC biology syllabus to 'Investigate the Growth of Leaf Yeast Using Agar Plates and Controls', was adapted to the FTPA. The title of this practical activity leaves the investigation open to many different interpretations, however, a ubiquitous recipe-style method for using laboratory aseptic technique to produce pink colonies of leaf yeast on malt agar plates is presented in most biology textbooks (O'Callaghan, 2013; Scott-Sweeney and Maume, 2015) and in the syllabus laboratory handbook (Government of Ireland, 2003). Once pink colonies are observed, the experiment is deemed complete.

With the FTPA, the following changes were introduced by the Teacher Practitioner (TP):

- The first experiment focuses on teaching competency in using laboratory aseptic technique, to reduce the cognitive load in the second experiment
- An 'aseptic technique worksheet' is given to students during the first experiment. It puts choices and questions to the students as they work their way through this technique during the first part of the practical activity (Appendix 4.1a)
- Before the second experiment, students are presented with a reading comprehension (Appendix 4.1b) that contains additional information about leaf yeast (e.g. it can be used to indicate the quality of air, older leaves have more leaf yeast than younger leaves). Students are presented with a selection leaves from the same plant species collected at different times of the year, and from different areas (rural, urban). Students also have the choice of using leaves from different species of trees (oak, beech, holly, sycamore).
- The students are asked to devise a question they could investigate using what they have learned from the first experiment (aseptic technique – hands-on) and

gleaned from the reading material (minds-on), to carry out their own experiment (hands-on).

Anticipated student questions: Do other types of leaves have leaf yeast on them? Do leaves grown in an urban area have less leaf yeast that leaves grown in a rural area? Is there more leaf yeast on leaves collected in August than those collected in June?

- Having come up with a question, the students need to propose a hypothesis they can test by carrying out their own experiment – they then collect / analyse / present data to confirm or refute their hypothesis.

The completed FTPA for this experiment is presented in Table 4.3 (resources in Appendix 4.1)

Table 4.3: Initial prototype of the Leaf Yeast FTPA

Title of Experiment: Investigate the growth of leaf yeast using agar plates and controls.	
Context **Procedural (hands-on)** **Informational (minds-on)**	Investigation of the growth of leaf yeast using agar plates • Making malt agar plates (optional for students) • Using agar to grow leaf yeast Students need an understanding of • leaf yeast and the conditions under which it grows • leaf yeast as an indicator species • leaf yeast basidiospores Students are asked to propose a question, develop a hypotheses and conduct an experiment to test their hypothesis
Preparation for Experiment	Reading comprehension for students (inc. tips for teachers) – *Appendix 4.1b* Making malt agar plates- *Appendix 4.1c* Setting up equipment
Laboratory skill attainment	Teacher :Making up malt agar plates – *Appendix 4.1c* Student : Aseptic technique- *Appendix 4.1f*
Risk assessment	Risk assessment carried out by teacher beforehand and sheet filled in and signed – *Appendix 4.1e*
List of equipment needed	Ash Leaves – from a variety of areas (wood, country, town) and a variety of months (June, July, August, September) Other leaves – sycamore, alder, oak, holly etc Sterile malt agar plates; Vaseline Disinfectant / Alcohol; Cork borer / scalpel Chopping board.; Bunsen burner Lighter.; Forceps Parafilm / tape.; Marker Paper towels __To make agar__ Malt agar powder Bunsen burner Sterile agar plates Large beaker Stirrer Deionised water
Teaching methodology: Hands-on Minds- on	Show students how to make up agar plates (optional) Teach aseptic technique using the method to investigate the growth of leaf yeast and Visual Sheet on desk (*Appendix 4.1d).* Use the worksheet in conjunction with the procedure as an assessment for learning tool – *Appendix 4.1a*

Minds-on **Minds-on** **Minds-on** **Hands-on**	Hand out reading comprehension – *Appendix 4.1b* Ask students to come up with a question that they would like to investigate based on the reading. Convert the question into a hypotheses Repeat the experiment so that the student can conduct their own investigation into leaf yeast growth.
Data collection	Students will investigate their agar plates after a week to look for and count pink colonies of yeast
Data presentation and analysis: Minds-on	Depending on the questions asked by students First experiment: Students will examine plates and record the presence or absence of leaf yeast Second experiment: Students will count colonies and record the results in a graph/ bar chart and report on whether the result is in agreement with their original hypothesis.
Data presentation: Minds-on	Students create a poster or a report under the following headings: Title, Hypothesis, Procedure, Data Collected, Data presentation, Analysis of data, Conclusion
Real World Application: Minds-on	After doing the experiment and reading the extra material, students should understand the value of leaf yeasts as indicator species and that scientists use leaf yeasts and other indicator species to determine the health of the environment.
Evaluation	Teacher evaluates the lesson under the following headings: *What worked* – what aspects of the lesson did students understand *What needs improvement* - where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge *What will I do differently next time* Teacher evaluates the learning by facilitating a class discussion on their findings
LC exam questions relating to Leaf Yeast	2018 Q9 2015 Q8 b 2012 Q8 2007 Q8 2005 Q9

4.5.2 DNA FTPA

Appendix 4.2a contains the FTPA for the DNA experiment entitled Isolation of DNA from a Plant Tissue. It is essentially an outlier in the 22 mandatory LC experiments because it does not easily lend itself easily to a double-experiment, enquiry-based activity. There are three reasons for this:

1. The scientific principles underpinning the lesson are more complex than those of the Leaf Yeast FTPA, meaning it is more difficult to scaffold a real world application without confusing the students.
2. The purpose of this activity is simply to isolate DNA from a plant tissue. In terms of data analysis and interpretation, it is confirmatory only.
3. It was difficult for the design team to connect the lack of minds-on data analysis and interpretation with a real world application, while simultaneously considering

the equipment that teachers have at their disposal in secondary school laboratories. A logical real world application to extend this experiment would be to use gel electrophoresis to run out the DNA samples, however teachers do not have access to this equipment in their school laboratories, despite a syllabus requirement to understand the steps in the procedure of gel electrophoresis.

In the biology classroom, students generally follow a stepwise recipe culminating in the observation of white thread like strands of DNA in a test tube. The challenge for the design team was to adapt the FTPA to include a minds-on experience for students, taking into consideration the three parameters outlined above.

The following changes were made using the FTPA:

- Students are presented with background information about DNA and a rationale that relates how the structure of the cell must be broken down systematically before DNA can be released into solution (Appendix 4.2b).
- A PowerPoint presentation is used to show students a series of pictures; living human, glass, plastic chair, apple, dead human. Students are asked to identify the pictures that DNA could be isolated from, following which they must deduce why DNA can be isolated from both dead and alive organisms (because DNA is a stable biomolecule). The hypothesis for the practical activity is that DNA can be isolated from anything containing cells. (Appendix 4.2b)
- The laboratory skill that students learn is both hands-on and minds-on; how to make up a %w/v solution of salt/detergent, which is accompanied by a worksheet to assist students with their calculations (Appendix 4.2c).
- The procedure then follows; a laminated protocol is placed on each bench along with a fill-in-the-blanks worksheet (Appendices 4.2d& 4.2e). Students fill in the worksheet as they follow the laminated procedure, relating each step in the procedure (hands-on) to the structure of the cell (minds-on).
- The design team rationalised that the real world application in this case did not necessarily have to take the form of a second experiment, it could be linked to another aspect of the biology course; gel electrophoresis. After students have collected qualitative data that confirms the presence or absence of DNA, they are then asked;

Once DNA has been isolated from kiwi, what might the next step be in confirming that it is actual kiwi DNA? (Answer: gel electrophoresis).

- Students are presented with a real world application relating to a case of food fraud where, in 2013 in Ireland, burgers marketed as 100% beef were found, by DNA analysis, to also contain undeclared horsemeat, which led to a national scandal (Appendix 4.2b). Students then use the concept underpinning the entire practical activity to develop hypotheses about the potential use of the technique in other real world situations. The experiment concludes with students sharing their hypotheses with the class.

4.5.3 Expected Outcomes of the FTPA

The creation of a screening checklist to evaluate a global design in its early stages for relevance, consistency and expected practicality was employed here with both exemplar FTPAs (Nieveen and Folmer, 2012). Table 4.4 shows how the design guidelines (left column) form the basis of this list.

Table 4.4: Screening checklist for the exemplar FTPA lessons, adapted from the design guidelines

Checklist item	Evidence in the Leaf Yeast FTPA	Evidence in the DNA FTPA
Pedagogical scaffolding for thinking	• Worksheet provides students with opportunities to make and justify decisions • Real World Application – students think about a question they could investigate using the concept that leaf yeast grows on agar	• Initial hypothesis scaffolded for thinking using pictures • Experimental technique connected to structure of DNA prior to practical activity • Laboratory skill accompanied by worksheet • Development of second hypothesis after the experiment
Minds-on work specified in framework	Yes - the context, the procedural teaching methodology, data presentation and analysis and the real world application sections of the FTPA specify this	Yes - the context, the procedural teaching methodology, data analysis and presentation specify this.
Lessons are enquiry based	Yes, using the scientific method, students ask a question, develop a hypothesis and investigate it using an experiment of their own design	• Students ask a question and develop a hypothesis but the procedure is a standard procedure, with a recipe to follow. • Following the experiment, a potential hypothesis is developed but students do not investigate it.
Scientific method of	All aspects of the scientific method are included in the lesson	All aspects of the scientific method are included in the lesson

enquiry evident		
Meaningful questions asked	• Students ask a question and investigate it • Worksheet presents questions where students must make choices and justify their choices.	• Hypothesis at the beginning • Laboratory skill calculations • Final question and hypothesis
Data collection, analysis, interpretation and presentation conducted by students	• Students count the colonies of leaf yeast that have grown. • Students then decide how to interpret the results they obtain, compare with other groups in the class and present their results and conclusions in a visual format. • They revisit their hypothesis and accept or refute it	• Students collect samples of kiwi DNA in test tubes • Analysis and interpretation confined to presence or absence of DNA
Real World Application as an extension experiment	Students use aseptic technique to conduct their own investigation based on a question they develop from the reading comprehension	Students hypothesised about a possible real world application but did not do an extension experiment
Lab skill included	• Aseptic technique • Preparation of malt agar plates	Learning how to prepare a %w/v solution
Discussion before, during and after the lesson	• During the first experiment – students collaborate to do the worksheet • Before the second experiment – students conceive a new experiment • After the experiment – students decide how to interpret and present results	• Before the experiment- students develop a hypotheses • During the experiment – students collaborate to do the worksheet • After the experiment – students conceive of another hypothesis
Content beyond the 'recipe' included	• Students shown how to make agar plates • Students given background information on leaf yeast and use it to conduct an investigation.	• Teacher shows understanding of the structure of DNA beyond the recipe style experiment • Students shown how to make up chemical solutions • Students learn how the structure of DNA and the cell is related to the extraction and isolation of DNA from kiwi • The use of gel electrophoresis to identify sources of DNA

To assess the quality of the framework during the screening stage it must adhere to three conditions (Nieveen and Folmer, 2012);

1. Relevancy - there is undoubtedly a need for the product, whose design is grounded in academic literature and field observations (Chapter 3)

2. Consistency – both FTPAs are logically designed to follow the scientific method of enquiry, incorporating the hands-on/minds-on theory into the lesson design.

3. Expected practicality - the product is expected to be useful in the setting for which it is designed, as it aligns better with the syllabus intentions for enquiry than the current recipe-style pedagogy. It pioneers a move towards embedding the scientific method of enquiry into senior cycle biology lessons by specifically identifying hands-on and minds-on activities.

Outward appearances indicate that the framework is a much needed improvement for senior cycle biology. The Leaf Yeast FTPA is undoubtedly an enquiry-based lesson. The areas (retrospectively) highlighted in red in Table 2, identify where the theory does not translate so well into practice. The two main problems with the DNA framework are only identified after the lesson is taught;

1. The worksheet, intended to solidify the hand-mind connection, had the opposite effect, distracting students from their task.
2. The development of the second hypothesis did not enable students to build on what they had learned in the first experiment since there was no clear link between the experiment and the new hypothesis.

As a result, it could be argued that it the lesson was hands-on and minds-on, but not enquiry based. The consequences of this are discussed further in the evaluation stage, where the prototype is trialled and evaluated in two settings, both of which are discussed here:

- The pre-service teacher (PST) practical biology teaching module (PBTM) in the university setting
- A fifth year classroom in the secondary school setting

4.6 Evaluation of the FTPA within a PST module

Within this module the two exemplar lessons were taught to 3rd year PSTs who in turn designed and taught a different lesson using the FTPA. The evaluation of these events is documented here.

4.6.1 Evaluation of Exemplar lessons at third level

The two exemplar practical activities were taught to PSTs by the TP (Leaf Yeast) and the RP (DNA Isolation). Afterwards PSTs (n=28) were asked to complete an anonymous questionnaire to determine whether the exemplar lessons aligned with certain aspects of enquiry. 24 out of 28 questionnaires were returned (Appendix 4.3). Questions were coded into categories, using MAXQDA software.

The answer to the first question, 'what is your understanding of enquiry based practical work?' conveyed the belief that enquiry teaching must incorporate *thinking* as well as *doing*, and can involve students asking and investigating their own questions.

> *Is as much minds-on as hands-on. Gets students thinking about what they are doing and why they are doing it.*
>
> Questionnaire, Q1, PST 19

> *Practical work based on students asking questions and their understanding of the answer*
>
> Questionnaire, Q1, PST 2

Students were shown a list of elements of the scientific method of enquiry and asked to check off those that were included in their secondary school experience of practical work compared to the two exemplar lessons they experienced in the PST PBTM module. The results are presented in Figure 4.3

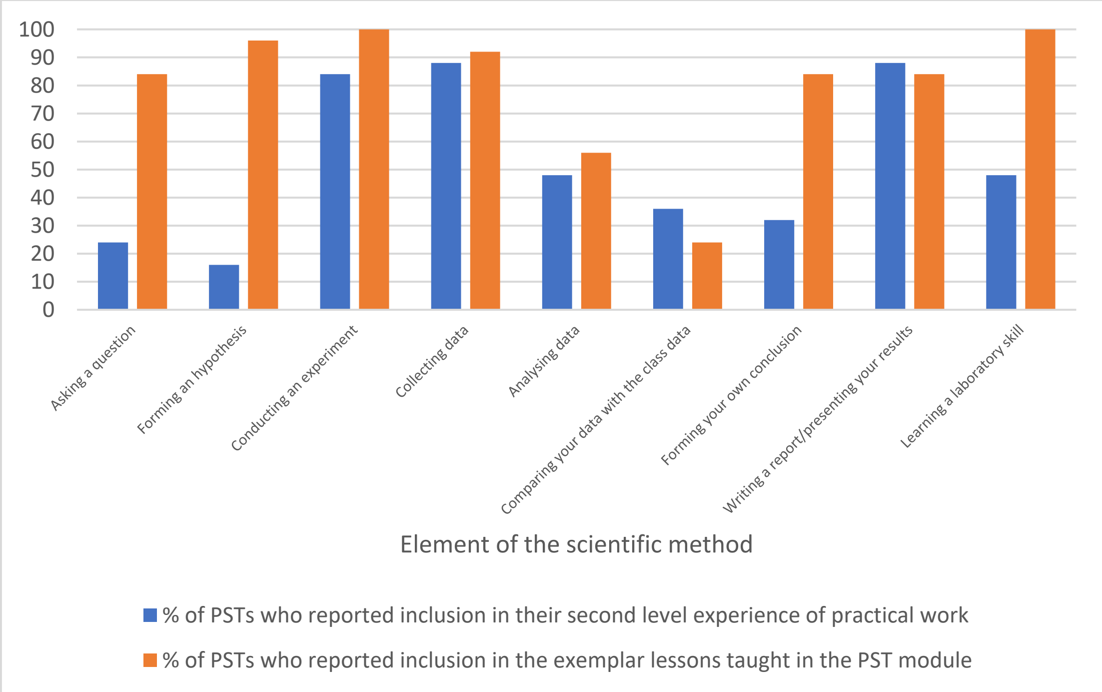

Figure 4.3: Comparison of PSTs second level and exemplar lesson experience of using the scientific method to teach practical work.

At second level, three elements of the scientific method were consistently a feature of practical activities; conducting an experiment, collecting data and writing a report. In comparison, the PST lessons were successful in incorporating further minds-on activities: asking a question, forming a hypothesis, forming your own conclusion. Learning a laboratory skill, which occupies the hands-on domain, was noticed by all of the PSTs who answered the questionnaire. Overall, the majority of students were able to recognise that the exemplar lessons contained most of the aspects of scientific enquiry, with two notable exceptions; only 56% (just over half of respondents) recognised that data analysis had taken place in the two exemplar lessons and 24% recognised that they had compared data with a class set. This may be explained by noting that data collection and analysis for both practical activities was mainly confirmatory. In retrospect, selecting one exemplar lesson with a more significant amount of data analysis would have been more appropriate, since this is an essential minds-on part of any investigation. The impact of this became clear when PSTs were tasked with designing and teaching their own experiment, which is discussed later in this chapter. That said, PSTs indicated that there was an overall improvement in the use of the scientific method to teach the exemplar lessons.

When asked to compare the exemplar lessons with their experience of LC biology, PSTs saw clear differences:

> *I understood why I was conducting the experiment on Friday. In school I conducted an experiment because I was told to and gained no knowledge from it*
> Questionnaire Q5, PST 9
>
> *In LC biology we were given a method and followed it but didn't think of any real world applications or have any enquiry ourselves. However on Friday we had both*
> Questionnaire, Q5, PST 3

Overall PSTs reported that the exemplar lessons gave them an understanding of *what* enquiry means. In order to see if this understanding translated into *how* to embed enquiry into practice, PSTs were then tasked with using the FTPA to design and teach a practical activity. The results of this are outlined in the next section.

4.6.2 Evaluation of PST-Taught Lessons

PSTs in groups of 4-5 adapted the framework to design and teach a 90-minute practical lesson from the LC syllabus. Prior to teaching their practical activity each group was allocated a 3-hour time slot in the laboratory with the design team, to practice setting up and teaching their chosen practical activity, and also to troubleshoot any practical problems that may arise. Subsequently, over three consecutive Fridays each group was allocated 1.5 hours to teach their prepared practical activity. The data collected were analysed by examining the PST use of the FTPA, followed by an evaluation of how the FTPA translated into practice.

4.6.2.1 Evaluation of PST use of the FTPA

Data was collected from five PST-designed FTPAs, with accompanying resources (see Appendix 4.4 a-e). Each FTPA was screened against the design principles, the results of which are shown in Table 4.5 below:

Table 4.5: Comparison of PST FTPAs with design principles

Checklist item	Evidence in the FTPA				
	Production of Alcohol by Yeast	Effect of IAA on Plant Tissue	Effect of Temperature on Rate of Enzyme Activity	Effect of pH on Rate of Enzyme Activity	Effect of Light Intensity on the Rate of Photosynthesis
Pedagogical scaffolding for thinking	No	Yes	No	No	No
Lab skill included	Yes	Yes	Yes	Yes	Yes
Student-student discussion before, during and after the lesson	Yes	Yes	Yes	Yes	Yes
Data collection, analysis, interpretation and presentation conducted by students	Yes	Yes	Yes	Yes	Yes- data collection and presentation No – data analysis and interpretation
Real World Application as an extension experiment	No	No	No	No	No
Minds-on work specified in framework	Yes	Yes – but not clearly distinguished	Yes – but not specific enough	Yes	Yes – but not clearly distinguished
Lessons are enquiry based	No	No	No	No	No
Scientific method included	Partly – no question, no hypothesis	Yes	Yes	Yes	Yes
Meaningful questions asked	No	No	No	Yes	No
Teachers allow students to do minds-on work	No	Yes	Yes	Yes	Partly
Content knowledge beyond the recipe shared with students	Yes	Yes	Yes	Yes	Yes

Each FTPA highlighted the importance of teaching laboratory skills to students, encouraging student discussion and developing PST subject content knowledge. Hands-on, minds-on work was also included, but the distinction between the hands-on and minds-on activities was unclear in three of the FTPAs. Data collection, analysis and presentation were documented as the students' domain, meaning a large portion of the minds-on work comes under the students' remit. While the scientific method of enquiry was engaged by PSTs in their lesson *design* for the first experiment, it did not lead to minds-on thinking during their *enacted* lesson since none of their FTPAs included the use of a question and hypothesis that led to a second experiment.

Some of the themes running through PST FTPAs are highlighted below

a. The absence of teaching for understanding

PSTs noted *what* they wanted to be understood by students but did not explain *how* they were scaffolding student understanding into their lessons, nor did they use pedagogies that enhanced understanding.

b. The confusion between hands-on and minds-on work in the framework

Half of the groups struggled to clearly identify minds-on activities and to distinguish them from hands-on activities.

c. The real world extension was misconstrued by all students in their FTPAs as a didactic exercise, rather than an enquiry activity.

Incorporating enquiry into the FTPA was contingent on the use of an extension activity to take the experimental technique learned to investigate how it could be applied to a novel context. This confusion about the use of the real world application was attributed to the exemplar lessons. The real world application in the Leaf Yeast FTPA involved a second experiment that used the experimental technique in a novel situation. However as already outlined, the real world application for the DNA experiment may have been a thinking exercise, but it did not involve an experimental technique.

The mixed message PSTs receive from both exemplars resulted in the translation of the real world application into a didactic exercise, mimicking the DNA experiment, since it more closely aligned with their own experience and perception of practical work (Karavas and Drossou, 2010). Scaffolding learning for students to conduct an enquiry investigation is cognitively and creatively challenging (Ball, 2000), and given this was the first time the PSTs taught any LC experiment, it was understandable why they reverted to didacticism.

d. The use of meaningful questions (i.e. questions that stimulated the application of the concept to new ideas) was absent from all but one framework document. The majority of questions in the FTPAs and the accompanying worksheets were confined to lower order recall questions. It was an oversight to assume that PSTs could frame enquiry oriented questions when they had so little experience of genuine enquiry. For example, an enquiry-oriented minds-on worksheet, requiring students to make and justify decisions about the experimental technique, was designed for the Leaf Yeast experiment as an accompaniment to the hands-on aseptic technique that students were learning (Appendix 4.1a). The DNA exemplar lesson is accompanied by a 'fill in the blanks' worksheet (Appendix 4.2d), which does not require any level of decision making. All groups of PSTs replicated the latter style of worksheet to accompany their frameworks (see appendices 4.4 a-e). Griffiths et al., (2018) found that within the complexity of the educational setting, it is essential that the 'message' behind any professional development programme is clear, otherwise the recipients receive 'mixed messages', which are difficult to translate into practice. It is hard enough for students to see beyond the "script" of their own classroom experience (Sarason, 1990), therefore sending out mixed messages regarding the worksheets, compounds the problem. Students tend to revert to their own conceptions even after having experiences that directly challenge these conceptions (Burgoon et al., 2011). Loughran (2014) argues that changing PST beliefs requires that their assumptions about science teaching are sufficiently and *consistently* challenged which in this case, they were not.

4.6.2.2 Evaluation of PST teaching

Data for the evaluation of the PST lessons came from three sources:

1. Two audio-recorded lessons
2. The Structured Enquiry Observation Schedule (SEOS),

Evaluation of the Audio-recorded Lessons

Two PST taught lessons were selected for audio analysis and are discussed in detail here.

- Investigation of the Effect of Light Intensity on the Rate of Photosynthesis
- Preparation of an Enzyme Immobilisation and Examination of its Application

Audio transcripts of both lessons were coded using template analysis via MAXQDA software, using the scientific method of enquiry as a guide for the template. Below is an evaluation of the coded analysis, with the codes taken from the categories of the FTPA:

Introduction:

The introduction followed a similar format where teachers began the lesson with a PowerPoint presentation that indicated a greater depth of subject content knowledge than scoping stage investigations.

Hypothesis:

The sole experiment where students were asked for a hypothesis was the Photosynthesis experiment however it appeared to be an afterthought. The teacher had to be reminded to ask students for it:

> Teacher: Our hypothesis sorry! I want you to think of a hypothesis about what we're going to test today in pairs. So I'll give you about 2-3 minutes to think of something, and then we'll ask for a few suggestions
> *Photosynthesis audio 09:10*

The PST was aware that a hypothesis should be a part of the lesson, but did not understand that it required pedagogical scaffolding for thinking by encouraging higher order questions.

The information students had was that they were investigating light intensity in an aquatic plant, and that bubbles of oxygen would be seen. For third year undergraduate biology PSTs, it was conceivable that it should not have been difficult for them to devise a hypothesis. The response of the students, sitting near the Dictaphone, to the teacher's request was captured here:

J: I'm so bad at coming up with a hypothesis
K: I don't know what a hypothesis is
D: It's a statement and then you have to pick a side
P: I feel like I don't even know what a hypothesis is about
K: Well I was never taught, like, "this is a hypothesis"
D: I think it's a part of the scientific method –
K: -yeah, but like, that was never tested, yeah –
D: -but like, who actually gives a **** about the scientific method?
Photosynthesis audio 09:40

The hypothesis as a part of the scientific method was clearly not a concept that this group are comfortable with using as an investigative tool. At this stage of the research it began to emerge that PSTs had limited experience and understanding of either enquiry teaching or of the scientific method as an experimental tool.

Method:

Generally, the introduction of a laboratory skill in the prototype framework, which emphasised the importance of learning a new experimental skill each time a practical lesson is taught, was one of the design principles that was successful. The PSTs were very well organised for the hands-on activities in the lessons and incorporated some pedagogical learning strategies throughout the lesson; such as think-pair-share and placemat.

When it came to carrying out the experimental method, in the photosynthesis experiment, the teacher began by telling students to design their own experiment, making the assumption that students were familiar with the materials on the bench in front of them.

> Teacher: So in your pairs, if you want you to design an experiment to come up with how we could test light intensity, thinking that we use our masking tape as well.

Photosynthesis experiment 16:06

The students in the vicinity of the Dictaphone found this difficult and eventually, after some minutes trying to write their own method for the experiment, one of the students called the teacher over and the following exchange takes place:

D: I assume we're going to…Are we going to get a method?
Teacher: We'll give you a diagram method
Photosynthesis 20:33

These comments further crystallised how PSTs did not understand how to teach through enquiry. In the Leaf Yeast exemplar, students were asked to devise their own experimental method as an extension exercise, but only *after* they had practiced the experimental aseptic technique. Here, PSTs were asking students to devise an unfamiliar experimental method without any guidance, other than the materials on the desk in front of them, evidencing Yoon et al.'s (2012) claims that most teachers' view of enquiry teaching is limited to open enquiry activities only.

Furthermore, when students had finished grappling with writing their own experimental technique, their efforts were undermined by the teacher giving them a pre-prepared written method. In short, the students in the excerpt above (understandably) were too uncertain to execute the task without a written method, and the teacher anticipated this by providing one for them to follow, simultaneously ticking the 'enquiry' box while, ironically, scuppering any potential enquiry.

The immobilisation experiment was very clearly an exercise where students followed a set of instructions to produce a phenomenon, the result of which was that the experiment became a minds-off exercise where students could clearly be heard *not* talking about the experiment, instead chatting about other aspects of their lives. The one situation where students were asked to predict what was going to happen, when the substrate (sucrose) was added to the enzyme (sucrase), indicated their struggle to construct a prediction:

C: Em, what will happen sucrose when it encounters our beads? It will be immobilised?
N: I don't know
C: What will happen to sucrose?
N: What's in here, yeast? Yeast, sodium alginate and?

C: Calcium chloride
N: But in the yeast are sucrase?
C: Yeah
N: So sucrose encounters…..? I don't know
Immobilisation experiment 35:40

Data Collection:

Data collection was a problem in the photosynthesis experiment as the plant was not producing bubbles of oxygen that could be counted on the day. With the immobilised enzyme experiment, students were told exactly how to collect the data, taking a reading every 30 seconds, and then they were asked whether they noticed any changes. Rather than giving students the minds-on opportunity to interpret those changes, the teacher interpreted them herself:

> Teacher: Ok so it takes a lot longer, and what you'll notice is, in your free yeast, there's that yeast in your product, whereas in your immobilised, there's no yeast in your product, it's clear.
> *Immobilisation experiment 1:01:48*

Data analysis:

Data analysis in both experiments involved drawing a graph. The teacher took control of this aspect of the lesson by both drawing and interpreting the graph herself, again losing an opportunity for minds-on engagement.

Conclusion:

Having completed the graph on the board the teacher asked:

> So what can we conclude from this? So hands up, what do you think we can conclude?
> *Immobilisation experiment 1:11:35*

This question is met with silence. The teacher concluded the experiment herself.

Real World Application:

The extent of the content knowledge that the PSTs integrated into the lesson compared to the IST scoping observations was commendable, particularly the research they unearthed regarding the real world application. However, this was a didactic exercise where the teacher gave a talk to the class about an application of the scientific principle. There was no class interaction during this part of the lesson, it was the teacher who researched and presented the topic.

To summarise these findings, reminiscent of the scoping stages, it was clear that the minds-on work (data analysis, data interpretation, conclusion, real world application) was conducted by the teacher, while the hands-on work (following the method, producing the phenomenon) was firmly in the students' domain. It was also evident that PSTs did not understand what was meant by enquiry, which made it difficult to design and teach enquiry-based lessons.

The SEOS

The findings above were reinforced by the Structured Enquiry Observation Schedule (SEOS), which assessed the level of student and teacher involvement in the lessons. It could be clearly seen from Table 4.6, that hands-on activities such as following instructions and manipulation of apparatus, were effected by students, while minds-on activities, such as interpreting data, applying the learning to a wider context, practical enquiry and use of the scientific method were implemented by the teacher. When it came to data recording, students were tasked with recording what they saw but then the teacher assumed the responsibility for data analysis and presentation. Neither of these two experiments utilised the minds-on syllabus skills effectively, resulting in a lack of enquiry.

Table 4.6: The compatibility of the requirements of the syllabus documents with two PST-taught practical lessons

Skills as outlined in the syllabus document	Breakdown of syllabus skills	Photosynthesis	Immobilised enzymes
Following instructions	Follow instructions step by step Listen carefully to the teachers instructions	5 5	5 5
Correct manipulation of apparatus	Labelling solutions and equipment Using given apparatus in the correct manner Correct preparation of solutions and mixtures Using and/or measuring time as a variable Correct use of a measuring instrument Take an accurate reading	1 5 1 5 5 *	1 5 5 5 5 5
Observation	Accurate observation (using equipment) Appropriate observation of the phenomenon under study – (was the correct aspect of the phenomenon observed) Complete observation of the phenomenon under study (producing the correct phenomenon)	0 0 0	5 5 5
Recording	Careful recording of data Write up the procedure Perform calculations as required Tabulate results Draw diagrams or graphs to represent data collection	* 5 3 1 1	3 5 - 1 1
Interpretation	Draw reasonable conclusions from your observations and results Conclusions should ensue from hypothesis being tested Coherent final interpretation that explains how results are reached	0 1 1	2 1 1
Application	Awareness of any other application of what was learned Consider the results in a wider context Identify an activity that serves as a model for further investigation	1 1 0	1 1 0
Practical enquiry	Consideration of ambiguous results Repetition of activity if necessary Design of a new activity	1 0 0	- - 0
Use of the scientific method as outlined in the syllabus documents	Making initial observations Forming a hypotheses Designing a controlled experiment Reporting and publishing results Appreciation of errors Use of controls to reduce errors Collecting data- *see observation / recording above* Interpreting data & reaching conclusions - *see interpretation above* Placing conclusions in the context of existing knowledge & development of theory and principal – *see application above*	1 1 3 5 1 - 1 1 1	0 0 1 5 - 1 3 2 1

Rating Scale:
0 = recommended by syllabus documents but not a feature of this experiment
1 = Teacher completes this part with no input from students
2 = Teacher mostly completes this part with a little input from students
3 = Most students complete this part with some assistance from teacher
4 = Most students complete this part with a little assistance from teacher
5 = Most students complete this part without assistance from teacher
* Teacher showed a data set to class because the phenomenon was not produced

4.6.3 Summary of the PST Design and Development Cycle

The responses from the students who filled in the questionnaire following the exemplar lessons, revealed that an overwhelming majority of students had neither experience of practical work taught through enquiry, nor of the scientific method. Focusing on the Leaf Yeast Experiment, this was the first time that an enquiry-based lesson had been modelled for this PST group, hence, it was naïve to assume that a group, shown how to teach an enquiry lesson once, will easily integrate enquiry into their own lesson design.

Yoon et al., investigating how PSTs implement hypothesis-based enquiry, find three common barriers "under the lesson" (2012, p.605), i.e. in the minds of PSTs, that prevent them from engaging properly with enquiry teaching. Firstly, PSTs understanding of the type of enquiry teaching expected of them seems confined to open enquiry, which they view as too difficult to teach. Secondly, PSTs do not have a proper understanding of what a hypothesis is, often confusing it with a prediction, and thirdly PSTs have a lack of confidence in their subject content knowledge, which is shown by research to have a direct impact on the ability to design and implement enquiry teaching (Appleton, 2002; Ball et al.,2008; Gustafson et al. 2002; Lee et al. 2000; Shulman, 1986). All three barriers were evidenced in the PST lessons. The net effect of these barriers was that PSTs had difficulty stimulating curiosity in students, they struggled to guide students to develop hypotheses and they floundered with guiding data interpretation and discussion among students. Given the extremely complex nature of enquiry teaching, it was no surprise that the PSTs in this study reverted to what they were familiar with namely, hands-on/minds-off teaching.

While PSTs declared an understanding for enquiry following their participation in the exemplar lessons, it did not necessarily follow that they were able to translate this understanding into practice. Dewey explains that it is "absurd to suppose that a mind which needs training because it cannot perform these operations can begin where the expert mind stops" (Dewey, 1910/2012, p.61-62).

Teaching is complex process and teaching PST show to teach in a manner that they are not familiar with is even more complex (Strom and Martin, 2017). It should be noted, that PSTs taught a lesson that would not be out of place in any Irish biology classroom, but none of the lessons they taught were enquiry based, or minds-on, rather they were taught from the familiar “safe ground in which the results were known in advance” (Shedletzky and Zion, 2005, p.35).

Added to this (during the exemplar lessons) the lack of focus on data analysis, the lack of clarity around the formation of a hypothesis, the difference in presentation between the two exemplar lessons, and the confusion over the format of the real world investigation only served to compound the difficulties PSTs faced in making design choices for their lessons.

The actual outcomes for the FTPA in the PST setting in terms of relevance, consistency and practicality were (Nieveen and Folmer, 2012):

- It had some relevance in terms of improving laboratory skills and building confidence in subject content knowledge but was is not relevant in terms of the minds-on improvements it sought to address
- The PST enactment of the FTPA was not consistent with their written FTPA
- It was not suitable for the minds-on enquiry classroom

4.7 The IST Lesson

The first cycle of the prototype was trialled simultaneously with PSTs and ISTs between September and December 2019.

There were three significant events with ISTs during this time:

1. A meeting was held in late September with six teachers.
2. In late October one teacher designed a lesson using the framework.
3. In November one practical lesson was observed.

4.7.1 The Meeting

Six teachers from three different schools attended a meeting in September 2019. The aims of this meeting were to:

1. Present the exemplar Leaf Yeast FTPA to ISTs
2. To recruit ISTs to use the FTPA to design and teach their own enquiry based lessons

Findings from the scoping stage lesson observations were presented to teachers following which the prototype Leaf Yeast FTPA was introduced as an alternative to the recipe-based method of teaching.

Opening the floor to comments, teachers acknowledged the difficulties they regularly encountered around conducting practical work. This excerpt, taken from field notes, pinpoints how the lack of confidence in their subject content knowledge, downplayed by light hearted banter, affects their ability to conduct practical activities:

> It became clear that teachers have issues with pedagogical content knowledge – support needed particularly around subject knowledge, e.g. discussion about ecology: teachers laughed about how they were unable to identify plants, *"I just tell them it's plantain!"*
> E.g. discussion about malt agar: If teachers don't have ready-made plates – they don't know what to do!
> *Meeting Field Notes*

There is a wealth of academic evidence that connects the teacher's subject content knowledge with their ability to teach through enquiry (Kang et al., 2012; Shedletzky and Zion, 2005; Yoon et al., 2012). Carlsen (1992) finds that teachers' subject content knowledge influences the extent to which they open their classrooms to student participation. A lack of robust knowledge and understanding of enquiry means that teachers struggle to teach their subjects or to effect innovative teaching strategies like enquiry (Capps and Crawford, 2013). Recipe-teaching confines instruction to didacticism.

Findings from the meeting stage:

- Teachers realised that their lack of confidence in their subject knowledge was not unique to them.
- As the first ever professional development opportunity for teaching practical activities attended by these ISTs, it created a forum for teachers to discuss why some practical activities do not 'work', and how to troubleshoot these issues.

With recipe-style experiments, ISTs were never obliged to broaden their subject content knowledge, or if confronted with activities that required a lot of subject knowledge (such as an ecology field trip), they outsourced the activity or avoided it altogether. There was clearly a need for professional development through discussion and collaboration where science teachers could learn about teaching practical activities through research-based pedagogies (Putnam and Borko, 2000).

FTPA recruitment:

During the second stage of the meeting, each teacher was asked to consider which of the senior cycle mandatory experiments had potential to be converted to enquiry based practical activities. Of the 22 experiments, teachers suggested the four least complicated activities on the syllabus as possibilities for enquiry-based lessons;

Microscopy

Food tests

Osmosis

Germination

They agreed to develop FTPAs for these practical activities, which the TP would observe them enact in the classroom. The findings from the DNA Isolation trial were also shared with ISTs and it was explained that it did not fully fit the enquiry bill. This FTPA was shared with teachers after the meeting via email, and they were asked think about how to make it more enquiry based.

4.7.2 The IST Lesson Design

One month later, one of the teachers (Niamh) sent me an enquiry-based microscopy lesson using the FTPA. It was accompanied by a PowerPoint presentation, a worksheet and a marking rubric for student self-assessment (Appendix 4.5 a-d).

In contrast to scoping stage investigations, Niamh had a clear conception of enquiry teaching and understood how to incorporate minds-on activities into her lessons. There was a structured enquiry exercise to scaffold the first experiment (examining stomata under the microscope), including a worksheet that asked minds-on questions (Bybee, 2000). In the lesson, once the students understand how to use the microscope (Experiment 1), they are given a self-directed enquiry task as a real world application (Llewellyn, 2013), where they asked their own question, designed their own investigation and made choices about the collection and analysis of data. Students were required to collect qualitative *and* quantitative data. Niamh gave consideration to how her students were to analyse their results by asking questions

(What type of data have we collected? Is this what we expected? Can we summarise it? Can we draw a graph? Does it support or reject our hypothesis?). Students then presented their results in a report. As an assessment for learning exercise, she asked them to design an exam question that could accompany the investigation, and finally she asked them to evaluate their experiment by using a marking rubric to self-assess their learning.

The expected outcomes for this lesson showed that it was an exceptional example of a lesson designed to incorporate minds-on activity. It fulfilled all of the requirements of the design guidelines and displayed the three quality aspects required of a prototype in the screening phase;

1. It was relevant, based on state-of-the-art pedagogical instruction.
2. It was consistent with the framework.
3. It was practical in the senior cycle enquiry classroom.

It must be stated this lesson was not observed and therefore, there can be no claims made as to its effect on student learning. However, it was the first lesson designed by either an IST or a PST to be scaffolded comprehensively for the minds-on cognitive domain as well as the hands-on domain using the scientific method of enquiry.

Niamh's ability to design a lesson to this standard proved to be something of an exception among ISTs. Her comprehensive understanding of enquiry was an outlier from a research perspective and was not reflected anywhere else during this research cycle, as shown in the next section.

4.7.3 IST Isolation of DNA Lesson Observation

The FTPA for DNA Isolation was shared with all ISTs, who were asked to consider how they could align it more with the Leaf Yeast FTPA. One IST volunteered to teach this exemplar lesson, which was observed and recorded. The video and audio recordings were analysed as follows:

1. The video and audio of the lesson was transcribed and analysed using template analysis via MAXQDA software. The template was the same one used for the PST lessons.

2. The enactment of the practical lesson was compared with the aims of the framework to assess how the framework translated into practice

3. The SEOS was applied to the lesson to assess the level of student involvement in minds-on and hands-on activities during the lesson

4. The PAAI was also applied to the lesson to assess the effectiveness of the lesson (Millar, 2009)

4.7.3.1 Evaluation of the Observed Lesson

As with the PST lessons, this lesson was subject to the same coded template based on the scientific method of enquiry and was coded into different stages. Each stage is discussed here:

Introduction:

The teacher had used the previous lesson to address the background information and, other than addressing safety hazards, the students were told to read over their protocols and to fill in the worksheet as they conducted the experiment. (See Appendix 4.2 for all documents relating to the DNA framework)

Hypothesis:

At the beginning of the lesson, the teacher quickly reminded students of the hypothesis they had decided upon the previous day:

> T: Oh, I'll ask one question. What was our hypothesis from yesterday?
> S1: That we would be able to extract DNA
> S2: To find DNA
> T: Why?
> All students talk together
> T: Ok bio-? (No answer) It's a something kind of biomolecule?
> S: Stable
> T: Stable biomolecule. It is a stable.. right lads off you go
> *DNA Isolation experiment 05:40*

The hypothesis was that DNA is a stable biomolecule and can therefore be isolated using the extraction technique. This hypothesis was not revisited at the end of the lesson to confirm or refute this claim.

Method:

Unlike all of the other lesson observations, the teacher challenged the students to work independently – she provided all of the materials they needed, a protocol to follow and a worksheet to fill in. She did not directly instruct the class, which did not deter a number of groups from asking her what they should do but she directed all of them back to the protocol.

The teacher adopted the role of facilitator, keeping an eye on the time, the equipment and redirecting questions back to the students:

> S6: Guys there's a seed in it! Does it matter if there's like one little seed in it?
> T: What do you think?
> S6: Em, no, maybe?
> T: Give it a go and see what happens
> *DNA Isolation experiment 32:50*

It was clear that the teacher was trying to encourage the students to exercise a little independence in doing the experiment, but she confused working independently with enquiry, as the next excerpt shows. The students were filtering a thick mixture through filter paper. The protocol recommended the use of four layers of filter paper, which the students used, but this was too slow, so, prompted by the teacher, they remove a layer of filter paper. This has no effect, so they remove one further layer:

> S6: Right, so nothing's happening yet
> T: How many layers?
> S5: Two
> T: I would go with one maybe
> S6: Then why did it say 4?
> T: Why did I say 4? It's enquiry!
> *DNA Isolation experiment 30:30*

When the student asked why the instructions indicated the use of four layers of filter paper instead of one, the teacher's explanation that this is how enquiry is done portrayed the narrow view of enquiry as focused on "something you have to find out for yourself" relating to the procedure (Yoon et al., 2012). Converting a methodological error into an opportunity for enquiry can be a learning moment, but it can also mislead students into believing enquiry is confined to materials and methods. The exchange above also shows that the teacher did not trial the experiment herself before the lesson.

In this experiment, there was no productive student discussion regarding the method that focused on the scientific ideas underpinning the experiment. All of the student conversations were about the materials and objects that the students were using, rather than relating the process of releasing DNA from a cell, to the structure of the cell. The worksheet was intended to address this issue but instead, it had the opposite effect, distracting the students. The excerpt below outlines a conversation between three students who are trying to fill in the worksheet:

> S5: Physical chopping breaks the – the cell wall?
> S4: That's what I kept thinking and then I was thinking the nucleuses (sic)
> S5: I'm really confused now
> S6: "Breaks down the lipids in the something (blank in cloze test) bilayer of the plasma membrane and causes the something (blank in cloze test) in the membrane to break apart". What's in the membrane?
> S5: I'm so confused
> S4: In the cell wall? (fills in 'cell wall' – incorrectly - in the first blank)
> S5: Would you say that they probably (inaudible)
> S4: The cell walls bilayer of the plasma membrane causes the –
> S6: - protein to be broken down? "Causes protein to break down. After 5 minutes the DNA itself will be broken down"
> S5: To be honest, I don't know where you are
> S4: Breaks down the lipids in the cell walls bilayer of the plasma membrane
> S6: Cell walls bilayer??
> S4: I'm guessing at this point
> S6: Yeah. Just write anything down then, she'll probably go through it
> *DNA Isolation experiment 20:30*

The students were not able to relate the worksheet to the steps in the protocol that they were following. They were following instructions but did not know why they were doing each step, and rather than assist them in their endeavours, the worksheet only served to confuse them further to the point where they were filling in random words in the blank spaces, and assuming that the teacher would clarify the answers later for them.

Laboratory Skill:

There was no laboratory skill taught during this experiment, despite two opportunities to do so. The first opportunity was the correct use of a dropper to remove one drop from a solution and add it to another container and the second opportunity was to show students how to swirl a test tube properly:

> S4: Am I shaking this right?
> S5: I don't know, it's just swirling
> S4: Is this what swirling is? I only ever swirl conical flasks. It's never test tubes
> *DNA Isolation experiment 36.30*

Data Collection:

As already discussed, data collection for this experiment was qualitative only; students were merely required to see DNA at the interface of two solutions in a test tube. All students produced the phenomenon.

Real World Application:

This was mentioned briefly to two individual groups in the class, but not as a discussion with the whole class. They had previously covered the topic of DNA profiling in class and the teacher was trying to get them to apply their knowledge of it as the next step in the process after DNA isolation. She literally had to spell it out for them:

> T: Well, what could you do? Say, for example, you got that little piece of DNA, what could you do with it?
> S6: You could analyse it and all
> T: Yeah. What could you make from it? A DNA what?
> S10: Sample?
> T: No, go again
> (No answer)
> T: P?
> S10: pH?
> T: r, o, f
> (No answer)
> T: I ….. i,l,e. A DNA ….
> S9: Profile!
> T: Yeah

DNA isolation experiment 46:10

Conclusion

To conclude the lesson, the teacher read through the worksheet, telling students the correct answers to questions.

4.7.3.2 Comparison of enacted lesson with design principles

A comparison of the FTPA design principles with the actual taught lesson revealed that the framework, much like the syllabus documents in the scoping stages, had not significantly altered the ingrained recipe style method of teaching that pervades senior cycle biology. From the data presented in Table 4.7, it is seen that the enacted lesson was lacking in the following areas; student discussion, minds-on work, enquiry based design, meaningful questions, content knowledge. The real world application, instead of embedding student enquiry into the lesson, was not addressed in any meaningful way. It appeared the framework had very little impact on the enactment of the lesson. While the lesson was very well organised, it was still a recipe experience for the students.

Table 4.7: A comparison of the design principles the enactment of DNA Isolation in the IST classroom

Checklist item	Evidence in the enactment of the DNA Isolation experiment
Pedagogical scaffolding for thinking	Hypothesis and lab skill taught in another lesson that was not observed. No evidence in this lesson of scaffolding for thinking
Lab skill included	Solutions made up in previous lesson No lab skills addressed in this lesson
Discussion before, during and after the lesson	No discussion before the lesson Student discussion during the lesson No discussion after the lesson
Data collection, analysis, interpretation and presentation conducted by students	Students collect samples of kiwi DNA in test tubes Analysis and interpretation confined to presence or absence of DNA
Real World Application as an extension experiment	Two groups asked to recall the name of an extension exercise No extension experiment
Minds-on work specified	There was no minds-on work during this lesson
Lessons are enquiry based	No
Scientific method of enquiry evident	Hypothesis, experimental method and data collection evident.
Meaningful questions asked	No
Teachers allow students to do minds-on work	No minds-on work evident
Content knowledge beyond the recipe	No

4.7.3.3 Evaluation using the SEOS

A summary of the SEOS (Table 4.8) demonstrated that students conducted the hands-on work (following instructions and manipulating apparatus) and they observed the phenomenon that they were intended to observe. In the domain of minds-on work, the teacher mentioned the real world application to two groups only and there was no data interpretation or analysis in this experiment (the full SEOS can be found in Appendix 4.6)

The experiment was similar to the scoping stage investigations in all but two ways:

1. This was the first time that students were asked for a hypothesis in an IST observed lesson.
2. The teacher encouraged students to follow the instructions without assistance.

Table 4.8: Summary of the SEOS for the IST DNA Isolation observation

Skills as outlined in the syllabus document	**DNA**
Following instructions	4
Correct manipulation of apparatus	3.3
Accurate, appropriate and complete observation of the phenomenon	5
Recording of data	0
Interpretation of results to draw conclusions	0
Application of concept to further activities	2
Practical enquiry	0
Use of the scientific method as outlined in the syllabus documents	0.1

Key: 0 = recommended by syllabus documents but not a feature of this experiment
1 = Teacher completes this part with no input from students
2 = Teacher mostly completes this part with a little input from students
3 = Most students complete this part with some assistance from teacher
4 = Most students complete this part with a little assistance from teacher
5 = Most students complete this part without assistance from teacher

4.7.3.4 Evaluation using PAAI analysis

This analysis shows that the lesson was somewhat effective in the hands-on domain but ineffective in the minds-on domain (See Appendix 4.7). The main aim of the experiment was to follow a set of instructions so that students could recall observing DNA.

Unlike the scoping stage PAAI evaluations, this lesson did endeavour to include a hypothesis. Unfortunately, the hypothesis was not revisited at the end of the lesson.

In the hands-on domain, students had plenty to do with materials and objects; use a measuring instrument, follow a protocol, make a sample of a material, make an event happen, observe an aspect/property of the material.

In the minds-on domain, students did not 'do' anything with ideas. There was no whole class discussion before or after the activity and the only record students had of the activity was the worksheet they were given to fill in. Therefore, in the minds-on domain, this lesson was not effective, since students did not learn what was intended, namely, how the steps in the procedure were related to the breakdown of the structure of the cell to release DNA. Evidence that attests to this is written in the PAAI analysis as follows:

> In the audio transcript, students can be heard discussing the worksheet– they struggle to fill in the blanks. The worksheet was designed as an accompaniment to the protocol so that the students would understand the reason for each step. One student repeatedly says she doesn't understand. Another group can be seen on the video struggling with the worksheet. Students did not connect the steps in the protocol to the task of releasing DNA from plant cells
> *PAAI analysis of IST DNA Isolation Experiment*.

4.7.3.5 Summary of DNA Isolation lesson

Overall, the students followed a list of instructions and produced a phenomenon. Despite having a clear step by step protocol, students continued to ask the teacher what they should do (but not to the same extent as in the scoping stages).

The pedagogical scaffolding that was supposed to relate each step in the protocol to the structure of the cell (the worksheet) proved to be a distraction rather than a minds-on learning tool. While a hypothesis was mentioned at the beginning of the lesson, it was not revisited at the end of the lesson. The majority of conversations recorded during the lesson centred on materials and equipment rather than ideas underpinning the experiment. In short, this was another hands-on/minds-off experiment.

ISTs interviewed in the scoping stages had no professional development experience around integrating enquiry-based pedagogy into practical lessons. In retrospect, if the design team, with all of their years of experience, had difficulty developing this experiment as an enquiry-based practical activity, it was naïve to ask less experienced teachers to improve on the FTPA design, without first establishing a clear definition of what enquiry teaching looks like. The teacher's view of enquiry does not align with the view of enquiry underpinning the FTPA.

Assessing the actual outcomes for this lesson leads to the following conclusions:

1. It was not relevant in terms of enquiry teaching or minds-on teaching.
2. It was not consistent with the framework – there were too many discrepancies between the framework design and the enactment of the framework in situ.
3. It was not practical as a senior cycle enquiry-based minds-on lesson.

4.8 Summative evaluation of the first design cycle:

The FTPA is an enquiry-based innovation that was intended to be enacted as a double experiment. The first experiment is designed to teach students laboratory skills and experimental techniques, familiarising them with the materials and equipment, thereby reducing the cognitive load for the second hypothesis-led experiment. The second experiment is hands-on and minds-on. Once students are familiar with the experimental technique, they use it to ask a question, develop a hypothesis and conduct an investigation in a novel situation. The Leaf Yeast FTPA exemplified this method for conducting practical activities.

The DNA FTPA was developed to show how laboratory skills and epistemic knowledge could be addressed, however, in retrospect; it should not have been selected as a FTPA at this early stage in the development of the prototype because the focus should have remained on using a consistent double-experiment approach to embedding minds-on activities into practical work. This particular experiment did not lend itself easily to the FTPA approach, and was adapted to be a double-hypothesis, single experiment. In practice it was quite prescriptive, with the data presented in this chapter indicating that it was not as successful in the minds-on domain as the Leaf Yeast FTPA.

All PST-designed FTPAs used the DNA activity as the template for planning their own lessons, but they scaled it back to the point that it resembled a recipe-style lesson, rather than a hands-on minds-on experience. No PST used the Leaf Yeast FTPA (an enquiry-based lesson) as a template to design a practical activity. Hodson (1998) explains that learners find it difficult to replace their own conceptions with new ideas, so they find ways to maintain their views by either denying the efficacy of the new idea or by reworking it to fit with their own beliefs about practical work, in some cases, distorting the new idea (the FTPA) until it is compatible with the old idea (recipe-style practical work). It is suggested here that this is what occurred with PSTs.

For ISTs, their long-standing familiarity with recipe-style teaching acted as a deterrent to re-appraising their pedagogical approach (Jeffers, 2006), even after they had experienced events such as the FTPA, that challenged their beliefs (Burgoon et al., 2011). One IST lesson was observed, where, prior to the lesson the teacher was given the DNA Isolation FTPA and asked to find ways to make it more enquiry-based, but the lesson was actually less enquiry-based than the exemplar FTPA. This evidences how "it is difficult if not impossible to teach in ways in which one has not learned" (Loucks-Horsely 2003, p.1)

Even when teachers know enquiry-based activities present better learning opportunities for students, fear and a lack of confidence in such approaches can lead to a preference for older, less-effective approaches (Hamilton, 2018). Furthermore the pressure to make change 'work' can mean that teachers will avoid implementing the change because there is a risk that their students will learn less (Guskey, 2002).

The FTPA was successful in certain ways, for example, embedding skills into a lesson, but it was undermined by the general inability of teachers to understand and apply scientific enquiry, (which is implicit in including minds-on work in practical activities). Teaching though enquiry requires an epistemological shift in the beliefs teachers hold about their role, from one who delivers content to one who facilitates thinking (Gormally, 2016).

> "Beliefs reflect what we think we know ….. or what we are coming to know based on new information. They are supported by experience and people are strongly committed to them ……. Knowledge refers to information that is sure, solid, dependable and supported by research"
>
> (Loucks-Horsley et al., 2010, p.52)

There is a reciprocal relationship between knowledge and beliefs, with both informing the choices teachers make around pedagogy. Increases in knowledge contribute to changes in beliefs, and beliefs shape the development of knowledge (Jones and Leagon, 2014). Evidence in the literature suggests that deficits in scientific content knowledge are linked with the persistence of traditional and teacher-centred beliefs about science teaching (Jones and Leagon, 2014; Luft and Hewson, 2014).

It is not unusual for PSTs to have low confidence in their science content knowledge (Yoon, 2012) and this was evidenced in their reversion to the "safe ground in which the results are known in advance**"** (Shedletzky and Zion, 2005,p.35). Retrospectively, it was a stretch to expect PSTs to design and implement an enquiry-based lesson based on two exemplar lessons, when they had insufficient experience of enquiry, and their beliefs about teaching are directly influenced by their prior experiences.

Equally the assumption that ISTs would be able to take the concept of enquiry and apply it in other contexts to design their own practical activities proved erroneous. Only one IST designed her own lesson using the FTPA (she was the exception). Posner and colleagues (1982) provide the explanation that conceptual change cannot occur unless the learner experiences dissatisfaction with their beliefs – in the case of recipe-style teaching, this dissatisfaction is never experienced overtly because the method of teaching (recipe) and the method of assessment (rote learning) align. Teachers have no reason to examine their practice because, as far as they know, it serves its purpose.

Enquiry teaching requires that teachers organise their thoughts and ideas, a process which is unfamiliar to them (Yoon et al., 2012). Teachers prepare lessons for hands-on activities but not for minds-on thinking. They do not have the knowledge of enquiry that is required to implement minds-on lessons, nor do they have belief systems that match the epistemology of enquiry.

Content knowledge is one of the most powerful indicators of a teacher's willingness to use enquiry-oriented pedagogies (Supovitz and Turner 2000). In science education, to teach through scientific enquiry, teachers need in-depth subject specific knowledge, knowledge of the process of scientific enquiry and knowledge of enquiry pedagogies (Capps and Crawford, 2013). The findings of this design cycle align with international evidence that suggests that teachers do not understand what enquiry is (Capps et al., 2012; Kidman, 2012, Millar, 2004, Osborne, 2015) and often have little formal training and a lack of content knowledge around enquiry-based instruction (Loucks-Horsley, 2010).

The notion of the liminal space, where learners experience a shift in how they make meaning (Land at al., 2014), can be applied to many educational situations where the learner must cross an epistemic divide to understand a more developed way of thinking. There is no liminal space for enquiry at senior cycle level in Ireland. Teachers cannot teach students the meaning of enquiry if they do not know themselves what enquiry looks like. An enquiry vacuum opened during this cycle, where neither ISTs nor PSTs could design lessons with what we had given them because they had no epistemic understanding of enquiry. Teachers did not have sufficient tools, professional structures or culture to address enquiry in their practical lessons. The FTPA, and the way in which it was shared with PSTs and ISTs was insufficient at enabling teachers to integrate mind-on activities into practical lessons within this vacuum. The next cycle of research begins at this point, with the design principles set out below:

1. Separating the lesson into different hands-on and minds-on parts allows for systematic *evaluation* of a lesson but not for the *design* of a lesson, since it does not reflect the reality of practical work; that the hand and the mind cannot be separated when true enquiry is underway (Dewey, 1910). Even where the FTPAs state that minds-on work is to take place in a lesson, lesson observations indicated that this was not the case.

   Design Principle: Develop a theory of enquiry to underpin the FTPA that synergistically employs hand and mind in unison.

2. PSTs and ISTs knowledge and beliefs about teaching practical work did not align with enquiry. To enact change, it is important to specifically target teachers' beliefs and practices (Lavonen, 2004). One way to effect changes to beliefs is to engage teachers in learning experiences similar to those they will be expected to facilitate in their classrooms (Capps and Crawford, 2013). Deep change can only happen when beliefs are restructured through new understandings and experimentation with new behaviours (Loucks-Horsley et al, 2010). Teachers need sustained support structures to learn to design and teach lessons through enquiry. In addition, teachers need to see the effects of new pedagogies before they will change their beliefs about teaching (Guskey, 2002). Changing beliefs about teaching and learning will have reciprocal gains in terms of increased knowledge of scientific enquiry.

   Design principle: Teachers need professional development to provide them with the liminal space in which to engage effectively with enquiry teaching. This will include the development of more enquiry-oriented exemplar FTPAs and opportunities for professional dialogue.

Chapter 5 reports on the development of the first design principle; a new theoretical framework to underpin the FTPA, and Chapter 6 outlines the programme for professional development for enquiry teaching.

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Chapter 5 – Developing a Theory of Enquiry

5.1 Introduction

The previous design cycle uncovered an 'enquiry vacuum' at senior cycle level, whereby teachers did not have the knowledge or experience to adapt practical lessons to a more enquiry-based, minds-on style. The assumption that teachers understood how the FTPA could engender enquiry-oriented lessons was derailed by a dearth of understanding of enquiry itself.

This chapter begins with a review of the literature around enquiry, which provides an explanation of how difficult it is to characterise enquiry academically, both in written policy and as a pedagogical tool for teaching. Section 5.3 outlines a theory of enquiry suitable for LC practical activities that is grounded in Dewey's ideas about overcoming the hands-on/ minds-on dichotomy. In section 5.4 this theory of enquiry is translated into a second prototype, the Framework for Teaching Enquiry Activities, using the Leaf Yeast experiment as an exemplar.

The research questions answered during this design cycle are:

> What are the characteristics of a theory of enquiry that can be used to articulate curriculum intentions for enquiry-based practical activities in the Irish biology classroom?
>
> How does this theory translate into an artefact that teachers can use to teach practical activities?

5.2 Review of Literature

Llewellyn (2013) divides enquiry into three parts, enquiry, scientific enquiry and science enquiry. Enquiry can be applied to any subject and involves posing questions and searching for answers. Science enquiry relates to enquiry-based instruction, specifically the characteristics of activities and investigations that students carry out based on a proposed question. Scientific enquiry is derived from 'authentic' science and generally refers to a set of skills and practices that scientists need to produce new knowledge, including critical thinking and scientific reasoning skills, problem-solving skills, communication and decision making skills and metacognitive skills. The disentanglement and translation of the latter two aspects of enquiry into classroom practice is the focus of this section. When teachers have a good understanding of the relationship between them, it leads to a better understanding of scientific concepts, skills and abilities for students (Minner et al., 2010), however, the converse is also true, that poor understanding of what it is to teach science as enquiry has a negative effect on student learning, leading to criticism of enquiry as an instructional method from some academic corners (Osborne, 2014; Jerrim et al., 2020).

This section begins with an examination of how enquiry in the science classroom is difficult to describe, define and characterise. This is followed by an examination of how enquiry is understood and enacted by science teachers. Evidence around effectiveness of enquiry as a pedagogical tool is then presented through a lens that critiques the view of the 'pupil as scientist' approach to practical activities. Pedagogical tools for teaching practical activities through enquiry are then presented, and the section finishes with a look toward future orientations for practical activities. Throughout this section 'enquiry' and 'inquiry' are used interchangeably, reflecting their use in the literature.

5.2.1 Characterising Enquiry:

In terms of understanding teaching science as enquiry, Joseph Schwab (1960) was one of the first to identify three levels of enquiry ranging from closed (teacher-directed) to open (student-directed), with the level of enquiry depending on whether it is the student or the teacher who is asking questions, collecting data and interpreting the data. Colburn (2000) terms the three stages structured, guided and open enquiry. In open enquiry it is the student who asks questions, collects and interprets the data. Similarly, Banchi and Bell (2008) identify four levels of enquiry; confirmation, structured, guided and open, which are also determined by the level of teacher or student involvement in asking questions and collecting/interpreting data.

In a similar vein, Fradd and Lee (2001) developed an enquiry matrix, consisting of the following activities: asking questions, planning, implementing, concluding, repeating and applying. Teachers are encouraged to use these scales to gradually assist students to develop the six skills which move them from closed towards open enquiry.

The problem with characterising enquiry in this way is that it fosters a misconception, perpetuated in the science education policy documents above, that the 'ideal' goal for practical work is open-enquiry and authentic practice (Hofstein and Kind, 2012). This is at odds with the reality at classroom level of time constraints, high stakes testing of low level knowledge and the lack of a realistic, clear and usable definition of enquiry (Rop, 2003).

Settlage describes enquiry as "one of the most confounding terms in science education" (2003, p.34). Because of its nebulous nature, Abrams (2008) suggests viewing enquiry in terms of 'Niche Theory' (niche, being a term borrowed from biology to describe the functional role of an organism in its environment). Mirroring its function in biology, the niche for enquiry in the science classroom is not fixed because the variables upon which it is defined can change according to different learning environments. Take, for example the manner in which teaching science as enquiry is often characterised as an amalgamation of three separate but related niches (Bybee, 2000; Dewey, 1910/2012; Llewellyn, 2013; NRC, 2000):

1. A pedagogical tool to teach science content and the methods scientists use with the goal of assisting students to actively construct an understanding of scientific concepts
2. The ability to 'do' scientific processes by successfully performing some semblance of scientific enquiry
3. An understanding of the guiding principles for doing scientific enquiry (often called the Nature of Science).

Teachers are expected to understand that teaching science as enquiry (no.1) also includes teaching about the other two aspects of enquiry; 'doing' science (no. 2) and understanding the Nature of Science (NOS) (no.3). Understanding enquiry in terms of Niche Theory means that the goal of a lesson determines the niche that enquiry should occupy; sometimes it is one of these entities, other times it can be two or, all three together.

A more concise way of looking at teaching science as enquiry is found in Cairns and Areepattamannil (2019), where they identify three entities:

1. Teaching *of* enquiry – teaching science process skills
2. Teaching *about* enquiry – teaching how scientists use enquiry methodologies
3. Teaching *through* enquiry – teaching scientific knowledge using enquiry

Providing an agreed upon definition of enquiry that applies to school science as a whole has, thus far, eluded academia (Abrams, 2008; Martin-Hauser, 2002; Minner, Levy and Century, 2010; Minstrell and van Zee, 2000). Achieving consensus on a definition for enquiry is hampered by a lack of consensus about what enquiry actually looks like. Bybee points to a long history of enquiry in science education which runs parallel to "an equally long history of confusion . . . . . In short, we espouse the idea and do not carry out the practice" (2000, p. 20).

Kennedy (2013), in a paper discussing the role of investigations in promoting enquiry-based science education in Ireland defines enquiry as:

> "the art of developing challenging situations in which students are asked to observe and question phenomena; pose explanations of what they observe; devise and conduct experiments in which data are collected to support or contradict their theories; analyse data; draw conclusions from experimental data; design and build models; or any combination of these."
> (p. 291)

Alozie et al. (2012) define enquiry in similar terms to Kennedy:

> "Scientific inquiry involves engaging learners in scientific practices such as asking scientific questions, experiencing phenomena by designing and conducting investigations, collecting and analyzing data, constructing explanations based on evidence, and sharing findings with others."
> (p. 486)

Crawford (2014) articulates how teaching students to "do" enquiry involves:

> "engaging students in asking scientific questions, designing and carrying out investigations, interpreting data, developing models and explanations, and communicating and using arguments to defend these explanations."
> (p.517)

Common to the three definitions is that teaching science as enquiry includes conducting scientific investigations by asking questions and formulating strategies to find answers to those questions (teaching *of* enquiry). However only in Crawford's (2014) definition are elements of teaching *about* enquiry found, and these are implicit, rather than explicit, in the definition. For example, "communicating and using arguments to defend these explanations" is related to how scientific knowledge is consensually agreed among communities of scientists, which is aligned with the movement towards making the NOS more explicit in practical activities through argumentation (Llewellyn, 2013). Alozie et al. (2012) and Kennedy's (2013) definitions do not make this link with the NOS. Therefore, Crawford's definition of enquiry aligns best with the vision for the Framework for Teaching Practical Activities (FTPA).

Taking a turn towards how enquiry is represented in policy documents, in England, the Association for Science Education describes scientific enquiry as: "the processes and skills pupils should be taught and use to find out more about the world and how it works" (2018, p.2). This particular document goes on to identify four areas where scientific enquiry should be used to develop children's capacity; problem-solving, working independently, being a scientist and communicating effectively. In the English National Curriculum for Science, scientific enquiry is referenced as "working scientifically", which, it is expected, should include enquiry processes such as

> "observing over time; pattern seeking; identifying, classifying and grouping; comparative and fair testing (controlled investigations); and researching using secondary sources. Pupils should seek answers to questions through collecting, analysing and presenting data."
> (Ofsted, 2015)

It has been argued that both the English and American policy documents have led to a misinterpretation of enquiry in the science classroom because they do not distinguish between learning through enquiry and learning about enquiry (Osborne, 2014). Crawford (2014) suggests that enquiry is misrepresented in American policy as one particular niche, that of 'doing' science. This has been interpreted loosely into 'hands-on' experiences in the classroom, which are generally not enquiry-based (Abrahams & Millar, 2008). English policy is at pains to emphasise that scientific enquiry (the processes and methods carried out by professional scientists) and enquiry-based instruction are not the same (Ofsted, 2021), yet it emphasises the 'pupil as scientist' approach to learning science, which blurs the lines between these two approaches.

In Europe, Rocard et al. (2007) plump for enquiry-based education as a way to improve science education. However PISA 2015 indicates that science is taught in a similar fashion throughout Europe, including Ireland (OECD, 2016). In terms of levels of enquiry, open enquiry has a negative association with performance in science, while more closed enquiry is positively associated with academic success (Sheil et al., 2016). Therefore, recipe-style instruction prevails when success is measured in terms of terminal examinations that do not cater to higher order thinking skills (Burns et al., 2018)

An examination of recent STEM policy in Ireland (Oideachas, A. R., 2020) indicates that policy makers recognise that enquiry-based learning poses a challenge to STEM education provision. Notwithstanding, the vision for STEM Education is that teachers "should provide learners with opportunities for real-world and inquiry-based tasks" (ibid, p.9). One of the "areas of ambition" in the document is to enhance teacher capacity by having STEM teachers adopt an "inquiry-oriented approach to their teaching and learning", (ibid, p.15). While there is no definition or explanation in the policy of what enquiry-based teaching and learning means, it is expected that teachers' "practice will be informed by their engagement in and with relevant research" (ibid, p.15). Given the lack of consensus on what teaching science as enquiry actually means, the next section explores how teachers understand, interpret and implement enquiry-oriented lessons.

5.2.2 Teachers' Experience of Enquiry

This research has uncovered an 'enquiry vacuum' at upper senior cycle biology (Chapter 4). In the United States, Crawford (2014) reports that enquiry-based instruction remains "enigmatic and rare", with similar reports internationally, from England (Abrahams and Millar, 2008), Australia (Kidman, 2012) and Singapore (Kim & Tan, 2011). Abrams (2008) posits that the absence of a concrete definition of teaching science as enquiry places the 'burden' on teachers to formulate their own understanding and definition of enquiry. This is evidenced in a study conducted by Capps and Crawford (2013), with what they termed "well qualified and highly-motivated" teachers, to interrogate their understanding of enquiry-based instruction. The teachers they interviewed believed they were teaching science as enquiry, yet no teacher was able to describe the features of enquiry in their instruction. Osborne argues that school science enquiry has been conflated with the notion that enquiry requires students to "handle, investigate, and ask questions of the material world" (2014, p. 582) leading to teachers equating 'hands-on' activities to enquiry-learning. Almost two decades prior to this Millar (1998) identified the same conflation of the goals of enquiry with the goals of laboratory work. Both Millar and Osborne are in favour of downplaying the role of the laboratory in school science because of the rhetorical nature of most practical work (in producing a pre-determined phenomenon). In addition, when practical activities occasionally move outside the realm of rhetoric, it is to focus on the manipulative skills of 'doing' an activity rather than on analysis and interpretation of data, or any understanding of the NOS (Osborne, 2014). This is evidenced in Chapter 4, where all PST lessons were successful in incorporating laboratory skills into their lesson designs, but could not include enquiry. Osborne (2015) argues that core features of the practice of science (critique and argumentation) are also essential features of human learning, yet are rarely evident in science classrooms. He also discusses how teachers may teach students the procedures required to produce new scientific knowledge (knowing how) but do not explicitly teach knowledge of the rules, standard procedures and ways of minimising errors that are required to produce data that is reliable and accurate (knowing that). Furthermore, Osborne argues that there is a total absence of epistemic 'knowing why':

> "knowledge of how these procedures justify our belief in science's claim to know, and the constructs and values that are commonly used in science—what might be termed "epistemic knowledge,"
> (2014, p.580)

Teachers' understanding of enquiry is polarised into two sides of the same coin. On one side is the belief that hands-on activities suffice as enquiry activities, and on the other side is the misconception, upheld by policy, that teaching science as enquiry means open-enquiry activities, where students conduct investigations with little to no guidance (Abrams, 2008).

The challenge of open enquiry leads teachers to eschew this method because they do not believe it fosters meaningful learning. In Ireland, Kennedy (2013) calls for a tempered approach to teaching practical activities, recommending a balance between Hattie's (2009) Direct Instruction approach and enquiry-based open investigations, in light of findings by Hattie that direct instruction had a greater effect on student achievement than enquiry-based methods.

Llewellyn (2013) identifies the misconception that if a teacher asks a lot of questions then the lesson is enquiry-based. In many cases the type of questioning that is typical of many science classrooms is often referred to as IRE (initiation, response, evaluation) and has been found not to engender cognitive skills such as critical thinking or reasoning (Michaels et al., 2007). Despite the difficulties teachers encounter there is ample evidence that enquiry-based instructional practices implemented correctly have a greater impact on students' ability to understand scientific knowledge (teaching *through* enquiry) (Minner et al., 2010), and to understand the Nature of Science (teaching *about* enquiry) (Crawford, 2014). Given the unclear understandings of enquiry instruction, the next section examines research that measures the success of enquiry as an instructional approach.

5.2.3 Does Enquiry 'Work'?

Empirical studies have found that enquiry-based instruction results in better learning outcomes when compared to direct instruction, unassisted discovery learning or traditional recipe -based instruction (Alfieri et al., 2011; Blanchard et al., 2010; Crawford, 2014; Furtak et al., 2012; Minner et al., 2010; Wilson, 2010). Akuma and

Callaghan (2019) evidence the many studies attesting to the superiority of enquiry as an instructional method, to explain why policy makers internationally argue in favour of enquiry-based science education. Capps et al. (2012) identify how enquiry teaching focuses on “active student knowledge construction in place of merely drill” (p. 295). Schroeder et al. (2007), present strong evidence in support of enquiry pedagogy, which is also credited as being better placed to address the achievement gap between students from differing backgrounds (Lynch et al, 2005). Conversely, Klahr and Nigam (2004) claim that enquiry-based instruction is actually less effective than direct instruction in supporting learning. Gott and Duggan argue in favour of the abandonment of practical work altogether because it does not yield any measurable gains in learner understanding (2007). Kirschner, Sweller and Clarke (2006) famously criticised unguided and minimally guided discovery learning and problem-based learning, along with any kind of enquiry-based instruction which views the “student as scientist”. The basis of their criticism is that “the major fallacy of this rationale is that it makes no distinction between the behaviors and methods of a researcher who is an expert practicing a profession and those of a student who is essentially a novice” (p.19).

Kirschner and colleagues are not alone in their fulmination of instructional methods that confound school science with the practices of professional scientists, much of whose knowledge and understanding of scientific procedures and processes is tacit. Osborne (2014) distinguishes between the goal of ‘real’ science as producing new knowledge (doing science), and the goal of school science as helping students to understand ‘old’ knowledge (learning science). Osborne asserts that the conflation of the two goals has resulted in enquiry (the methodological tool used for doing science) being used as a way to learn science in school, and he concludes by recommending that, rather than using our knowledge about how science is done to teach science (because there is little consensus about this), we should use knowledge and understanding of how people learn.

Chinn and Malhorta (2002) conducted an often-cited study comparing the authentic enquiry practices of professional scientists with the ‘simple’ enquiry that teachers conduct in the science classroom. Their study suggests that common classroom approaches to teaching science as enquiry actually divert students away from a sophisticated understanding of science. However, their argument is based upon the irreconcilability of two different epistemologies; school enquiry as 'verification' enquiry, which is closer to recipe-style instruction, and the constructivist view upon which genuine scientific enquiry is based. It is argued here that if they had compared genuine enquiry-based activities with the activities of scientists, they would have seen more epistemologically similar characteristics between the two.

Taking a more measured stance to teaching science as enquiry, Crawford argues that traditional recipe-based science instruction requires nothing more of students than memorising facts to be regurgitated at a later date, whereas:

> "In contrast, inquiry gives students opportunity to grapple with data and construct possible answers. On the one hand, scientists' science is not exactly the same as classroom science in its sophistication and use of elaborate equipment, scope, and duration. On the other hand, classroom inquiry can resemble many aspects of a scientist's inquiry. A reasonable goal of classroom science teachers includes helping students learn how to think in similar ways to that of scientists, do the kinds of work of scientists do, and develop insight into tenets of nature of science."
>
> (2014, p. 526)

Crawford (ibid, 2014) is advocating for teaching *of, about* and *through* enquiry by endeavouring to bring aspects of the NOS and the ways of thinking that are a part of authentic science into the classroom. Since students of biology are studying at upper secondary level, it seems reasonable that they would be in a better position to learn of, about and through enquiry than the elementary school students in Chinn and Malhorta's study (2002). Therefore, this research takes an approach to teaching practical activities that aligns with Osborne's view that we should use knowledge of how people learn to teach practical work, combined with Crawford's measured approach to teaching of, about and through enquiry. There are pedagogical tools available to teachers to assist in designing enquiry-based lesson and these are explored in the next section.

5.2.4 Enquiry based Pedagogy

The scientific method, which is most commonly associated with teaching practical activities, has been criticised in academic circles as presenting a naïve empiricist view of science, where students are required to apply a stepwise method in order to develop scientific knowledge (Hofstein& Kind, 2012). The problem is that textbooks, and Irish syllabus documents, promote the misconception that science is done in this prescribed linear fashion, leading teachers to believe that the scientific method is a set of rigid steps that must be followed (Capps & Crawford, 2013). The procedural steps in the scientific method are then falsely credited with providing evidence for knowledge claims (Driver et al., 2000). Jenkins (2007) writes how, in academic circles, the term 'scientific method' has lost much of its 'valour' because there is a missing link in terms of understanding that it is one of a number of processes scientists use to make sense of data which is then presented to a community of peers for debate, critique and discussion (Duschl and Osborne, 2002).

To put into context how far removed Irish practical lessons are from enquiry-based learning, the scientific method is presented as a separate chapter at the beginning of the textbook, but Chapter 3 provides evidence from students and teachers that it is not incorporated into the practical work they undertake. While it is 'naïve' and 'empiricist', it is preferable to not using any process at all to make sense of data, and its use in the Irish classroom would shorten the epistemological journey required of teachers to reach an enquiry-based understanding of teaching practical biology.

A move towards enquiry would have to acknowledge recent developments in science education that have incorporated the use of argumentation into practical activities as a way of buffering the effect of the scientific method (Driver et al., 2000). Llewellyn describes scientific argumentation as: "a critical thinking skill that helps students propose, support, critique, refine, justify and defend their positions on issues" (2013, p. 19). The development of argumentation skills enables students to practice the scientific thinking skills needed to understand how scientific knowledge is created (Park and Kim, 2006). Students interpret and evaluate data as evidence to develop arguments and explanations within their own community of peers (Crawford, 2014). Thinking and discussion occupy a central role in the practical classroom, focusing students' attention on how they know what they know and how they can accept one statement as true while rejecting another (Hofstein and Kind, 2012). For teachers, fostering this kind of enquiry in the classrooms provides opportunities to observe and listen to their students' dialogue, and to ask questions that can help students develop epistemological understanding of scientific knowledge along with argumentation skills (Jimenez-Alexandre et al., 2000). Simon et al. (2006) point out that the social context of the classroom is an ideal place for students to develop reasoning and argumentation skills. Including argumentation in practical activities is one way of counter-balancing the claims that school science and authentic science are not related epistemologically. Using the idea of argumentation in the FTPA, students can work in groups to interpret and evaluate data from the diagnostic experiment, and then generate a question/hypothesis that could be investigated in the applied experiment.

Using enquiry-based heuristics is another way for teachers to implement enquiry in the classroom. A learning cycle approach to teaching science as enquiry has been widely utilised in the literature (Atkin and Karplus, 1962; Lawson, 1989). Grounded in the work of Piaget, it has three phases to an activity; exploration where experiments are conducted under the guidance of the teacher, concept development from the data obtained and conceptual expansion where the student applies the concept learned by doing additional experiments. Bybee's 5E learning cycle is developed and extended from this has gained the most traction internationally as a classroom tool for enquiry teaching (Bybee et al., 2006). Grounded in constructivism, there are five stages; engagement where the teacher asks a question or poses a problem, exploration of hands-on phenomena, explaining phenomena, elaboration of concepts by challenging students with new situations and evaluation of learning by the teacher. Using the entire cycle over one practical lesson decreases its effectiveness (Bybee, 2014), therefore it may not be as useful in the Irish context of mandatory practical activities. In addition, teachers can have their students engage in all five stages of the cycle outside of the context of scientifically oriented questions and without engaging meaningfully with data (Capps et al., 2013). Once teachers have developed an epistemological understanding of enquiry, the 5E cycle may be a useful tool, but in light of how far removed Irish biology teaching is from enquiry-oriented approaches, a gradual shift in pedagogy, beginning with practical activities may be more suitable.

Perhaps more useful for mandatory activities is the framework developed by Pedaste et al. (2015) which identifies the core features of enquiry cycles and subsumes them into one “inquiry-based learning framework”. The framework allows for either a question-driven or a hypotheses-driven approach to practical activities. It is flexible enough to allow a non-linear approach to investigation with argumentation in the form of communication or reflection built into each stage of the investigation.

In American science education policy there has been a shift towards the term ‘science practices’, to account for the scope of cognitive, social and physical practices that are embedded in an understanding of enquiry in science teaching (NRC, 2012). This provides a broader approach to enquiry under an umbrella term, which is characterised by eight interconnected practices as follows: asking questions, developing models, constructing explanations, engaging in argument from evidence, planning and carrying out investigations, analysing and interpreting data, using mathematical thinking and obtaining, evaluating and communicating information (ibid., p.3). The FTPA is modified in this chapter to use these science practices as a reference point for designing each lesson, moving between levels of enquiry, and laying the foundation for teaching of, about and through enquiry (Crawford, 2014). Henceforth, the FTPA will be known as the FTEA (framework for teaching enquiry activities).

Osborne’s (2015) suggestion that enquiry should be grounded in how people learn, provides the inspiration for the next section, a theory of enquiry based on the work of Dewey.

5.3 A Theory of Enquiry

> *We cannot permanently divest ourselves of the intellectual habits we take on and wear when we assimilate the culture of our own time and place. But intelligent furthering of culture demands that we take some of them off, that we inspect them critically to see what they are made of and what wearing them does to us*
>
> (Dewey, 1925/1958, p.37).

In order to change the culture of recipe teaching in Ireland, it is necessary to examine why it is no longer acceptable as a method of teaching. There is widespread academic research that attests to the purely mechanical nature of recipe style tasks, that separate the body from the mind leading to research on practical work being separated into two domains: hands-on and minds-on. Through the writing of Dewey, a theoretical examination of how this separation between body and mind came about is applied to recipe teaching in section 5.3.1. The next section argues against a mind body dualism in the teaching of practical work in biology. It seeks to develop and explicate an embodied experience of learning through mind and body. Dewey's solution to the mind / body dualism that has dominated teaching for the last century or more is to use the scientific method (now replaced with science practices) of enquiry to reconnect the body with the mind through a complete act of thinking that involves both induction and deduction. In the Irish biology curriculum to date, the inclusion of mandatory experiments that have set procedures and pre-determined results has been underpinned by the view of knowledge as something that can be imposed on one mind from another. The result is that knowledge is seen as a possession, something complete, something that can be *had* and therefore does not require further thinking or investigation (Leach & Moon, 1999). The biology curriculum document advocates for teaching the mandatory experiments through the scientific method of enquiry, but this is impossible to achieve as long as the view of knowledge in the curriculum remains as it is (Government of Ireland, 2001). Changing the way we view knowledge is the key to changing the way we teach practical work. When we no longer see knowledge as something that can be imposed onto young minds but rather as something that we must strive for, an interconnected part of our past, present and future experience, then the landscape of learning and knowledge looks dramatically different (Dewey, 1910/2012).

The final subsection uses Dewey's ideas about the complete act of thinking, to re-develop a worked example of the Leaf Yeast (FTEA) to reflect how enquiry has been embedded within it.

5.3.1 The Difficulty with Recipe Teaching

Recipe teaching is a habit inherited from the culture that existed at the turn of the last century that we still, inexplicably, cling to, despite decades of academic research that attests to its intellectual ineffectiveness (Abrahams and Millar, 2008; Millar 2004; Osborne, 2015). Through Dewey, we can gain some insight into the nature and origin of recipe teaching along with an understanding of why it still persists today. We can equate recipe teaching with what Dewey calls 'traditional education':

> "…. that which is taught is thought of as essentially static. It is taught as a finished product, with little regard either to the ways in which it was originally built up or to changes that will surely occur in the future"
>
> (1938/2015, p.19)

Recipe teaching is synonymous with teaching a topic in isolation, without thought given to any connection to prior knowledge or to further future experiences.

> "It imposes adult standards, subject matter and methods upon those who are only growing slowly toward maturity………the required subject-matter, methods of learning……are beyond the reach of the experience the young learners already possess"
>
> (ibid., p. 18-19)

When teachers expect ideas to emerge from data, it is because they are teaching from the perspective of one who has reached the end of a journey and knows the route, not as one who is only at the beginning of the journey with no map. Dictating the steps to be undertaken in order to produce a phenomenon may enable students to see the end result of an experiment, however it diminishes the students' ability to think critically or to understand the subject matter since -

> "the pupil is enjoined to do this and that specific thing, with no knowledge of any reason except that by doing so he gets his result most speedily; his mistakes are pointed out and corrected for him; he is kept at pure repetition of certain acts till they become automatic"
>
> (Dewey, 1910/2012, p.51).

Students are not able to connect intelligently the practical skills learned in the course of recipe instruction with the scientific principles that underpin them because intelligence has not played any part in their acquisition. The misguided idea that this is the logical way to teach practical work results in the external imposition of subject matter on the student mind that is never internalised or understood personally. Dewey sees it as absurd "to suppose that a mind which needs training because it cannot perform these operations can begin where the expert mind stops" (ibid., p.62). Recipe teaching fosters superficial, uncritical thinking where what is taught is accepted unquestioningly at face value. According to Dewey, "it is obviously undesirable that their chief intellectual problem should be that of producing an answer approved by the teacher" (ibid., p.50), yet this is exactly the outcome that occurs when experiments are taught by recipe.

The crux of the problem with recipe teaching is in the view of knowledge that it portrays.

> "Genuine science is impossible as long as the object esteemed for its own intrinsic qualities is taken as the object of knowledge. It's completeness, its immanent meaning, defeats its use as indicating and implying"
> (Dewey, 1925/1958, p.130).

Dewey is critical of the view that sees knowledge as something that can be possessed, something complete, comprising a subject matter that is fixed; an "end-in-itself". Once knowledge is "had", there is no need to strive to find out more, hence enquiry and curiosity are stifled. Contrast this view with one of knowledge as an "end-in-view" and we change the landscape of learning to one where there is a continuous search for further knowledge, the experiment is not seen as the end-in-itself but instead becomes an object of conscious intent that enables the learner to verify one end by bringing it back to real world applications that become the basis for observations and new experiments to be performed.

> "To know, means that men have become willing to turn away from precious possessions, willing to let drop what they own, however precious, in[sic] behalf of a grasp of objects that they do not as yet own"
> (ibid. p.131).

We have to learn to grasp at knowledge we do not yet own, to use principles learned as materials for learning new ideas so that the experiment is no longer an end-in-itself, instead it becomes an end-in-view, something dynamic and transitive, a vehicle for further exploration. Otherwise:

> "The child comes to the traditional school with a healthy body and a more or less unwilling mind, though, in fact, he does not bring both his body and mind with him; he has to leave his mind behind, because there is no way to use it in the school"
>
> (Dewey, 1915/2013, p.50)

The age-old problem of mind body dualism is described by Dewey as one that makes "a division where none exists and then resorts to an artifice to restore the connection which has been wilfully destroyed" (Dewey, 1925/1958, p.283). Millar and Abrahams (2008) very clearly identified a division between body and mind when students are engaged in practical work and have attributed much of it to recipe style instruction. It is interesting that in order to assess the effectiveness of practical lessons that they thought to separate the lessons into two levels: one level relating to the body, the other level relating to the mind. Dewey traces the mind/body dualistic problem back to two historical events. The first is the simultaneous rise of two separate philosophical movements, a psychological movement that formed a "separate and isolated mental world in and of itself, self-sufficient and self-enclosed" (Dewey, 1925/1958, p.15), and a physical movement which "set up physical objects as correspondingly complete and enclosed" (ibid, p.15), leading to a physical and a psychical subjective world that separated body from mind.

The second factor is the dominance of the Catholic Church in the history of Irish Education in many of our schools leading to a separation for moral purposes between flesh and spirit (Clarke, 2012). The body is viewed as corruptible and impermanent, while the spirit is incorruptible and permanent. When God becomes the master teacher, teaching through official representatives, knowledge becomes an affair of grasping already given sureties. "Truth was given to reason and faith; and the part of the human mind was to humble itself to hearken, accept and obey" (Dewey, 1925/1958, p.153). Knowledge in this environment becomes something already *had* and therefore there is no need to *know* it. Hence the mind is excluded from learning. In more recent years, modern science has usurped the divine as the master teacher, but the net result on teaching and learning practical work is still the same, knowledge is pre-packaged and presented to students as complete. Students do not get to see inside the 'black box' to understand how science 'works' (Latour, 1987).

If we look to the Irish biology syllabus (Government of Ireland, 2001) we can see that there are 22 mandatory experiments on the course that that are presented in the textbooks and online as "ready-made intellectual pabulum to be accepted and swallowed" (Dewey, 1910/2015, p.198), yet the syllabus document recommends that practical work should be taught through enquiry. Here we have the "artifice to restore the connection which has been wilfully destroyed" to which Dewey refers (1925/1958, p283). It is disingenuous to write in a policy document that practical work should be conducted through enquiry when the view of knowledge presented in the same document is incompatible with enquiry teaching.

5.3.2 Changing the View of Knowledge

Dewey uses the analogy of islands floating on the sea to explain how to move away from a dualistic view of mind and body. The islands may look isolated from each other but that is only what we perceive, since "the connecting links do not ordinarily appear; they are there, but are not had" (Dewey, 1925/1958, p.137-138). It is important to delve, probe and extend thinking beyond that which is apparent in order to push the boundaries of knowledge. The practical and theoretical importance of this idea rests on inference, "which would not exist if things appeared to us in their full connections" (ibid, p.138).

With inference we are able "to link the things which are immediately and apparitionally had with one another by means of what is not immediately apparent and thus to create new historic successions with new initiations and new endings" (ibid, p.138).

When we weave together the underlying 'reality' (that which is not immediately apparent) with the surface 'appearance' we can override the disconnect between the physical and mental domains. What is underneath and joining the island peaks is inferred when we think reflectively; we use inference to connect what we observe above the surface with what we cannot see below. In this way the physical and the mental work in unison and the duality between body and mind is replaced by a body-mind, an interdependent body and mind.

When we teach using a recipe method, we treat peaks as ends-in-themselves, meaning they emerge here and there with no apparent connection. When effective production of a phenomenon is the sole aim of a practical lesson, the results of experiments are treated as the end of knowing, which "*is to burden ourselves with an unnecessary and insoluble problem*" (ibid, p.139), because it situates us between two realms that are rivals of each other, that of immediately apparent things (physical) and that of inferred things (mental). Knowledge in this sense is fixed and pre-determined, something to be possessed, which, as already elaborated above, leads to a deepening of the divide between mind and body.

What we need to explore is what underpins practical work, what is submerged that we cannot see – the scientific principles upon which the experiments rest, and what can connect experiments sequentially to each other and to further peaks in order to develop a "scheme of constant relationships" (ibid, p.139). We move to looking at experiments as ends-in-view, never isolated, instead always indicating a new direction in which we can look for further connections. With this outlook, if knowledge means to reach for something just out of grasp, then a transformation occurs in which isolated experiments form an interconnected series, each experiment based on what is learned and inferred from the previous one, with freedom built in to each experiment to ask questions, develop hypotheses, make mistakes, gather and interpret data, share knowledge with peers and to apply knowledge to further investigations.

Knowledge in this sense cannot be possessed because it is always subject to further connections, always moving towards the future, always indicating something else, always just out of reach. The divide between mind and body dissolves in this situation as we explore through enquiry not just what is apparent but also what lies beneath the surface. We are compelled to use body and mind together to make sense of that which we can see and that which is inferred. Knowledge is no longer immediate possession, it becomes a vehicle for searching and connecting previous, present and new ideas in order to continuously forge new connections. Knowledge is only held subject to its use and cannot be a fixed entity since it is dependent on discoveries that make it possible and has to be adjusted when new discoveries question its verity. Practical work in this sense is conducted through enquiry where informed opinion is used to induce hypotheses and experiments and those experiments become the forerunners of truth. "The mind is freed from captivity to antecedent beliefs" (Dewey, 1925/1958,p.155), because knowledge is no longer ready-made, it has to be uncovered, connected to prior knowledge and then utilised for a purpose.

5.3.3. Converting Theory into Practice

To work out what is involved in teaching students to think when they conduct practical work, it is a worthwhile exercise to define what is meant by thinking. Dewey defines thinking as "…that operation in which present facts suggest other facts (or truths) in such a way as to induce belief in the latter upon the ground or warrant of the former" (1910/2012, p.8-9). That is, using evidence to apply knowledge. Reflective thinking occurs as a conscious and voluntary effort to establish belief based on solid evidence which involves what Dewey terms an "interruption" in the flow of thought that needs to be accounted for and, an investigation into acquiring further facts that either corroborate or negate the suggested belief. This interruption creates a "forked-road" situation that leads to genuine thinking since a person has to pause, survey the situation and the facts that present themselves and examine how the facts stand related to one another, before a solution can be achieved. The forked-road has to be first underpinned by similar prior experiences in order for students to make informed decisions based on fact that can be used to form new connections otherwise "confusion remains mere confusion" (Dewey, 1910/2012, p.12).

This section outlines the changed role of the teacher in the enquiry classroom, followed by a description of the complete act of thinking that is required for enquiry learning.

5.3.3.1 The Role of the Teacher

> *"Were all instructors to realise that the quality of mental process, not the production of correct answers, is the measure of educative growth something hardly less than a revolution in teaching would be worked."*
>
> (Dewey, 1916/2011, p.98)

Teaching through enquiry changes the role of the teacher from one who shares facts to be learned and recited to one who teaches students how to think intelligently as part of a community of scholars. It is the teacher's responsibility to see that the student is able to take advantage of a learning occasion by exercising his/her intelligence. The teacher needs an awareness of the capacities, needs and past experiences of students and the ability to make suggestions as starting points for plans that all students can become engaged in. In this way, the teacher fosters a cooperative enterprise in the classroom through social intelligence, similar to how scientific knowledge is generated in the world of research. Learning is social, science should be taught from the standpoint of the relation it bears to the life of society as part of a system of needs and aims of the student, which are also social (Dewey, 1915/2013). The conceptual and social dimensions are rarely taken into account by teachers even though academic literature discusses both of these aspects extensively (Erduran and Dagher, 2014; Osborne, 2011 & 2015; Stroupe, 2015). In teaching through the science practices, students work as a community of learners since they collate observations, data and analyses in order to negotiate conclusions that either reinforce or negate the principle under study.

The practical problem for the teacher is “to preserve a balance between so little showing and telling as to fail to stimulate reflection and so much as to choke thought” (Dewey, 1910/2012). The teacher needs to put thought into the selection of subject matter for study and must also be able to improvise since instances that cannot be foreseen will arise when there is intellectual freedom (Dewey, 1938/2015). Dewey emphasises the importance of an experiential continuum for students, where each experience takes place between an individual and his environment and what a person learns in one situation becomes an instrument of understanding and dealing effectively with the situations that follow. Following Hodson, we cannot expect students to enquire into something they have no experience of, otherwise they learn nothing -“You cannot discover something that you are conceptually unprepared for. You don’t know where to look, how to look, or how to recognise it when you have found it” (1996, p120).

An experience is only valuable when it is connected to past and future experiences; it is the teacher’s role to scaffold instruction to ensure this connection (Pardo and Parker, 2010). The students’ own personal experience has to be taken into account by the teacher and utilised in the practical lesson, since “there is a tendency to connect material of the schoolroom with material of prior school lessons, instead of linking it to what the pupil has acquired in his out-of-school experience” (Dewey, 1910/2012, p.199) which has led to detached and independent systems of knowledge and ordinary everyday experience instead of one system that enlarges and refines both interdependently.

The teacher has a twofold responsibility then, with regard to how students learn through enquiry in the classroom. First, they have to present the students with a problem that grows out of the conditions of the experience being had in the present and it must be in the range and capacity of the student. Secondly, the teacher must be able to ensure that the problem arouses a quest for information in the learner that leads to the production of new ideas. The new ideas then become assimilated into what the student can consider knowledge and becomes the ground for further experiences in which new problems arise. Dewey calls this a "spiral process" because it can continue indefinitely; "foreign subject-matter transformed through thinking into a familiar possession becomes a resource for judging and assimilating additional foreign subject-matter" (1925/2013, p.223).

Vygotsky theorised that "a child's development proceeds in a spiral, passing though the same point at each new revolution while advancing to a higher level" (1978, p.56). He coined the term "Zone of Proximal Development" (ZPD) to explain that in order for a child to solve an unfamiliar problem they may need guidance from a knowledgeable other, such as a teacher, but once they have mastered the solution, they can then solve other similar problems unaided as they move into the next spiral of learning and growth. The teacher-directed pedagogy is what underpins Vygotsky's ZPD and expands the spiral of learning in a cooperative and social environment (Watkins, 2006).

The role of the teacher is transformed when the pedagogy of interruption is considered as a part of enquiry. This form of teaching is at the forefront of revolutionising how we teach through enquiry by creating situations that require a body-mind rather than a body separated from a mind (Biesta, 2015). Interruption in this sense allows the body/mind problem to fade into the background and replaces it with a focus on consciousness. Dewey (1925/1958) distinguishes between the mind, which is a whole system of meanings that are constantly in the background and foreground of our thoughts, "a constant luminosity" (p.303), and consciousness, which is a perception of meanings, the perception of actual events *in* their meanings, the *having* of ideas. Consciousness is "focal and transitive…… a series of heres and nows……a series of flashes of varying intensities. Consciousness is …..the occasional interception of messages transmitted" (ibid, p.303).

Consciousness occurs as there is a need and demand for filling out what is indeterminate. When we are conscious, we are fully in the present, paying attention to the task at hand, focused and intent. What is familiar to us is often not in our consciousness unless it is presented in an unfamiliar setting where a new adjustment is required. We become engaged in what is happening because we have to re-direct, re-organise and re-adapt. The possibility of re-engaging the mind with the body interdependently in practical activities now becomes real. Through the use of interruption, or the forked-road situation, teachers call attention to students to "stop and think", causing temporary confusion so that the student has to recall previous situations, take opportunities to observe events, redirect his/her attention and anticipate new situations in which a change in meanings and perceptions can emerge.

In using the mind consciously this way, action is moderated, it no longer occurs as an isolated event that has no meaning but instead, action and thought occur dynamically. "One acts not just to act, nor rashly, nor automatically, but with the consciousness of purpose and for the sake of learning" (ibid., p.315).

When students do perceive a meaning, it can then be used to implicate other unperceived consequences in addition to the perception itself.

> "That a perception is truly cognitive means that its active use or treatment is followed by consequences which fit appropriately into the other consequences which follow independently of its being perceived"
>
> (Dewey, 1925/1958, p.322)

Relating back to Dewey's island analogy, thinking involves reaching the absent from the present:

> "The exercise of thought is, in the literal sense of that word, inference; by it one thing carries over to the idea of, and belief in, another thing. It involves a jump, a leap, a going beyond what is surely known to something else accepted on its warrant"
>
> (Dewey, 1910/2012, p.26)

This leap, because it is into the unknown, emphasises the importance of guidance (from the teacher) in the right direction. The teacher should be cognisant of the quality of thinking that is asked of the students particularly with regard to the level of thinking that his/her questioning exacts. Asking questions at the level of recall, does not promote conscious thought but if questions are asked at a higher level where students' thinking is interrupted, then conscious thought and action follows (Bloom, 1956). Since physically doing science does not necessarily mean that students understand science, it is the teacher's responsibility to ensure that students are encouraged and scaffolded to follow up and link together specific suggestions that specific observations arouse (Wood, Bruner and Ross, 1976).

Dewey sees that the way to do this is through the scientific method of enquiry, but the recent move towards science practices is more suitable to the modern biology classroom (NRC, 2012). To move beyond recipe teaching, students require a "variety and change of ideas combined into a single steady trend moving toward a unified conclusion" (Dewey, 1910/2012, p.40).

The teacher provides an environment for learning so that intellectual development grows with each investigation the student undertakes, and the student learns to think to "accomplish something beyond thinking", to make the leap, to use inference to weave an ordered system of knowledge that resides in the body-mind. It is important to remember the difference between the teacher's thought and the students' thought; the teacher is one who already understands the subject matter and can describe a uniform linear course from problem to solution. The student is one who is learning and may find their path from problem to solution is more indirect since they cannot see the problem in the same way the teacher sees it. This means that not only does the teacher have to prepare for teaching the subject matter but also for how they are going to nurture intellectual independence in their students. Viewing thinking as an integral part of any activity the student undertakes, that facilitates movement through a spiral of development, where each successive stage prepares thoroughly the way for the next stage, while resisting the temptation to impose external arbitrary tasks on students, will lead towards intellectual independence in practical lessons (Dewey, 1938/2015). Letting students grapple with ideas is important because it leads to reflective thinking which "involves willingness to endure a condition of mental unrest and disturbance……..to maintain a state of doubt and to carry on systematic and protracted inquiry" (Dewey,1925/1958, p.13)

5.3.3.2 The Complete Act of Thinking

According to Dewey a complete act of thinking is a double movement between induction and deduction. Teaching through scientific enquiry fosters this double movement in thinking.

Induction is the movement from partial or confused data to a suggested comprehensive entire situation, a whole meaning (Dewey, 1910/2012). Deductive thinking is a movement from a whole meaning or hypothesis back to the particular facts. If inductive discovery is uncovering a principle, deductive proof is the development, application or testing of that principle in a new situation (ibid.,1910/2012). A complete act of thinking is a double movement from observation of partial data towards a coherent meaning via induction and from the meaning itself towards further observations via deduction (See Figure 5.1).

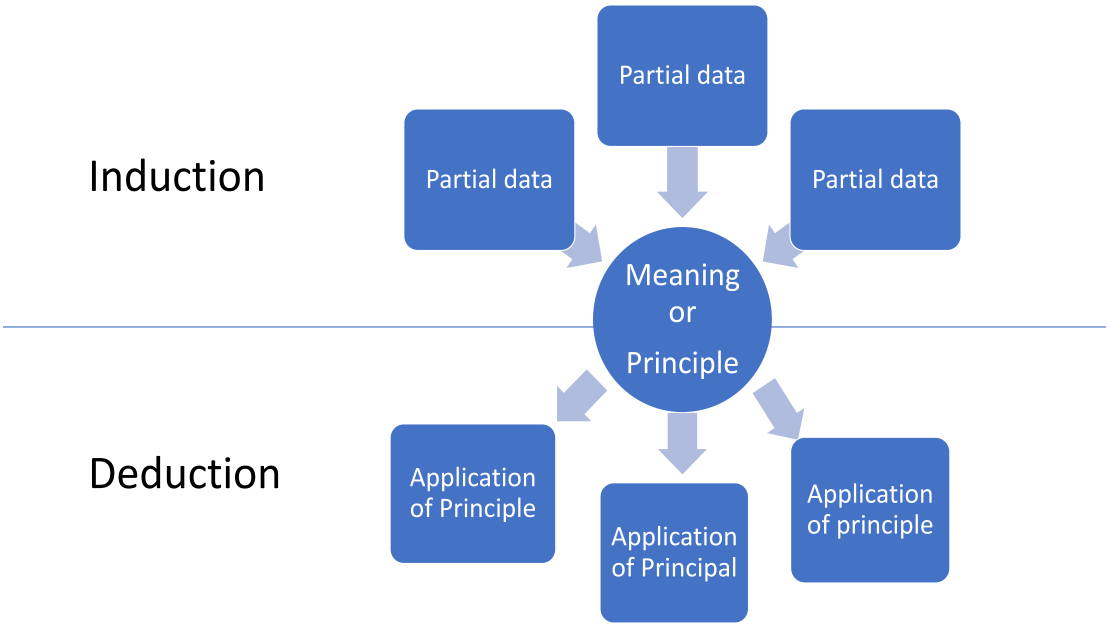

Figure 5.1. The complete act of thinking

Regarding practical work, it is easier to think deductively if the general principle that is being applied to the experiment is understood. Recipe style experiments cannot foster deduction in this sense, since they are concerned with discovering something already known; there is no inclusion of the body-mind in reaching for knowledge that is unknown, therefore there is no need to make the leap from what is observable to what underpins the observations (from the partial data to the whole meaning). Learning through enquiry on the other hand means analysing observations and data from experiments to infer a general principle or meaning (induction) and then using that principle to locate and define the nature of new and related problems relating to the principle (deduction). The answers to these new problems then become the inductive starting point for further enquiry activities, which links learning cumulatively for students.

Elaborating on a principle is attainable if the student asks a deductive question that is likely to suggest its own solution, which can only be possible if the student has first understood inductively the principle under study. Asking a question and locating the problem require the principle learned to be brought into fullness of meaning by applying it intellectually to new and unfamiliar situations.

The current situation with practical work in upper secondary biology is based solely (and very loosely) on inductive learning. Deduction is ignored in favour of following a recipe to attain a pre-determined result. Dewey describes it perfectly,

> "the pupil is encouraged to form, on the basis of the particular facts, a general notion, a conception of how they stand related; but no pains are taken to make the student follow up the notion, to elaborate it and see just what its bearings are upon the case in hand and upon similar cases" (1910/2012, p.97).

Students miss the opportunity to explore what a principle means by thinking through and reasoning out what may happen when an experiment is applied to an unknown situation.

Induction in the absence of reasoning does not direct or train intelligent thinking, instead it leaves the student staring at island peaks, with no concept of what lies beneath the surface nor of what connects the peaks to each other.

5.4 A Model for the Complete Act of Thinking

Scientific induction is defined by Dewey as "all the processes by which the observing and amassing of data are regulated with a view to facilitating the formulation of explanatory conceptions and theories" (1910/2012, p.86).

It is incumbent on the students to selectively determine the facts that allow them to *infer* a hypothesis. In order to infer a meaning from initial observations, the students are required to conduct a diagnostic experiment to determine the nature of the problem before proceeding at attempts at its application. There is an overwhelming body of research attesting to the dearth of scientific skills used when students carry out practical activities, hence, the development of an initial diagnostic experiment to ensure that students are equipped with the meanings and skills they will need to follow their enquiry through to new knowledge (Abrahams et. al., 2013; Coil et. al., 2010; D'Costa and Schleuter, 2013; Grunwald & Hartman, 2010, NRC, 2012).

Experiment design and implementation that targets all of the aims for practical work set out in the syllabus (GOI, 2003, p.3) requires a pedagogical shift towards teaching through enquiry, so that meanings and principles can be inductively learned through practical activities. The diagnostic experiment, then, is an inductive experiment that is used as a vehicle through which the student can uncover the underlying principle which is then used deductively to apply the principle to new ideas.

The aim of the diagnostic experiment here is not to produce a phenomenon but to use the phenomenon produced to develop a working hypothesis in order to apply new knowledge to new situations. If scientific enquiry is employed in a pedagogically intelligent manner, the intentions for practical work as outlined in the laboratory handbook can be fully implemented leading to a better understanding of the principles underlying practical work. The student must use their observations, data and analysis of the diagnostic experiment to make the leap from what is present to what is absent, they must *infer* the connection between the practice and the theory. The student begins to move from induction to deduction by finding a way to apply the experimental technique to a new situation. The student develops a working hypothesis by asking a question that can be teased out using a second experiment – the applied experiment.

It is important to note that not all hypotheses need to be the same – in fact, to promote reflective thinking, rival conjectures are to be encouraged at this point since investigating a principle from different angles can add robustness to any data collected if the data can be related back to the underlying principle. The applied experiment is utilised as a tool to apply the ideas behind the hypothesis and generate new data for observation and incorporation into the general principle being learned. Deduction here involves *reasoning;* the development of the implications of the hypothesis confirmed by experiment.

When facts are observed that agree in detail without exception, we can be justified in accepting the deduction as a valid conclusion, hence the importance of including a variety of applications of working hypotheses when conducting practical work. The philosophy for teaching practical work developed above is translated into a concrete Framework for Teaching Enquiry Activities (FTEA) which aligns with an aim of DBR, that of bridging the theory / practice divide (see Figure 5.2). The development of this educational innovation for improving practical lessons is undergirded by the complete act of thinking.

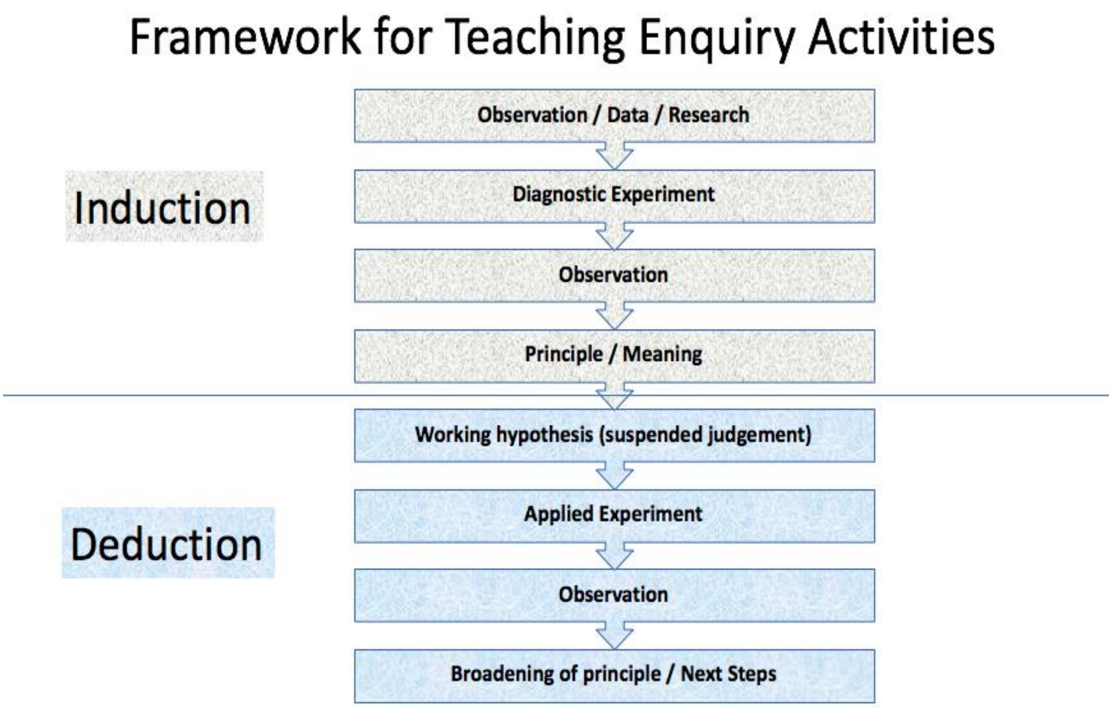

Figure 5.2: Framework for conducting practical work through scientific enquiry.

5.4.1 Leaf Yeast: Reimagined using the FTEA

Below is an example of how the FTEA is used to re-design a practical lesson through scientific enquiry (Figure 5.3). The Leaf Yeast FTEA that results, incorporates induction and deduction into a complete act of thinking. Teachers can think about how their students will develop a principle experimentally and use the principle to search for more information experimentally in order to add robustness to the principle that they are learning. In this way they do more than merely growing leaf yeast, they actually *investigate* the growth of leaf yeast as per the title of the experiment in the syllabus. The FTEA is a tool for teachers to plan for enquiry-oriented lessons.

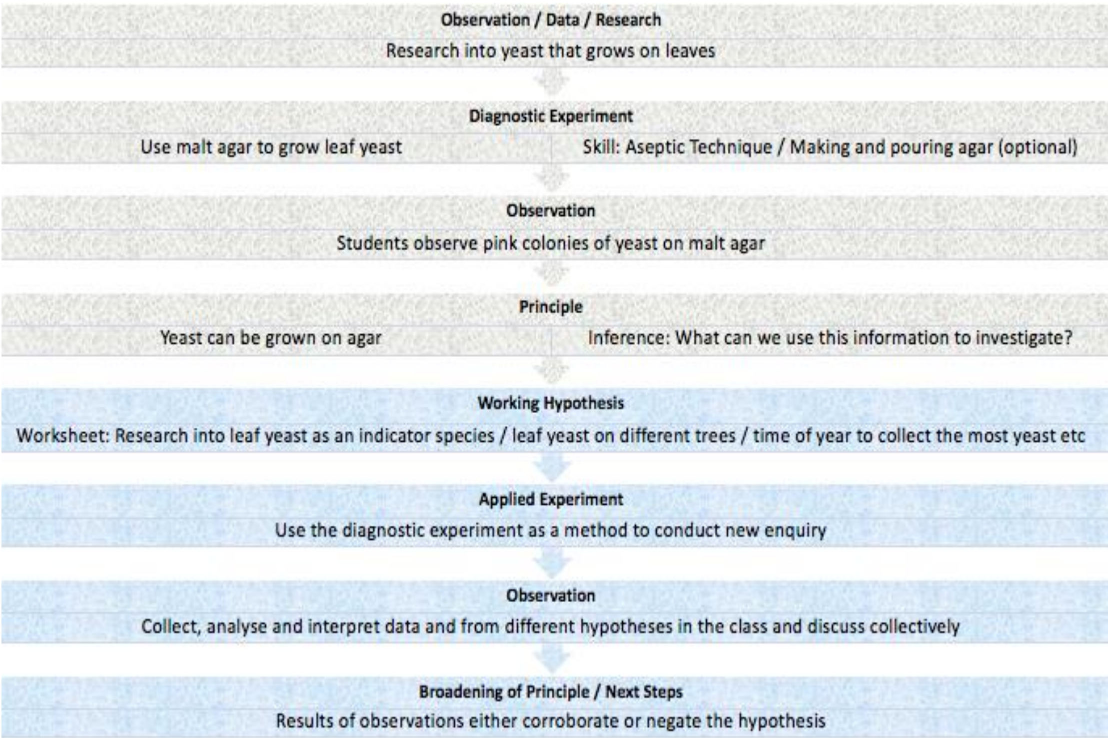

Figure 5.3: A worked example of the Leaf Yeast FTEA.

The design of the experiment itself has not changed, rather, the theoretical lens through which it is understood has shifted the focus away from the dualistic hand/mind dichotomy and towards the complete act of inductive-deductive thinking.

A redesigned lesson plan is presented below, which expands the FTEA into an enquiry-based lesson (Table 5.1). The left-hand margin in the expanded framework indicates where the teacher plans for either inductive or deductive *thinking*, which replaces hands-on or minds-on *activities*. Moving from recipe teaching to enquiry teaching means teachers must develop lessons for focused thinking through action, lessons that centre on consciousness as described above, and in doing so, the separation of the hand from the mind dissipates. Action is moderated by thinking, always reaching for future consequences, neither based on absolute certainty nor absolute ignorance, but instead occupying the space between the two, anticipating the outcome of action using what is known to reach for what is unknown. In this space is where scientific enquiry resides (Dewey, 1916/2011). "The material of thinking is not thoughts, but actions, facts, events, and the relations of things"(p.87).

The purpose of the FTEA is to enable teachers to design practical lessons for thoughtful action, their own and that of their students, which cannot be done by imposing ideas and facts on students. An integral part of lesson design through this lens is the use of foresight by teachers which requires bringing their own mind to close quarters with the minds of the students in order to think through ideas that may occur to the students as they begin enquiring into the topic at hand and setting up conditions for them to carry out those enquiries (Dewey, 1916/2011). The exemplar lesson below is an example of a situation designed through foresight. Through a re-imagining of the Leaf Yeast experiment using foresight, the student role is transformed from that of spectator who "is indifferent to what is going on; one result is just as good as another, since each is just something to look at" to participant, who "is bound up with what is going on; its outcome makes a difference to him" (ibid., 1916/2011, p.70).

In this way, the teacher can recognise that not all minds work in the same way just because they have the same teacher and the same textbook. It can be seen in the expanded lesson plan that a concerted effort has been made to find out what resources and conditions are available, and to scaffold the lesson for difficulties and obstacles that may impede genuine enquiry. Grounding the framework in foresight, it begins with the procedural and informational context, followed by preparation for the experiment, in order to facilitate a working through of what resources and conditions should be set up to promote thoughtful action on the part of the students. The students work in groups of two throughout, contributing all of their observations and data to the community of scholars in the room.

The laboratory skill attainment is included in the diagnostic experiment for two reasons

1. During the scoping stages it was observed that students were using laboratory equipment incorrectly and imprecisely.
2. It reduces the cognitive load on students if they have the opportunity to become familiar with laboratory skills and techniques in advance of the applied experiment (Sweller, 2011).

The inductive experiment is a means of establishing and solidifying prior knowledge for the students and guiding them towards the meaning of the underlying scientific concept. Placing the teaching of the laboratory skill under the remit of the inductive experiment was conceived as a response to the observation that what we teach the learner cannot be the same as the "formulated, the crystallised, and the systematised subject matter of the adult" (Dewey, 1916/2011, p.102)

We cannot assume experience with equipment and materials on the part of students. Knowing the use to which materials and equipment can be put is a precipitate for using them with a purpose, consciously and with foresight. As a result students can utilise thinking through action, rather than relying on second-hand "knowledge" when the time comes. The skill is taught during the inductive experiment as a pre-cursory scaffold, leading to the meaning underlying the experiment.

In addition to teaching a skill, there is a worksheet supplied which enables students in groups to tease out logically, the conditions for the experiment (Appendix 4.1a). The worksheet assists in solving a practical problem for the teacher, i.e., "to preserve a balance between so little showing and telling as to fail to stimulate reflection and so much as to choke thought" (Dewey, 1910/2012, p.208). The provision of choices in the worksheet creates "forked-road" situations for the students that simultaneously allows them to take risks and make mistakes, focusing on the process of practical work rather than the product, thereby creating the space for students to make the conscious leap from what is surely known to what is yet to be known.

In the case of leaf yeast, the leap is carefully structured by providing a reading that connects the student experience in the laboratory with their experience in everyday life (Appendix 4.1b). According to Dewey: "It is a sound educational principle that students should be introduced to scientific subject matter and be initiated into its facts and laws through acquaintance with everyday social applications" (1910/2012, p.80). When viewed as a social enterprise, the role of the teacher changes from that of external dictator to leader of group activities. Within the reading, students can connect prior everyday knowledge with present laboratory experience leading to future enquiry. Each pair of students is encouraged to think of a question that they ask about leaf yeast, to develop a hypothesis and to then deductively conduct an experiment using the technique they have learned to either confirm or refute the hypothesis. Not all students will ask the same question, and this is where the teacher's foresight comes into play. For this experiment, leaves were collected each month for six months (question: do younger leaves have less leaf yeast?), leaves were collected from different trees (question: do other trees have leaf yeast?) and leaves were collected from urban and rural areas (question: do leaves in urban areas have less leaf yeast?).

It is essential that students conduct the data collection, interpretation and analysis in both the inductive and deductive experiments, since the complete act of thinking requires that the person who makes the suggestion for enquiry should also be responsible for reasoning out the data collected and its application to new situations. The scoping stages of this research revealed that scientific explanations are often reserved for the teacher, which has a "disintegrating intellectual influence" on the student because it dissolves the students' ability to make connections between ideas. In the scoping stages, teachers expressed a belief that enquiry teaching would disadvantage their students by not preparing them properly for the Leaving Certificate exam. Thus, the exam question section is included in the framework as a form of summative assessment for teachers.

Table 5.1: Leaf Yeast FTEA Lesson Plan

Title	**Investigate the growth of leaf yeast using agar plates and controls.**
Context ***Procedural***	 Investigation of the growth of leaf yeast using agar plates • Making malt agar plates (optional for students) • Using agar to grow leaf yeast
Informational	Students need an understanding of

	• leaf yeast and the conditions under which it grows • leaf yeast as an indicator species • leaf yeast basidiospores Students are asked to develop a hypothesis and conduct an experiment based on what they learn in class
Preparation for Experiment	• Reading comprehension for students (inc. tips for teachers) • Making malt agar plates • Setting up equipment
Laboratory skill attainment	Making up malt agar plates Aseptic technique
Risk assessment	Risk assessment carried out by teacher beforehand and sheet filled in and signed
List of equipment needed	**<u>To make agar</u>** Malt agar powder. Bunsen burner Sterile agar plates. Large beaker Stirrer. Deionised water **<u>For the experiment</u>** Ash Leaves – from a variety of areas (wood, country, town) and a variety of months (June, July, August, September) Other leaves – sycamore, alder, oak, holly etc Sterile malt agar plates Vaseline Disinfectant / Alcohol. Cork borer / scalpel Chopping board. Bunsen burner Lighter Forceps Parafilm / tape Marker Paper towels
Procedural teaching methodology ***Induction:*** Diagnostic Experiment ***Deduction:*** Applied Experiment	Teacher: show students how to make up and/or pour agar plates (optional) Student: Learn aseptic technique using the method to investigate the growth of leaf yeast - Visual Sheet on desk Use the worksheet in conjunction with the procedure as an assessment for learning tool – allow students to make decisions about experiment during the experiment (the *forked-road)* Hand out reading comprehension Ask students to come up with a question that they would like to investigate based on the reading. Convert the question into a hypothesis Repeat the experiment so that the student can conduct

	their own investigation into leaf yeast growth.
Data collection ***Induction/Deduction***	Students will investigate their agar plates after a week to look for and count pink colonies of yeast
Data presentation and analysis ***Induction*** ***Deduction***	Depending on the questions asked by students First experiment: Students will examine plates and record the presence or absence of leaf yeast Second experiment: Students will count colonies and record the results in a graph/ bar chart and report on whether the result is in agreement with their original hypothesis.
Data presentation ***Induction/Deduction***	Students create a poster or a report under the following headings: Title, Hypothesis, Procedure, Data Collected, Data presentation Analysis of data, Conclusion
Real World Application/ Extension ***Deduction***	Students repeated the experiment to generate their own data around leaf yeast After doing the experiment and reading the extra material, students should understand the value of leaf yeasts as indicator species and that scientists use leaf yeasts and other indicator species to determine the health of the environment.
Evaluation	Teacher and students evaluate the lesson under the following headings: What worked? – what aspects of the lesson did students understand What needs improvement?- where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge What will I do differently next time? Teacher evaluates the learning by examining the student report or poster and grading the report as appropriate.
LC exam questions relating to Leaf Yeast	2018 Q9 2015 Q8 b 2012 Q8 2007 Q8 2005 Q9

5.5 Summary

The framework has been designed in line with Dewey's idea of education that:

> "experience as an active process occupies time and that its later period completes its earlier portion; it brings to light connections involved, but hitherto unperceived. The later outcome thus reveals the meaning of the earlier, while the experience as a whole establishes a bent or disposition toward the things possessing this meaning."
>
> (1916/2011, p.46)

Practical work is seen in light of the continuous re-organisation of experiences so that each experience builds on what is already known, integrates what is learned in the present and re-directs learning towards the future. The continuum of practical work links learning iteratively so that what is learned in one situation can be used to inform subsequent situations. Experiments are no longer isolated events, the connections between the island peaks are made explicitly available to the student for further use.

5.6 References

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Chapter 6

Third Design Cycle - Professional Development in a Community of Practice

6.1 Introduction

This chapter uses the lens of a community of practice to document a programme of professional development designed for teachers to learn to understand and use the Framework for Teaching Enquiry Activities (FTEA) as a tool for enquiry teaching. Evaluating previous design cycles through Shulman's concept of a signature pedagogy (2005), combined with Wenger's characteristics of a Community of Practice (1998), established design principles for a programme of professional development in the opening section of the Chapter. These principles were then enacted in two different professional development settings; Walkthrough Workshop (WW) and Micro-evaluation, which are described in the remainder of the chapter.

The research question for this design cycle is:

> What are the characteristics of a programme of professional development that would enable teachers to understand, design and teach enquiry-based lessons, and how can they be enacted?

6.2 Signature Pedagogies

Shulman (2005) describes signature pedagogies as "the types of teaching that organize the fundamental ways in which future practitioners are educated for their new professions" (p.52). Shulman refers to the pervasiveness of signature pedagogies in a professional field and to how they determine "what counts as knowledge in a field and how things come to be known" (ibid., p.54). There are three dimensions of a signature pedagogy that identify fundamental ways in which professional work is instilled; how members of the profession think (surface or intellectual structure), perform (deep or technical structure) and act with integrity (implicit or moral structure).

The surface structure describes the pedagogy, "the concrete operational acts of teaching and learning". It represents the intellectual dimension inherent in professional ways of doing things. The deep structure of a pedagogy describes what the pedagogy does in terms of learning, it is "a set of assumptions about how best to impart …. knowledge", or in other words, the technical dimension. The implicit structure of a pedagogy describes "a moral dimension that comprises a set of beliefs about professional attitudes, values and dispositions" – in short, know-how (ibid., 2005). Table 6.1 uses these categories to compare the signature pedagogies of recipe-style teaching with the enquiry-based teaching.

Table 6.1: A comparison of the signature pedagogies of recipe-style and enquiry-oriented teaching.

Dimension	Recipe-based teaching	Enquiry-based teaching
Surface / intellectual structure: pedagogy	Preparation for following a set of instructions	Preparation for the complete act of thinking
Deep / technical structure: assumptions of how knowledge is imparted	Following instructions, manipulating materials and production of a phenomenon	Learning a laboratory technique, asking questions, forming hypothesis, using a laboratory technique to see if the production of a phenomenon answers the question
Implicit / moral structure: professional attitudes and values	Transmission of knowledge to ensure certainty. Knowledge as an end-in-itself	Construction of knowledge through social interaction. Uncertainty is integral. Knowledge as an end-in-view

The signature pedagogy of recipe-style teaching is based on the view that knowledge is fixed and can be transmitted from the teacher to the student (Dewey, 1938/1986). Therefore the teacher is more concerned that the students do as they are instructed with experimental materials than with the ideas. Shulman (2005) calls this a, “compromised pedagogy”, because the intellectual dimension inherent in it is unduly subordinated to the technical and moral dimension. Enquiry-based teaching represents a more “responsible pedagogy” because all three dimensions (intellectual, technical and moral) are given an appropriate balance of attention. Knowledge is not certain, but it is scaffolded by teachers to develop understanding in a certain direction. This pedagogy of uncertainty, renders classroom settings as “unpredictable and surprising, raising the stakes for both students and instructors” (ibid., p.57). Reflecting on these differences, it is no surprise that teachers struggled to engage with the FTEA, because it represented a move towards a pedagogy with a different (and new) epistemology, outside of their realm of experience.

Parker and colleagues (2016) suggest one way to bring about changes in signature pedagogies is through the use of communities of practice (COP) for professional development. COPs come with their own signature pedagogy which is comprised of the same three dimensions as above.

1. The surface/intellectual structure is collaboration around a shared concern to generate knowledge that embodies a common search for meaning in the work lives of teachers (Cochran-Smyth and Lytle, 1999).

2. The deep/ technical dimension provides spaces for the collaborative examination and transformation of learning (Lieberman, 1992), where teachers can generate new visions of learning collaboratively (Cochran-Smyth and Lytle, 1999).

3. At the implicit/moral level COPs provide a safe environment in which teachers can “address knowledge deficits without feeling deficient” (Parker et al., 2016, p.146). Most importantly, they also challenge teachers to question routinised and long-held beliefs about teaching and learning through the exploration of new subject matter content and new pedagogies (Armour and Makopoulou,2012)

Changing the signature pedagogy of practical teaching was brought about using the signature pedagogy of a COP (Figure 6.1)

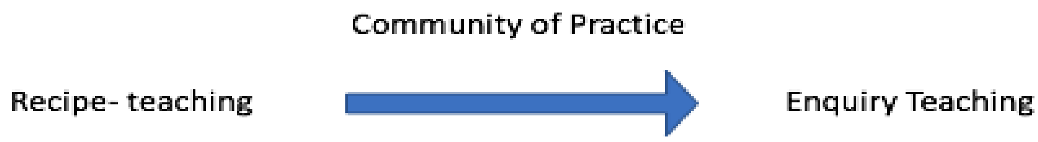


Figure 6.1: Using the signature pedagogy of a COP to change the signature pedagogy of recipe teaching to enquiry teaching

Using Wenger's (1998) Community of Practice in the next section, a reflection on why the first foray into using the original Framework for teaching Practical Activities (FTPA) was unsuccessful in establishing any meaningful change in practical teaching at second and third level is presented, and is then used to develop design principles for a programme of professional development.

6.3 Community of Practice

A community of practice is grounded in social learning theory and can be considered as:

> "collective learning that results in practices that reflect the pursuit of our enterprises and the attendant social relations. These practices are the property of a kind of community created over time by the sustained pursuit of a shared enterprise"
>
> (Wenger, 1998, p.45)

One of the tenets that underpins this theory is the concept that learning produces meaning, (Wenger, 1998). Meaning is a product of our interaction with the social environment in which we live. According to Dewey, society has the ability to influence our thoughts and behaviour, to influence the way we think and the practices we develop as a result (Dewey, 1916/2011). The profession in which biology teachers work is underpinned by a community of professionals whose signature pedagogy (recipe-teaching) is recognised as competence. However, a difficulty arises when what is considered as competence among biology teachers, does not translate into competence in understanding the purpose of those practical activities among the student population that they teach (Chapter 3).

Wenger’s (1998) concepts of meaning, community and learning, which are integral to professional development in a COP, are used to evaluate the manner in which the FTPA was shared with teachers. This reflection is then used to inform design principles for a programme of professional development to endeavour to effect change in the signature pedagogy of practical teaching.

6.3.1 Meaning

According to Wenger, meaning is negotiated in the interaction between two processes; participation and reification, which form an interacting duality where they are distinct but complementary. Participation refers to “a process of taking part and also to the relations with others that reflect this process” (1998, p.55). It suggests action and connection with other people, and within a COP it becomes a part of a person’s identity because it goes beyond direct engagement in specific activities with specific people, and becomes a form of mutual recognition. Reification refers to concrete material objects that create “points of focus around which negotiation of meaning becomes organised” (ibid,p.58). In this case, the original FTPA provided the point of focus around which the negotiation of meaning was created. To become meaningful, the FTPA should have been re-appropriated into teachers own lessons, but this was not the case.

Participation and reification exist as a dualism, to enable one implies enabling the other. “When too much reliance is placed on one at the expense of the other, the continuity of meaning is likely to become problematic in practice” (ibid., p.65). In creating the FTPA, there was an increase in reification (through the design of the FTPA) but there was no corresponding increase in participation in terms of a shared experience and interactive negotiation around the use of the FTPA. For teachers to trial an innovation with a completely different signature pedagogy, a change in their beliefs and values, a new epistemology about practical work would have been necessary which required professional development on a much deeper level than a simple focus group (Loughran, 2014; Wallace and Priestley, 2017).

Pete captured the sense of inertia he had in using the FTPA in his classroom following the focus group meeting:

> In my own head, I was kind of unsure of where to really start I suppose. I knew the concepts that you had put on paper were fantastic, but for myself to go about starting it, that's where I kind of sat back and struggled
> *Pete*

This led to the inclusion of Gregoire's (2003) concept of "mastery experiences" for teachers, where teachers get time to master new skills and receive feedback on new instructional strategies, if they are to implement them. This led to the first design principle for a professional development programme, which supports increasing participation among research participants.

Design Principle: Address the imbalance between participation and reification by increasing participation through the provision of mastery experiences for teachers.

6.3.2 Community

There are three dimensions to a community of practice that can be used to assess the coherence of that community. Without the first dimension, mutual engagement, practice cannot exist. "Practice resides in a community of people and the relations of mutual engagement by which they can do whatever they do" (Wenger, 1998, p.73). Ultimately this form of engagement involves including members of the community in what matters, which is what defines belonging to that community. Mutual engagement relies on the competence of all members of the community, yet this was diminished by excluding opportunities for teachers to participate in trialling the FTPA. The Research Practitioner (RP) engaged with the FTPA, but the lesson design that resulted did not quite align with its enquiry-stance. Both the RP and the Teacher Practitioner (TP) needed time to establish jointly how the FTPA could be used to design lessons. This corelates to the second dimension of a COP, that it should be a joint enterprise (ibid.). This does not imply that there should be a uniform response to any practice, but rather that the response is open to negotiation; living with differences of opinion is a part of the process. It is a form of interdependence, which brings about a growth in ability of the participants (Dewey, 1916/2011).

The manner in which the FTPA was presented to teachers, implied independence (rather than interdependence), which Dewey calls "an unnamed form of insanity" because it created the delusion of being able to act alone and "cuts off the relation of the self to others" (ibid., p.27). The expectation that an innovation that was designed independently of its intended users, could be reified in the practical classroom by teachers acting independently of each other, proved ineffective. Teachers needed interdependent opportunities to understand how the framework could be applied in classrooms.

Finally, a COP requires a shared repertoire of both reificative and participative aspects – this means there should be a repertoire of shared FTEAs and opportunities for shared participation in those activities. Wenger cautions that because COPs are indigenous productions, they can be a site for creative enterprises but also a site for inbred failures. "They are a force to be reckoned with, for better or for worse" (Wenger, 1998, p.85).

Therefore, in designing a programme for professional development, it was important to consider how to scaffold a shared repertoire that accounted for successes *and* failures, and which had an epistemologically different stance to that which teachers are familiar with. The transformation of the FTPA into the FTEA (Chapter 5), initiated the process of reifying a new epistemology, the next step was to include teachers as participants in a shared vision for enquiry-teaching.

Design principle: Develop a COP that shares knowledge and expertise and fosters mutual engagement through a negotiated form of participation and a shared repertoire of artefacts and expertise.

6.3.3 Learning

COPs are grounded in shared histories of learning, where there is an "intertwining" over time of participation and reification (Wenger, 1998). A COP forms an identity through a shared history in which transformation of oneself is possible with the support of a community. Wenger (ibid.) allows that newcomers to a community can experience difficulties establishing an identity (and thus in learning) within the community and suggests that participation can be scaffolded in stages to gradually bring them from the periphery of the group, towards full participation at the centre. He describes this "legitimate peripheral participation" as "modified forms of participation that are structured to open the practice to new members" (ibid., p.100). The term implies two concepts: peripherality and legitimacy. Peripherality provides new members to a COP with "an approximation of full participation that gives exposure to actual practice" (ibid., p.100). As a starting point, teachers needed risk-free, low accountability, high support opportunities to make sense of the FTEA in a laboratory environment, away from the demands of the classroom (Luehmann, 2007). Legitimacy means that the teachers involved are treated as potential members, which is not difficult as all were qualified biology teachers. "Only with enough legitimacy can all their inevitable stumbling's and violations become opportunities for learning rather than cause for dismissal, neglect, or exclusion." (Wenger, 1998, P.101). Changing the practice of teaching cannot be a matter of handing down a ready-made solution to a problem and expecting it will be implemented as intended. Instead, it is a "shared history of learning that requires some catching up for joining" (ibid., p.102). This equates to developing learning situations in which research participants can move through increasingly challenging zones of proximal development (Vygotsky, 1978), from understanding, to using, and finally to creating their own FTEAs as part of a community.

Design Principle: Scaffold learning experiences for teachers that bring them from the periphery of the community into its centre, through shared histories of learning.

6.3.4 The Foundation of the COP

Figure 6.2 represents the COP before the professional development programme. The TP occupied the central position alone. The relationship with the RP was considered marginal because, there was no shared history of designing lessons for enquiry-teaching. ISTs and PSTs could not legitimately participate in the use of the FTPA to design lessons because their lack of enquiry-based experience kept them outside the boundary of understanding how it was intended as an enquiry-based framework (Wenger, 1998).

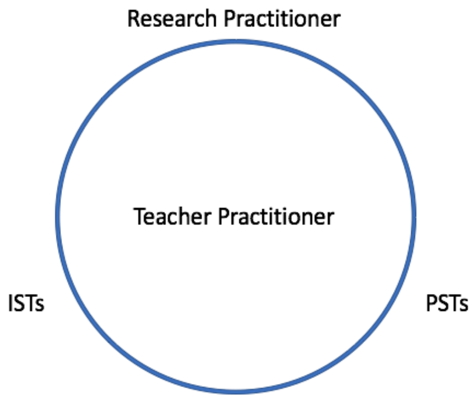


Figure 6.2: Application a COP lens to the participants in the first trial of the FTPA.

Central to the foundation of the enquiry COP was the working relationship between the TP and the RP, a professional scientist, who formed the initial Teacher Design Team (TDT) upon which the COP was built (Handelzalts et al, 2019).

The RP is a professional scientist, with expertise in biology, who also coordinates the biology module for pre-service teachers. As such she was perfectly positioned to understand the nature of enquiry at third level and the culture of recipe-teaching at second level. Wenger (1998) introduces the idea of a boundary as a line that separates a community from the rest of the world. The RP works within two communities, which both have clearly defined boundary lines that, generally, do not overlap. She teaches PSTs how to teach practical activities from the LC biology syllabus, and she is a research scientist.

Bringing the RP into the COP as a "knowledgeable other" was the first step towards the development of a programme for professional development (Vygotsky, 1978). Luft and Hewson (2014) report that scientists have mixed success in assisting teachers to develop their understanding of scientific enquiry in professional development settings. There is evidence from many of these studies that scientists struggle to communicate effectively about scientific enquiry to teachers and to translate practices in science into learning experiences for science teachers (Bell and Odum; 2012; Drayton and Falk, 2006; Hughes et al., 2012; Schuster and Carlsen, 2009). In her role teaching PSTs, the RP already had experience of communicating effectively with PSTs. Her other role as a professional scientist meant that she had content knowledge and laboratory experience beyond that of the TP, while the TP's experience as a science teacher and educational researcher meant she had pedagogical knowledge, knowledge of the second level biology classroom and an understanding of the FTEA (that she developed) beyond that of the RP. She also had experience of working with ISTs in a professional development capacity around embedding innovative pedagogy in the classroom. Between them they had the potential to develop unique pedagogical content knowledge around the use of the FTEA (Shulman, 1986).

Wenger (1998) talks about boundary objects as reified objects around which COPs can organise their interactions by connecting disjoined forms of participation. The FTEA served as a boundary object on three levels (Figure 6.3)

1. It enabled the RP to draw upon her experience of scientific enquiry and laboratory work as a professional researcher to connect with her practice as a teacher at third level
2. It formed the bridge between educational theory and second level practice for TP
3. It formed the basis of a shared practice between the TP and the RP, where they used FTEA to design enquiry-based practical activities that complemented their shared expertise

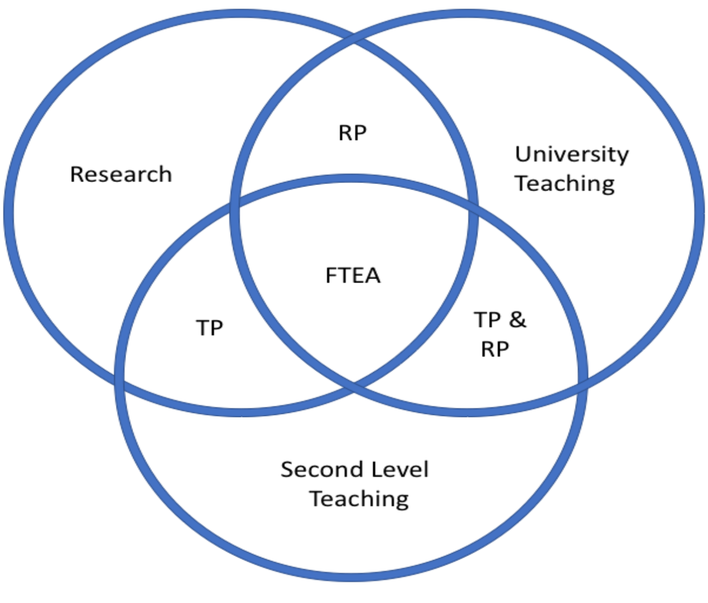


Figure 6.3: The FTEA as a boundary object that connects scientific and educational research with pedagogical practices at second and third level.

As the FTEA belonged to multiple practices (research, second level practical activities, third level teacher education), its meaning was obtained in the meeting of the perspectives of all three practices (ibid., 1998).

In the next section, the evolution of an enquiry-based COP is traced through two main strategies that are a part of the DBR methodology: Walkthrough Workshop (WW) and Micro-evaluation (Chapter 2). Figure 6.4 summarises the events of this design cycle. Both of these strategies were built around the FTEA as a boundary object and the TDT as a brokering partnership between second level teaching, research, and access to enquiry practices.

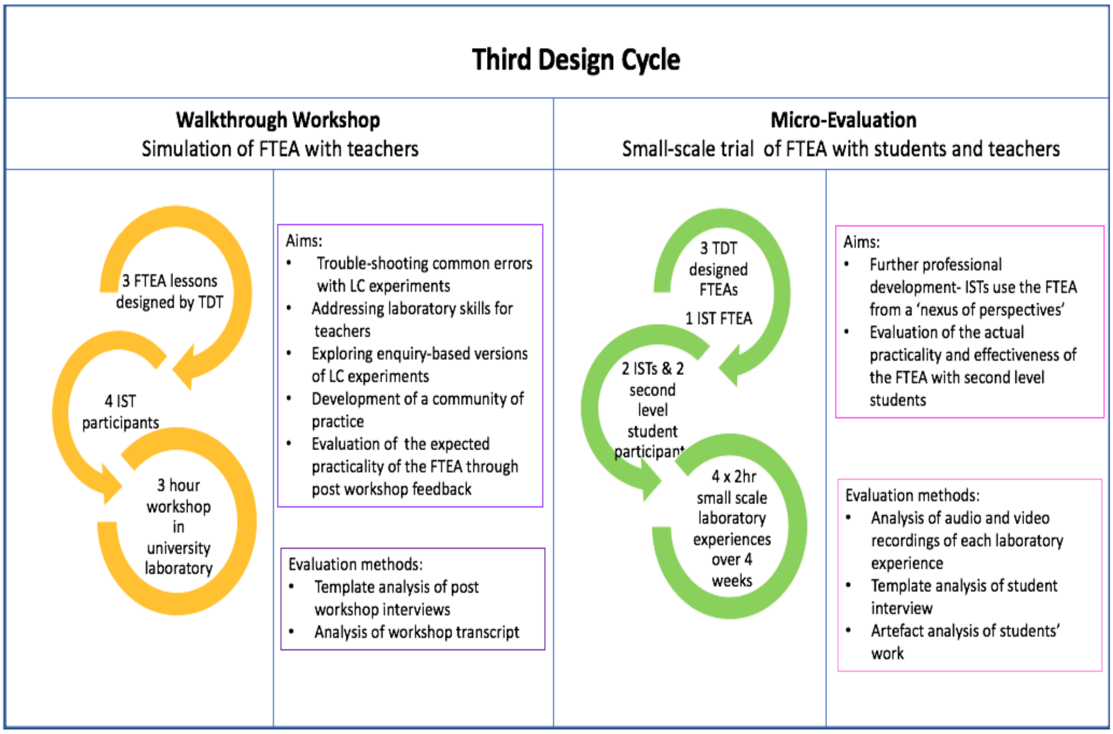


Figure 6.4: A summary of the events of the two stages of professional development in the third design cycle

6.4 The Walkthrough Workshop

Following Windshitl's (2003) argument that it is almost impossible to convey the complexities of enquiry-based science learning without direct experience, in February 2020, professional development in the form of a three-hour walkthrough workshop (WW) for ISTs was conducted, with the intention of providing mastery experiences through modelling of FTEA designed practical activities (Gregoire, 2003). Due to

Covid-19 restrictions, it involved a smaller than anticipated number of IST participants (Cora, Niamh, Pete and Rose), and took place in a university laboratory setting. The WW itself was evaluated from a coded analysis of the workshop audio recording, to determine how it contributed to the professional development of ISTs. Photographs taken on the day are used as artefacts to supplement the audio data. Initially a 'science teacher as learner approach' had been adopted here as it has proven success in effecting changes in teachers' practice (Loughran, 2014). Post-workshop interviews with each IST participant were conducted and analysed using TA (King, 2012).

To begin the process of creating a COP in which members could invest and eventually contribute towards, the focus of professional development was specific to the context of the teacher's own work, and appropriate to their stage as beginning enquiry teachers (El-Hani and Greca, 2013). Prior to attending, ISTs were asked to submit a list of experiments that they were preparing to teach in their schools. Three experiments, common to all teachers, were selected for the WW:

1. To investigate the growth of leaf yeasts using agar plates and controls (Leaf Yeast)
2. To investigate the effect of IAA growth regulator on plant tissue (IAA)
3. To use starch or skimmed milk plates to show digestive activity during germination (Digestive Activity)

Using the FTEA as the boundary object, the teacher design team (TDT), co-designed these as enquiry-based experiments in the month prior to the WW, by engaging and negotiating with each other to trial ideas in the laboratory, resulting in a shared history of learning about how to reify the FTEA for this purpose. Figure 6.5 illustrates how this work moved the RP from the boundary of the practice to its inside. FTEAs, with accompanying lesson plans and resources, for these experiments can be found in Appendix 6.1.

Figure 6.5: The initial enquiry-based COP showing the RP and the TP as members using the FTEA as a boundary object.

6.4.1 Aims of the WW

The four aims of the WW are addressed in turn here.

First Aim: To troubleshoot some of the issues associated with conducting these three LC biology experiments in schools

Data from the scoping stages suggested that one of the reasons why LC experiments often do not 'work' was because teachers did not have the content knowledge of the experimental set up required to ensure successful production of the phenomenon. Yoon et al. (2012) partially attributed difficulties science teachers experience in implementing lessons to a lack of content knowledge. It is suggested here that the converse may also be true- classroom practice (recipe teaching) affects teacher knowledge. Teachers are never required to develop their content knowledge because it is clearly defined for them in the syllabus and through the examination-based culture of the LC. Dewey terms this 'ready-made' knowledge as something which the user does not need to 'know', only to pass-on (Dewey, 1938/2015; 1925/1958). It limits the growth of teachers as curriculum developers because it does not account for the broader range of laboratory and thinking skills that enquiry teaching requires.

For example, the IAA experiment requires that students grow radish seeds in petri dishes in decreasing concentrations of IAA solution to examine the effect of those concentrations on growing tips. There was a reticence felt by teachers in conducting this experiment because it was perceived as too *"hard to set up".* Niamh admitted that she didn't know how to do this experiment before she attended the workshop and that none of the teachers in her school had endeavoured to teach it:

> I don't think we've done it in our school yet. The 6th year teachers are like, "hmmm we might just leave that one" [laughs]
> *WW Transcript*

The main difficulty with the preparation of this experiment was that the IAA solution was either prepared incorrectly or stored incorrectly. One teacher did not realise that the solution had to be made up fresh for every experiment and another two teachers were not aware that the chemical used to make this solution should be stored in a freezer at -20^{o}C:

> Rose: Our IAA, like, the last batch we've been using three years (laughs)
> TP: Oh really? And has it been working?
> Rose: [Shakes her head, no]
> *WW Transcript*

There was only one teacher in the group with a background in chemistry, so the meaning of terms such as 0.01%w/v and 1 p.p.m. were explicated for teachers, along with practice making a solution of IAA.

Data collection was also an issue in this experiment because sometimes the seeds did not germinate in the plates. The RP shared an alternative method of stacking the plates using class sets (rather than individual serial dilution sets), which achieves better germination rates for this experiment (Figure 6.6). Teachers can ask the students to collate measurements for all seedlings at each concentration of IAA (a known number of replicates) rather than just for the seedlings their own serial dilution of plates. In this way everyone in the class ends up with a complete data set even if some seeds do not germinate in some of the replicates, and the set up better illustrates the collaborative nature of scientific practices.

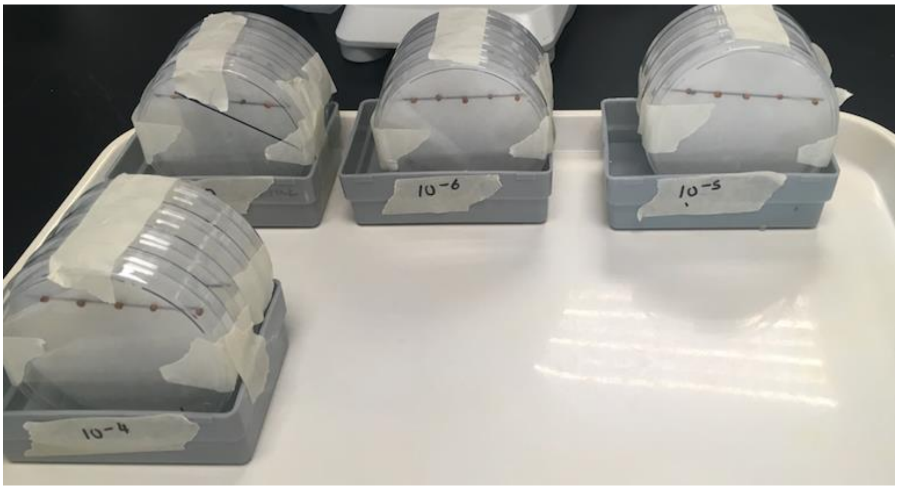


Figure 6.6: Radish seeds on plates containing different concentrations of IAA. Plates containing the same concentration of IAA are stacked together (four replicates) and placed vertically in troughs containing leftover IAA of the same concentration.

Teachers were impressed by this set up, which they spontaneously linked with the idea that it is the class data that is important not the data of individual groups:

> Rose: I love the idea of putting all the same powers together
> Cora: Yeah
> Rose: That was brilliant. I never thought of that. And I used to give them back their own set and they find it and they're like, "it didn't work" – you know, they've only looked at one set.
> TP: It doesn't matter whose set they look at
> Rose: Yeah, it's a class set
> RP: Yeah, it's an average. Some of them are going to be grown, some of them won't
> *WW Transcript*

The above exchange illustrated an important finding at this stage. Up to this point, student data had not been used in practical activities (Chapter 3). The realisation that a class set of data could be created and used to confirm a hypotheses was new to the teachers who attended the WW, yet it is a part of the everyday practice of the scientific community and it supports a sense of belonging to the field (Forbes and Skamp, 2013).

Second Aim: To highlight the laboratory skills needed by teachers to set up these LC biology experiments

Teachers reported a lack of experience preparing materials and solutions for senior cycle biology practical classes (three of the four who attended the workshop had no experience of preparing agar plates or of the aseptic technique that two of the WW experiments required). The WW offered initial practice in preparing laboratory materials (specialised agar, IAA solution) and in conducting laboratory techniques (serial dilution, aseptic technique). This kind of targeted support was "critical to move teachers past problematic areas" (Nelson, 2008, p.579). As peripheral members of the COP, teachers were negotiating a shared repertoire of laboratory skills as a scaffold to support them in developing a broader range of enquiry-based lessons.

Third aim: To introduce ISTs to enquiry-based lessons by modelling FTEA designed practical activities

While there was some enquiry during the diagnostic experiment, it was within the Leap and the applied experiment that enquiry came to the forefront. The redesigned Leaf Yeast FTEA provided an example of how "learning cannot be designed: it can only be designed *for*" (Wenger, 1998, p.229). Providing a reading comprehension (Appendix 6.1.2) and a variety of leaves (Figure 6.7) primed the Leap by facilitating teachers to ask their own questions.

Figure 6.7: Selection of leaves for the leaf yeast experiment

For example, Cora asked whether Leaf Yeast taken from different areas could tell anything about the air quality of those areas. She and Rose then conducted an experiment to find the answer to their question:

> The one thing that I found interesting here was, that jump – people think fungi are bad, so people think the presence of fungi is a bad thing, but yet in a high SO_2 area, you've low fungi. So that's something that I would jump out at…….. I think I'd like to find out the difference between a busy road and a country road.
> *WW Transcript*

By bringing teachers together in the WW, they were afforded the opportunity to engage in meaning-making through discussions with each other which led to a reconsideration of how they organise practical activities (Bruner, 1990). For example, they discussed how previously they would normally just do one control for the entire class (often because of limited resources), however Niamh changed her mind during the workshop because she understood that using a control should be a part of enquiry for all students:

> But I can see how, the fact that you asked them [students] how many they need [agar plates], they need to think about a control, whereas if I just give one control for the class, I'm giving them that information and they're not thinking about it. So maybe it would be a good idea just to sacrifice a couple [of plates]
> *WW Transcript*

Niamh's comments pointed to a need to provide adequate funding for practical activities in schools. Her reticence in allowing each student to use extra material as a control was directly linked to the lack of materials she had at her disposal in her school laboratory.

Rose believed the workshop was a valuable experience in terms of learning about enquiry *"to get people thinking".* She believed that the *"big experiments"* were what she was there to do, but specifically identified how the *"little things"* were what really made the difference to her on the day. When she talked about the little things she was referring to the pedagogical scaffolding of the Leap in each practical activity, which was grounded in a broader subject knowledge. To her, as a 'student' they were little things because they were perceived as *"simple and easy to do"* but to the lesson designers they were the 'big things' around which the FTEA revolved:

> I have done the experiments with students already but there were little things there on that day that I was like "oh, I never thought about that or I never did that". So, onion in the water - that's just so simple and so easy to do and I just thought that that's just such a good visual for people to be able to see and come up with their own conclusions on it ….. It was the little things that were said between the big experiments and between what we were there to do. Like the seeds under the microscope and you were able to see the cotyledon and I thought that was brilliant as well. There was things there that I had never done before with leaving certs, I had never done it with junior certs and I just thought they were brilliant. I suppose those little things are more of what I should be doing.
>
> *Rose - WW*

Teachers had been introduced to an alternative signature pedagogy, from which they could draw comparisons with recipe-teaching. A pedagogy can be considered ignorance or competence by varying the criteria that are used for judging it (Wenger, 1998). Recipe-based teaching formerly considered as knowledge, when seen through the lens of enquiry, started to look like ignorance to the teachers, because they could see it did not foster student thinking.

Fourth aim: To establish ISTs' membership of the enquiry-based COP

The WW provided the initiation into the enquiry COP by following common recommendations in the literature to situate and scaffold the learning of COPs in multiple sites (Akerson et al., 2009; Luehmann, 2007; Putnam and Borko, 2000). In this first site of learning, the university laboratory, the TDT opened the periphery of the COP and moved teachers from a position of marginality, to one of 'legitimate peripherality'. Wenger (1998) argues that this is the kind encounter at the boundary that newcomers to a practice need. The WW offered teachers casual but legitimate access to the practice of enquiry via a teacher-as-learner approach. An important characteristic of operating at the periphery of a COP is that it offers participants a way to cross boundaries; in this case from recipe-teaching to enquiry-teaching through the use of the FTEA as a boundary object. This "exposes our experience to different forms of engagement, different enterprises with different definitions of what matters, and different repertoires where even elements that have the same form belong to different histories" (Wenger, 1998, p.140).

The WW offered teachers tentative first steps towards working together to improve learning by refining their teaching (Lumpe, 2007). Teachers were able to negotiate the meaning of enquiry through participation in the WW and engagement with FTEA-designed lessons. In addition, teachers experienced some learning along the three dimensions of competence: mutual engagement, accountability to a joint enterprise and negotiability of the repertoire (Wenger, 1998).

For example, during the IAA experiment, the TDT's method of preventing seeds falling off the filter paper when the plates are stored vertically was found not to be fool proof. When all six participants collaborated to solve this problem, an improved method of keeping the seeds on the vertical plates was developed and trialled. This demonstrated mutual engagement and negotiability of the repertoire among the participants:

> Rose: -like I found the filter paper just kind of glues it to the outside-
> RP: Yeah, yeah, that's good
> Niamh: Yeah
> Rose: - and then you pad it up
> RP: How do you get them to stay on the line for you then?
> TP: Because if you put the filter paper on top and then you wet the filter paper –
> Rose: - and it kind of sticks it on
> Pete: And they stay on the line
> RP: Maybe if you had 2 filter papers you could line them up on one and then put the second one on top!
> Niamh: That's what I thought! Put it over them!
> RP: So try that
> *WW Transcript*

The WW provided supporting evidence to Park et al.'s, (2007) findings that teachers learn from each other when there is a COP aspect to their professional development. Rose shared how she makes gridded acetates for use in the IAA experiment on her printer at home, which can then be used to measure the length of roots and shoots. Cora revealed that she has difficulty getting a positive result from her Biuret reagent (the test for the presence of protein). She was given advice on the best foods to use for this experiment and it was suggested to her that the problem may lie with her reagent. The TP explained how she could make up her own Biuret reagent, to compare with the batch she had in her lab. This was clear evidence that an increase in participation in terms of time and space, accompanied by reification in terms of an enquiry-based framework, could lead to meaningful learning for teachers.

Pete commented on how professional collaboration can supplement gaps in individual teachers' knowledge. Niamh's comment indicated a move away from the pedagogy of knowledge transmission towards facilitation of the uncovering of knowledge for her students:

> We're all here to learn and I don't know everything. No one knows everything and that's kind of science really…….
> *Niamh - WW*

Within this collaborative atmosphere, all of the research participants identified the lack of collaboration in their professional lives as something that needs to change. When teachers were given space to engage in genuine collaboration, there was no longer the need to 'know' everything as a teacher. Just as knowledge ladled out ready-made does not foster deep engagement with the subject, pedagogical practice that is viewed as ready-made (as with the recipe method) also excludes deeper professional engagement with the subject (Dewey, 1986). When the view of practice was seen as a process of making, then space was created for, and value is attributed to, collaboration with practitioners. In selecting a context outside of the classroom, the WW provided space in which teachers could build trust, content knowledge and engage in a common goal (enquiry teaching) within a COP, and away from the pressure of the classroom context (Lotter et al., 2014)

None of this work would have been possible without the 'brokering' skills of the TP and RP.

Brokering is a term used by Wenger to describe people who enable coordination and open new possibilities of meaning by connecting COP members with new practices (1998). Lotter et al. (2014) describe the use of inquiry coaches as brokers to build a COP of enquiry instruction with middle school teachers. In a similar way, the TP acted as a broker between the RP and the translation of FTEA into a practical design, which moved the RP inside the COP as a co-designer of lessons. Subsequently, during the design of professional development for the WW, the RP acted as a broker by facilitating access to her university laboratory with up-to-date equipment and materials, while the TP brokered new professional relationships among the teacher participants, and with the RP. These brokering activities operated at (and crossed) boundaries to open up new practices to the potential members of COPs.

6.4.2. Evaluation of the WW

Post-workshop interviews were conducted with each IST participant to assess how well the aims of the WW were met. The data collected were analysed using TA (King, 2012) and coded according to five overarching themes which are elaborated in this section:

First theme: The workshop

Attending the workshop provided the impetus to begin a shift in the signature pedagogy of teaching practical activities (Schulman, 1986). ISTs previous insistence that there was no room for enquiry teaching within practical activities, was supplanted by a more open mindset in those who attended the workshop. Pete's comments reflected how he saw possibility within this enquiry pedagogy from his position at the periphery of the COP. One way in which teachers can move further inside the periphery is to align their practice with that of the group. Alignment means that "we become part of something big because we do what it takes to play our part" (Wenger, 1998, p.179). Pete was actively considering the value of this alignment in his own practice:

> I think even the one that really stands out for me is the leaf yeast and the concept of that extension work with the information about the leaf yeast and the article that you had given to us. I think the idea of that and giving the students real life scenarios based around the concept that you are looking at and having them then come up with their own questions that they may ask about it. And then have them actually scientifically go through the process of formal hypothesis and designing an experiment and gathering the results. I think that really stood out to me as "this can really work here".
> *Pete - Interview*

One of the most salient aims of the workshop was to afford teachers the opportunity to be with other biology teachers. Cora noted the effect of the dearth of collaboration within her school subject department and missed opportunities to engage with educational research through partnership with the university next door :

I was thinking after, that's what we need. Even our school alone because we have about between 12 and 16 science teachers. We've a university next door to us that we don't partnership with enough to improve our teaching methodology
Cora - Interview

Pete recognised that mutual engagement through collaboration addresses gaps in the knowledge of any one individual:

…. there are aspects of the practical course that I genuinely wouldn't have any background information on it.…and like that with the collaboration sitting down with teachers that have this experience, what you don't learn off one person you might learn off somebody else.
Pete - Interview

Wenger writes that "it is more important to know how to give and receive help than to try to know everything yourself" (ibid, 1998). Following the WW Pete recognised this by seeing the competence of the group as a resource for designing his lessons:

TP: Do you think it's something you could do? [use the FTEA to design a lesson]
Pete: Yes definitely.
TP: And would you go off and do it by yourself or would you ring someone and go, "hey I'm trying this out"?
Pete: No I think I'd definitely be in touch with yourself or Rose and kind of chat through it.
Pete-Interview

Pete recognised that engagement is inherently partial, but within a COP, this partiality is a resource rather than a limitation (Wenger, 1998). Pete said that he *"sat back and struggled"* with the idea of using the FTPA to design lessons independently. After the WW he understood the value of interdependence in enabling him to reinforce, build and expand upon his capabilities (Luft& Hewson, 2014).

Second Theme: Understanding of enquiry:

Teaching through enquiry can be enhanced through opportunities to participate in, and time to reflect upon modelled enquiry experiences combined with a focus on content knowledge (Capps et al., 2012). During post-workshop interviews teachers reflected on their understanding of enquiry:

> So to actually allow them to have a small understanding after gaining a skill to then come up with some new information themselves, that you have guided them towards, but they haven't just looked up this answer in this book that they have understood it enough that they go off do a second experiment or investigation and understand it a little bit more. I think they are the pieces of knowledge that kind of stick with you forever.
> *Pete - Interview*

All of the ISTs linked the enquiry-based experiments they did during the workshop to student thinking and understanding:

> Well, I think enquiry-based requires more thought on behalf of the participants so they're thinking more for themselves …… they have to think "right I want to do this so how can I do it?". So, they have to sit down and think how to do it and then they have to be able to tell "I want to do this because" …… and that's the difference. Again, understanding leads to better learning.
> *Cora- Interview*

One of the outcomes of integrating a philosophically developed theory of enquiry into pedagogical practice, was that it placed teachers in a position to cast a critical eye over whether the pedagogies embrace genuine enquiry or not. Pete was able to identify how the 'sloganising' of enquiry had led the assumption that *"everyone knows"* what it means to teach through enquiry, when the converse is actually true (Capps and Crawford, 2013).

Another outcome of sharing a clear definition of enquiry was the emergence of a common language and methodology around enquiry teaching. This finding can be perceived in terms of Mutch's (2003) distinction between "restricted" codes (whose use of language rests heavily on shared assumptions about context and is limited regarding its range of use) and "elaborate" codes (where assumptions are not shared and language has to be explicit) within communities of practice. Negotiating a shared repertoire of FTEAs among members of a COP required the explicit development of shared meanings and words (Wenger, 1998). For example, during the interviews, teachers used words such as "linking" or "connections" to denote how one practical activity extends into another in a continuum of learning, indicating an understanding of the view of enquiry underpinning the FTEA.

Third theme: A vision for using enquiry

Teachers were asked to think about how they could use the FTEA in their classrooms. There was a willingness to override the recipe-based pedagogy in favour of teaching through enquiry because ISTs believe it is a *"richer learning experience".* Changing the beliefs of teachers occurred *after* teachers have experienced a new practice and can see the benefits to their own practice (Guskey,2002). The WW struck a balance between participation and reification by combining understanding of a new philosophy (enquiry) with learning experiences that were modelled on what is possible within the biology classroom.

> Like linking let's say the germination project and the microscope and linking both of them together, there is no reason why they couldn't do it, right they are not going to be examined on it, but, surely we should be giving our students that opportunity to make those links and have them think outside the box, rather than just tell them how it is.
> *Pete - Interview*

A pre-requisite to embedding student thinking in practical activities was that teachers must also apply *"deep thought"* (Pete) to their lesson design and to the pedagogy that scaffolds enquiry learning for students. Pete was beginning to restructure his beliefs around teaching practical activities to include how he could embed thinking into his lessons. Loucks-Horsley and colleagues (2010) advocate for learning experiences of this kind (the WW) because teachers can break ties to their old models of teaching when they understand why it is important for students to learn in this way:

> And surely with that deeper thinking that you have applied as a teacher, that you will then be able to help the students further because of your deeper understanding, you really kind of start thinking about how you can guide them to further base of knowledge for them. So …..I think it will be beneficial in the long run.
> *Pete- Interview*

Following the WW Rose adapted one of the enzyme experiments on the syllabus to an enquiry activity. She was pleasantly surprised to find that her students enjoyed the lesson, learned more that she expected, and understood more than she anticipated they would:

> … they did do questions afterwards and their understanding was quite good so I was actually surprised by that and I was glad.
> *Rose - Interview*

Her experience of teaching an enquiry lesson assuaged the concern she had that it was too big a diversion from the syllabus:

> I understand now and I'm not changing the whole experiment, I'm not trying to get them to do anything off the wall here, I'm just trying to get them to think about what they are doing more.
> *Rose - Interview*

Perhaps one of the most successful changes to take place following the workshop was in the area of questioning. Comparing recipe and enquiry methods, Niamh explained that asking questions is the key enquiry:

> ……the knowledge of a more enquiry-based is "what kind of questions can I ask?" "Are my questions as good as my peers?" and "did my method …… work? Can I repeat it? Is there anything you would do differently?"
> *Niamh - Interview*

The WW planted the seeds for a change in teachers' beliefs and practices. Beliefs are supported by experience and people can be quite committed to them, therefore they affect how teachers engage in, and learn from professional development (Loucks-Horsley et al., 2010). Bearing in mind that this was the first opportunity of its kind that these ISTs had to develop an understanding of enquiry, it was impressive how quickly they demonstrated a more sophisticated understanding of enquiry and a willingness to engage further with it.

Fourth theme: The changing role of the teacher

Rose recognised that creating enquiry based lessons requires time and thought. She acknowledged that the teacher needs to scaffold a lesson built on prior knowledge to enable students to, in her words, *"move forward".* She was referring to knowledge as an end-in-view, which is consistent with the signature pedagogy of enquiry. Within this view, she saw her own role as a facilitator, assisting students to reach for the end-in-view rather than telling them information as an end-in-itself (Dewey, 1958).

Her lesson design and her approach to facilitating learning enabled students to engage in enquiry activities without overreliance on her to tell them what to do:

> Oh I think it does require more time sitting down because you don't want to give away what you want them to come up with or you want to teach them enough basics so that they can ask other questions …. I think that takes a little bit of time to give them enough knowledge but just enough. They can move forward with it……. So, I think for me it takes time to try rein it back in a little bit and say I know I want them to get to this point but I can't give away too much.
> *Rose – Interview*

Rose was beginning to understand that switching from recipe teaching to enquiry teaching meant a new way understanding her role as a teacher. Much of her work now means organising activities in which her students do much of the talking and doing among themselves in the classroom, without her direct presence (Loucks-Horsley et al., 2010)

Fifth theme: Room for improvement

While the workshop was successful in adapting three experiments to the FTEA, and teachers could see how some experiments lend themselves to easily to enquiry-based adaptations, there was still some reticence with using the FTEA for all of the experiments on the LC syllabus. The heart dissection was specifically identified as one where enquiry may prove difficult:

> I think there's a lot of the experiments that can lend themselves to enquiry which I think would make it a lot more interesting for the students. I really like the seed germination experiment and seeing the different effects of all of the different stains. That was brilliant. I loved that. But there's other experiments like the heart dissection. How are they going to come up with a way of dissecting the heart that's the way that they need to know it?
> *Rose - Interview*

Rose's comment indicated that the shift in her beliefs about teaching practical work, was tempered with some reticence when it came to teaching something difficult like a heart dissection. She did not see herself as the designer of lessons yet. Therefore, the WW provided an opening of the periphery of the COP to induct teachers into enquiry pedagogies, but the kind of transformational change required for teachers to transform their deeply held ideas about teaching practical work, requires further significant professional development over time (Mezirow, 1997). Teachers need to build on prior knowledge to develop more complex knowledge about science teaching, which reciprocally fosters more sophisticated ways of thinking. Duschl et al., (2007) call the process engendered by this a *"learning progression"* and it can take years of professional development to effect changes within it.

The next section describes the how the learning progression was advanced through the use of four Micro-evaluations where teachers engaged in a joint enterprise with students to appraise four further FTEA designed practical activities.

Note: Following the workshop in February 2020 there was a national lockdown imposed until July 2020, where schools were closed and teachers had no opportunity to trial the FTEA. Covid-19 restrictions imposed by the government meant that the research was temporarily halted. Restrictions eased in August 2020, permitting two teachers, two students and the TP to attend small scale laboratory Micro-evaluations.

6.5 Micro-evaluations - Learning within a Community of Practice

This part of the research was about providing professional development at a level deep enough to effect changes in teachers' beliefs *and* practice. There are strong links between Shulman's signature pedagogy (2005) and Wenger's "regime of competence" within a COP, which is defined as "what would be recognised as competent participation in the practice" (Wenger, 1998, p.137). In the previous section, the TP and RP demonstrated competent membership in their newly formed COP through the three dimensions of practice (mutual engagement, accountability to the enterprise, and negotiability of the repertoire), by using the FTEA as a reified object to jointly design and deliver the enquiry-based WW. Teachers also experienced some learning within the three dimensions, by taking part in the WW as learners. Wenger states that "for learning in practice to be possible, an experience of meaning must be in interaction with a regime of competence" (1998, p.138). For the teachers as newcomers, in order to achieve the competence defined within FTEA lessons, they must transform their experience until it aligns with the regime. More experienced members of the COP (the TP and RP) use their experience to change a community's regime and then invite others (teachers) to participate in their experience by reifying it for them (through professional development practices such as the Micro-evaluations). To change a regime of competence means "they may need to engage with people in new ways and transform relations among people in order to be taken seriously" (ibid., p.138-139). It is within the interaction of experience and competence that the potential for transforming both of them, and thus for learning, individually and as a community, takes place.

One way to keep the tension between experience and competence alive in a COP (and thus to continue learning) is to provide boundary crossing experiences for members of the COP. This is because crossing boundaries between practices exposes us to different ways of understanding the practice along the three dimensions; different ways of engaging, different definitions of what matters and different repertoires – "where even elements that have the same form [for example, the FTEA] belong to different histories" (ibid., p.140).

This section evaluates how, over the course of four Micro-evaluations, teachers gained a deeper understanding of the regime of competence of enquiry-teaching by looking at the FTEA (same form) from different perspectives. This meant creating continuities at three boundaries within a "nexus of perspectives", comprised of access to the student experience, access to the design experience and to the enquiry-teaching experience (Wenger, 1998, p.105). The continuities between the different perspectives were maintained by using a boundary object (the FTEA) to form interconnections between the perspectives, and a broker (the TP) to facilitate interconnections between the participants and to provide the space in which the participants worked.

Wenger (1998) argues that exposure to a practice alone is not sufficient for learning to take place. Learning comes about through a sense of belonging to the COP which in turn is comprised of three distinct modes: engagement, imagination and alignment.

Alignment means doing what it takes to play our part in coordinated enterprises, it is the ability to communicate purpose, needs, methods and criteria (ibid., 1998). Engagement is the ongoing negotiation of meaning, the formation of trajectories (or, in this case, the creation of a continuum of learning) and a shared history of practice between participants – in essence, the work of forming a COP (ibid., 1998). Imagination, the ability to take risks and create unlikely connections,

> "emphasizes the creative process of producing new "images" and of generating new relations through time and space that become constitutive of the self ….. imagination involves a different kind of work of the self - one that concerns the production of images of the self and images of the world that transcend engagement."
>
> (Wenger, 1998, p.177)

Throughout his work, Dewey constantly promotes the concept of learning along a continuum, and the importance of utilising the prior knowledge and everyday experience of students to design lessons that bring them further along the learning continuum - he called this reaching for the end-in-view (Dewey, 1925/1958). Envisioning the end-in-view, requires the work of imagination, "generating new relations through time and space" and producing "images of the world that transcend engagement" (Wenger, 1998, p. 177). It is forward looking, reaching into the future from the past and present, based on what-is-yet-to-be-known. At senior cycle, imagination has been notably absent, because the view of knowledge as transmission of information does not require its presence.

For learning to occur, imagination, alignment and mutual engagement must be integral to the work of the COP as three equally important modes of belonging. The lessons created by the TDT exemplify how the three dimensions of belonging fostered an identity for the COP of a group of enquiry practitioners. By the time the Micro-evaluations began, the TP and RP had developed a strong foundation of belonging to the COP. As the following section will show, facilitating access to a nexus of perspectives for Pete and Rose stimulated all three modes of belonging, particularly imagination, which up to this point had not been a part of their practice, and brought them further into the COP as participating members.

Figure 6.8 shows that each perspective within the nexus is interlinked with these modes of belonging. Each outer perspective can be rotated around the inner modes of belonging to indicate how each mode is an integral part of learning from each perspective. The evaluation of this stage of the research revolves around the interlinkage of the nexus of perspectives with the three modes of belonging. It is within this experience that learning occurred for the teachers.

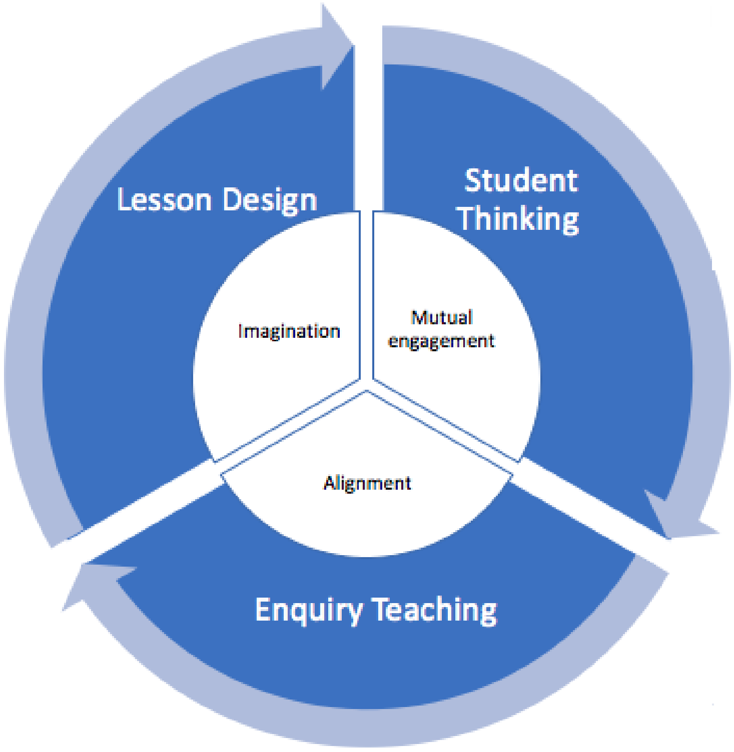


Figure 6.8: Diagram indicating how learning occurred within the nexus of perspectives (outer circle) and the three modes of belonging (inner circle)

Micro-evaluations are used as part of DBR to trial an innovation with a small group of users outside of the target setting. Brown (1992) advocated for the trialling of educational innovations in these small-scale 'laboratory' settings to allow their users to develop a deeper understanding of the innovation than would otherwise be possible in the wider target setting (classroom). A course of four Micro-evaluations took place over four weeks during August 2020 in a small-scale laboratory setting, with five research participants; the TP, two ISTs (Pete and Rose) and two students Ava and Mia (both aged 16, about to enter senior cycle to study biology). Singer et al. (2011) advocate for bringing teachers and students together in a collaborative high support setting where teachers can negotiate enquiry instruction by practice-teaching with a small number of students. Ava and Mia provided access to the student perspective during the course of the Micro-evaluations. Rose and Pete designed their own lesson using the FTEA and taught it to Mia and Ava, which meant they experienced enquiry from both the design perspective and the enquiry-teaching perspective.

Three of the four FTEAs were designed to link together two mandatory activities from the LC syllabus (see Table 6.2) since the theory that underpins the FTEA, advocates for this connectedness of experience (Chapter 5) as a way for students to make sense of and use the scientific principles that underlie practical activities.

The TDT designed two new 'linked' activities, which were taught by the TP, while Pete and Rose designed and taught the third linked activity around the use of the microscope. The Leaf Yeast FTEA was included to establish its effectiveness in fostering student thinking, since it had not previously been trialled with students. Appendix 6.2 contains the resources used for these lessons.

Table 6.2: Weekly micro-evaluations of mandatory LC experiments adapted to the FTEA

	Diagnostic experiment	Applied Experiment	Teacher
Week 1	To dissect and display a sheep's heart	To investigate the effect of exercise on pulse or breathing rate	TP
Week 2	To investigate the growth of leaf yeast using agar plates and controls		TP
Week 3	To be familiar with and use a light microscope / To prepare and examine plant cells under the light microscope	To conduct any activity to demonstrate osmosis	Rose, Pete
Week 4	To investigate the effect of pH on the rate of enzyme activity	To investigate the effect of temperature on the rate of enzyme activity	TP

As with the scoping stages, audio and video recordings of each micro-evaluation were transcribed and analysed using MAXQDA software. Photographic and written evidence of student work was collected to supplement this data. Student interviews were conducted after the micro-evaluations and analysed using TA to establish their experience of enquiry-learning.

6.5.1 Evaluation of the Micro-evaluations

The aim of the micro-evaluations was to provide teachers with experiences of imagination, mutual engagement and alignment with enquiry, through access to a nexus of three interconnected perspectives – enquiry-teaching, design and student.

Evaluating Micro-evaluations can be done in a number of ways within the DBR methodology; interview, observation, administering a questionnaire or testing/requesting a report (Nieveen et al.,2012). Three of these methods are used as evaluative techniques here. Discussions recorded during each lesson recording, along with student interviews, are used to assess how well the Micro-evaluations provided access to each of the three perspectives; enquiry-teaching, student and design. Testing is also used in the design perspective where Rose and Pete are challenged to design their own lesson using the FTEA.

6.5.1.1 The enquiry-teaching perspective

In answer to Rose's query about how other 'difficult' LC mandatory activities could be transformed into enquiry-based lessons, the heart dissection was adapted by the TDT as an enquiry-based activity. Using Dewey's Island Analogy (stripping away the water around the island reveals the connections between them), the FTEA vison for this experiment was that an understanding of the connection (that which is seen when the water is stripped away) between the heart and lungs would enable students to understand each individual system better (Dewey, 1925/1958). Figure 6.9 shows the FTEA designed by the TDT for this lesson. The TP taught this lesson to all four participants, hence Rose and Pete experienced enquiry as learners during this session.

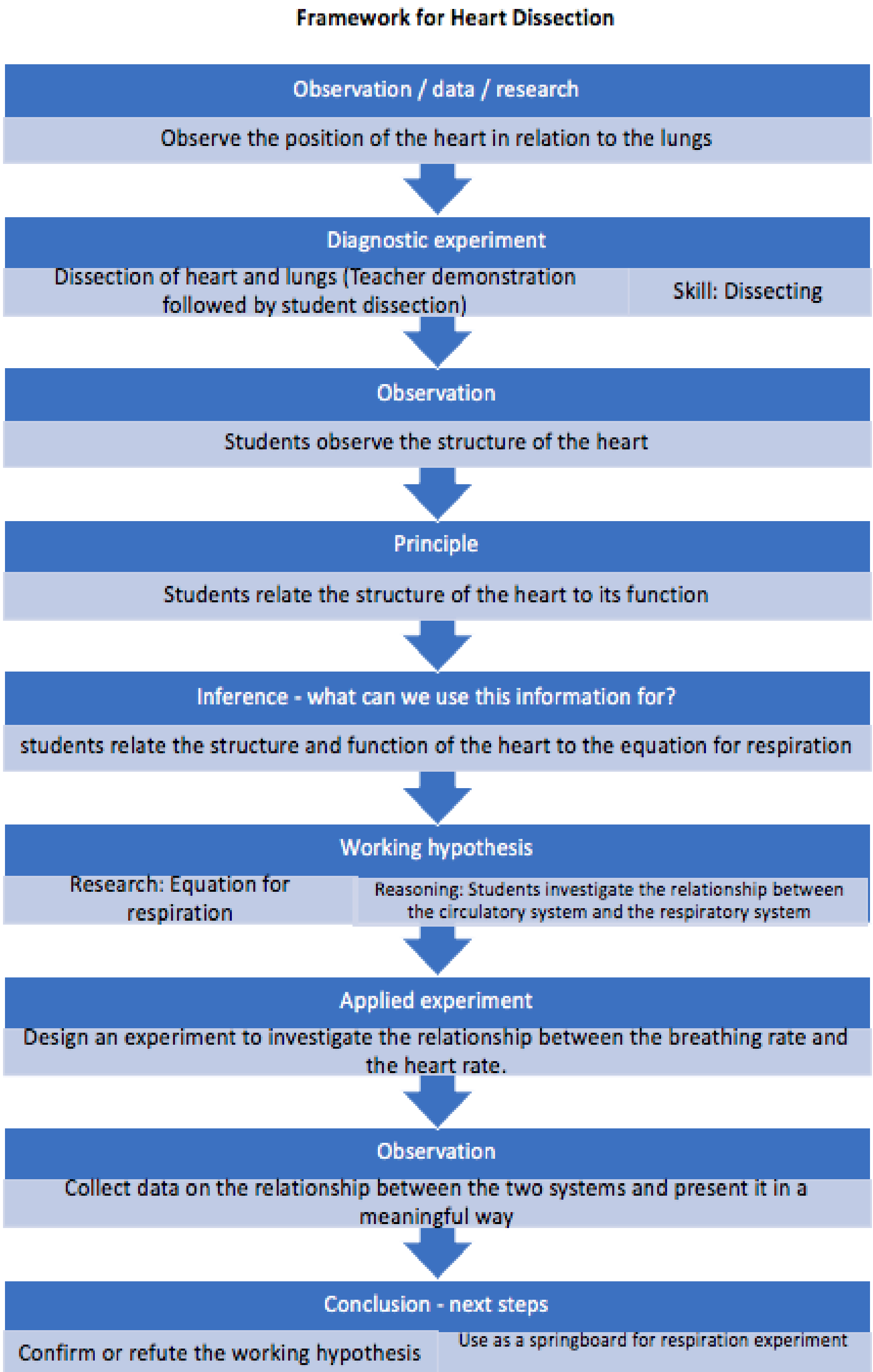


Figure 6.9: FTEA underpinning the heart dissection Micro-evaluation

Bryce and colleagues (2016) discuss the idea of cogenerative dialogues where participants in a process mutually "engage in discussions about how the process is unfolding" (p.247). In doing so every participant has a voice in the process, which helps to flatten the traditional hierarchical nature of the student-teacher relationship, which is a part of the signature pedagogy of enquiry (Siry and Lara, 2012). In this space, student learning can become explicit as they share their thinking overtly, and teachers can form an understanding of how their students learn. For example, one discussion (below) provided Rose and Pete with a valuable opportunity to heed the kind of misconceptions that students may have, and how teaching through enquiry can address those misconceptions, by providing evidence to the contrary. A lung dissection was introduced into the diagnostic experiment to complement the heart dissection. In the discussion below between all participants, both Mia and Ava articulated the same misconception about the structure of the lungs and Rose admitted that she had never seen a lung dissection before:

Pete: It's nice too because it's definitely a misconception that students have about the lungs

> Rose: I've never seen this before
> TP: Yeah did you think they were hollow or what did you think was in the lungs?
> Ava: Yeah
> Mia: I thought they were all just the little tubes, like the..
> TP: Like the diagram?
> Pete: Kind of even like broccoli or something
> Mia: Honestly I thought like grapes
> Ava: I though they just inflate, like they're nearly hollow
> TP: Like a balloon?
> Ava: Yeah
> *Heart Dissection Transcript*

This perspective also advocates for the role of teacher as facilitator, aligning with the signature pedagogy of enquiry-teaching. The lesson was scaffolded to consciously engage learners in making their own connections to the material, rather than telling them what those connections were. From Ava's comments during the student interview, this aspect of the lesson can be considered to have been achieved:

> Well considering we know it like, a month later, it's still fairly fresh kind of. You still have the image of the green food colouring going through, so you kind of know, you just have to piece it together if you don't remember it, where all the arteries are
> *Ava (Student interview)*

Ava believed she could *"piece together"* any information she could not remember, suggesting that she could not only remember the activity but she also understood it. Dewey writes that consciousness is the work of the hand and mind in unison, "the perception of actual events **in** their meanings" (Dewey, 1925/1958, p.303). It causes a person to "stop and think", which indicates that the mind and body are both engaged in the activity - "one acts not just to act, nor rashly, nor automatically, but with the consciousness of purpose and for the sake of learning" (ibid., p.315). The conscious activity built into every FTEA promoted learning of this kind.

There was also an aspect of imagination to the pedagogy used here. Using diagrams along with physical materials (straws, hearts and lungs) to connect the abstract structure of the diagrams (Figure 6.10a) to the real structure of the organs (Figure 6.11b), required the work of imagination on the part of the learners.

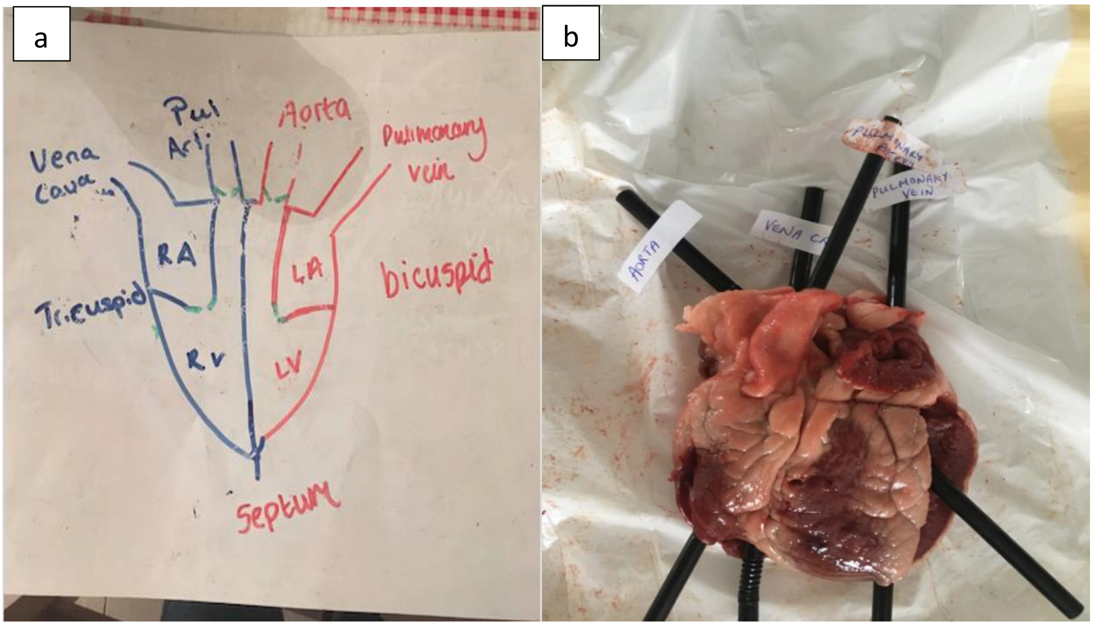


Figure 6.10: A diagram drawn by Ava prior to the dissection (a), and the actual heart dissection using straws(b)

Rose epitomised consciousness in the excerpt here where she is connecting her thoughts with her actions, (*I have to think about this*), and she received assistance from Ava, indicating a flattening of the hierarchy:

> TP: Yeah, what did you find there Rose? Oh you have them all done ..... Which is which?
> Rose: Yes, but I have to think about this
> TP: Have you gone through a valve?
> Rose: Em, with this one yes [points to one straw]
> TP: Ok, well if you've gone through a valve, what is it? What do you think? [looks at Ava]
> Ava: [Consults diagram] Pulmonary vein

Heart Dissection transcript

From the perspective of enquiry-teaching, the Micro-evaluations were an important experience for teachers to witness how to embed consciousness into lessons by using imagination to create tools that encourage thinking (diagrams, organs for dissection and straws). Additionally, the discussions between all of the participants, were less hierarchical than with traditional teaching because all of the participants, including the teacher (TP) were seen as learners in this process eliminating the need to "know" everything, instead fostering a desire to reach into the unknown, in the case below, by googling the answer:

Mia: What did you say this thing was?
TP: What thing?
Mia: This like, flab?
TP: an auricle
Mia: What does it do?
TP: [looks at Pete] Pete's googling it
Pete: [reading from the internet] The left auricle, also known as the left atrial appendage is a small muscular pouch at the upper corner of the left atrium. It collects oxygenated blood that leaves the lungs and moves the blood into the left ventricle
Heart Dissection Transcript

Having seen the physical connection between the heart and the lungs, the Leap activity was designed to connect the function of each organ to the equation for respiration, and the applied activity required students to design their own experiment to investigate this relationship. After this activity, Pete and Rose could see that Mia and Ava could draw their own conclusions based on evidence:

TP: So can you tell me what the relationship between the respiratory system and the circulatory system is then?
Mia: When one has to work harder so does the other
TP: Yeah so you do exercise and they both have to work hard. Why?
Mia: You need more oxygen
Ava: You're getting more oxygen
Mia: You're using energy and then you need more oxygen for your blood to get more energy
TP: Trying to get more oxygen into your blood, so when it does go in, what does your heart do?

Ava: Pumps it around faster
TP: And where is it going?
Mia: Cells
TP: Cells, muscles yes. And what's that process called?
Ava: Respiration
Heart dissection transcript

From this perspective, Rose could see the benefit of an activity like this for fostering understanding, she no longer believed that time was a barrier to teaching through enquiry. Echoing Ava's interview comments (above), she saw learning as more than memorising information:

TP: How do you feel as a teacher devoting some of your precious class time to something like this?
R: But the girls got the whole structure from dissecting, from a diagram and dissecting it, they got the whole structure of the heart which is what you really needed to know. You know that's where they want to get to, without learning it off by heart. It's not really time, it's using time –
TP: -wisely?
R: Yeah
Heart Dissection transcript

Pete saw how establishing a link between two activities (circulation and respiration) was preferable to teaching them as isolated instances.:

….tying those two things in together is far more beneficial than doing them as two separate [topics]
Heart Dissection transcript

When teachers see the benefit of a new practice to their students, their beliefs about teaching begin to change (Guskey, 2002; Loucks-Horsley et al., 2010). Pete and Rose were beginning to align their beliefs with this model of enquiry-teaching because they saw the benefits in terms of gains in subject content knowledge and student learning. Experiencing enquiry-teaching first-hand provided insight into the work of imagination, engagement and alignment that the teachers needed to include in each lesson, to create an enquiry-oriented lesson.

6.5.1.2 The student perspective

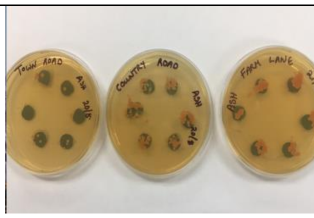
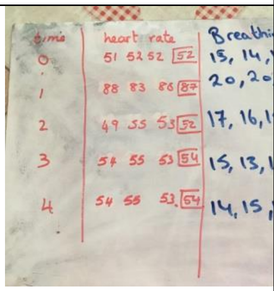
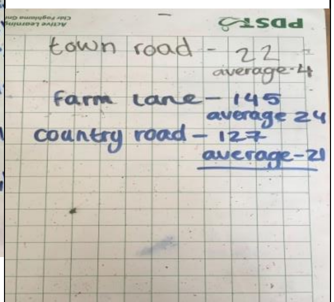
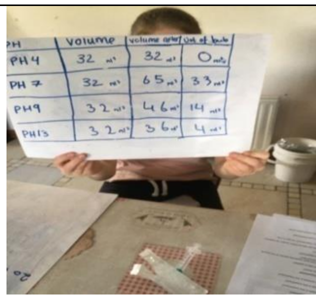
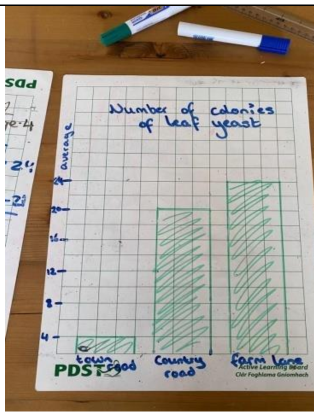
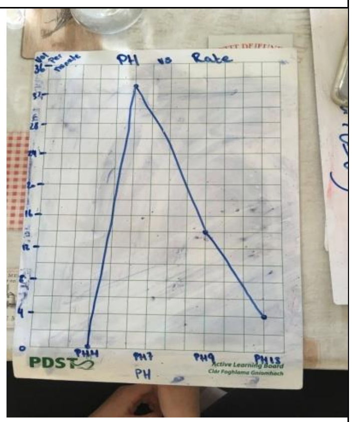
In all of the applied activities, it was found that when students asked their own question they were curious to know whether their predictions would be correct. Opening her agar plates to see how much leaf yeast had grown on each one, Ava made the comment *"it's like Christmas"*, referring to the excitement of unwrapping the plates to see her results. Dewey argues that it is the teacher's role to inspire curiosity, which can only be fostered when knowledge is seen as an end-in-view, i.e. when the student is anticipating the result (Dewey, 1925/1958; 1910/2012).

Decisions about what should be done to collect and present data, were pushed back onto students, indicating alignment with the enquiry-based pedagogy that promotes student decision making. While students were unaccustomed to making decisions about data collection, presentation and analysis, they did have the skills to do it and did not find it difficult to do. Ava makes reference to how when she *thinks* about the task, she can do it easily:

> TP: Like would you prefer if I handed you a table and said, 'here write your results in'
> Mia: Well I think everyone would prefer to just be handed the table but like, we knew how to do it, we can draw our own table
> Ava: It's just when you say it, you're like 'what?', but then you actually think about it and its fine like, it's not that hard
> *Student interview*

There is an "organisation of acts required to realise an end" (Dewey, 1910/2012, p.41) within the activities the students carried out. Students are required to take their observations, document them and explain what they mean. Mia and Ava were quite confident in their ability to do this. Table 6.3 below, provides evidence to support this claim. Mia and Ava understood that they should be calculating averages for the first two experiments, and they created a table to calculate the volume of foam produced in the enzyme experiment. They also understood how to select the most appropriate means of presenting their results (bar chart and line graph). While they were facilitated by the teachers present, they did not need step-by-step instructions on what data to record or how to record and present it.

Table 6.3: Results collected, data recorded and data presentation for three practical activities, leaf yeast, heart and enzymes

	Heart	Leaf Yeast	Enzyme
Question	How are heart rate and breathing rate related?	How can leaf yeast be used as an indicator of air quality?	What effect does pH have on the rate of enzyme activity
Result	Students measure heart and breathing rates before and after exercise	 Number of colonies of leaf yeast indicates quality of air	 Amount of foam produced per minute measures the rate of catalase activity
Data collection			
Data presentation	 Ava's heart rate		

	 Mia’s breathing rate		
Conclusion	Breating rate increases proportionally to heart rate during exercise	Leaves collected from the farm lane produce the most colonies. Therefore, the farm lane has the least air pollution	The optimum pH for calalase activity is 7

Following the leaf yeast activity Mia and Ava were correct in their prediction that a leaf collected from a busy town road would generate fewer yeast colonies than one picked from a more rural setting but they were still surprised at the paucity of leaf yeast in the urban area. Unprompted, Ava and Mia further hypothesised about the air quality in an even larger urban area:

> TP: So where’s the best air quality around here?
> Mia: Farm lane. And town road, not very good
> Ava: It’s terrible
> TP: I know. Isn’t it really surprising?
> Ava: Its actually so surprising how bad the air quality must actually be
> Mia: and that’s only [names local town]
> Ava: Imagine the air quality in some-?
> Mia: - in Dublin like?
> Ava: Its actually mad, I can’t get over it.
> *Leaf Yeast Transcript*

The leaf yeast activity fostered genuine interest on the part of the students, where they connected it to a real life, relatable situation, generating their own data to answer a question. This connection enlarges and refines school knowledge and everyday knowledge interdependently (Dewey, 1910/2012). Ava was already imagining what question she could ask next, indicating an alignment with the ethos of enquiry. In addition, Mia and Ava showed clear evidence of mutual engagement through their discourse during these activities. It was important for Rose and Pete to witness the kind of thinking that students were capable of through the enquiry pedagogy. Following Park et al. (2007) whose research suggested that within a teaching community, teachers learn more from each other than from a professional development expert, it also makes sense that collaborating with students to practice-teach in a small-scale setting such as this, can be a source of significant professional development for teachers (Luehmann, 2007).

An outstanding example of the value of a cogenerative dialogue approach to professional development came during the enzyme micro-evaluation when Ava questioned the validity of one of the suggested options for further investigation during the leap activity (Tobin and Roth, 2005). The option implied that students would use foods that act as indicators to investigate the effect of pH on the rate of enzyme activity. Ava's argument was that it was not a genuine 'link' between two ideas because it did not further the connection between the rate of enzyme activity and pH - all it did was change the colour of the reaction mixture depending on the pH:

> TP: OK. And your question was very good about the pH. When you were saying about the change in colour, that has no effect on enzyme activity. And I was going 'damn, you got me there'. It's just [it looks] cool, ok. But you were right, that was a mistake I made. Just because it's cool doesn't mean it should be a part of the experiment.
> Ava: Yeah, link in like. It doesn't link in
> *Enzymes Transcript*

Remembering that Ava has no experience of senior cycle biology or chemistry but that she was still able to call out the tenuousness of this 'link' in a room with three practicing biology teachers present, was a very encouraging testament to this approach to enquiry as a site for developing critical thinking skills in students, which enabled her to make obvious the flaws in the lesson design. In addition, Rose and Pete experienced the richness of the dynamic process of learning that can occur when the traditional teacher-student hierarchy was flattened. The enquiry signature pedagogy took the pressure off the them to "know" everything, because every applied activity the students undertook was reaching into the future, which is uncertain. The ownership of knowledge was no longer the privilege of the teacher, it became a shared practice brought about through investigation and dialogue.

6.5.1.3 The design perspective

Akerson et al. (2009), created a professional development programme using a COP approach where participants were given tasks to co-create materials, encouraging the process of reification and participation in the negotiation of meaning. El-Hani and Greca (2013) talk about the double movement required to bridge the research-practice divide; from research based knowledge to classroom settings where research is gradually implemented, and from teachers' knowledge towards an increasing capacity to implement and adjust pedagogy to new situations. In the third Micro-evaluation, Pete and Rose were given an opportunity to trial their own collaborative design for a linked lesson between microscopy and osmosis.

They taught this lesson to Ava and Mia during the third Micro-evaluation, which provided the opportunity to reflect upon and evaluate their lesson before bringing it to their own classes (*that run through is handy to have under your belt*- Pete). Having this opportunity to trial their lesson meant they could actively participate in taking risks with ideas (the work of imagination) without feeling deficient, because they were supported in this endeavour by the COP, whereas prior to the COP, Pete *"sat back and struggled"* to create an enquiry lesson independently (Luguetti et al, 2018).

Asked about how their lesson planning differed to their normal practice, Pete acknowledged that the most difficult part of the lesson design was "*figuring out what the leap was going to be"*. Rose admitted that their collaborative effort became intense at times as they attempted to agree on the most appropriate leap activity:

> ....we actually fought at the table, "that's not going to work, try this, that's not going to work*"*
> *Rose – Microscopy Transcript*

They invested time and thought into various directions that the leap could take, insightfully eschewing the most obvious one, preparing and viewing an animal cell, because they did not think their students would 'learn' from it:

> … we were saying, if we showed them the plant, they'd definitely be able to do the animal. And then we were like "that's not really learning that much actually.

Rose – Microscopy Transcript

Pete and Rose wanted to make a meaningful connection with other topics on the LC syllabus, settling on connecting microscopy to the osmosis experiment after getting inspiration from an experiment examining osmosis in an aquatic plant (Elodea) under the microscope:

> Rose: If you add a drop of water, a hypotonic solution and you add a coverslip you can observe the chloroplasts in Elodea.
> TP: Oh! That's so cool
> Rose: If you add a salt solution to it, you can observe the cell shrinking.
> TP: Cool
> Rose: And that's where we started. I think when we came up with that one, then we were like "could you do it with anything else?" And I was looking up osmosis and shrinking cells, so then we came up with doing the red onion, because it was as easy as doing a red onion with a normal onion
> *Microscopy Transcript*

This exchange identified all three modes of belonging within the COP approach. Pete and Rose aligned their lesson to an enquiry-oriented regime of competence. Within this alignment their mutual engagement was instrumental in discerning between what counts as learning and what does not. Perhaps, most importantly, their use of imagination created a forward thinking (end-in-view) lesson (Dewey, 1925/1958). Using imagination meant that they had to search for subject content for inspiration and then devise pedagogical ideas to integrate new scientific ideas into their lesson, indicating that within the three modes of learning, their subject and pedagogical knowledge increased. It is worth noting here that after the workshop Rose referred to the leap activities as *"little things"* but when she set about designing an enquiry-based lesson, she found that scaffolding leap activities is actually the *"biggest thing"* in the process.

Translating new beliefs into changes in practice takes time, support and structured experiences for teachers (Loucks-Horsley, 2010). Having the experience of designing and enacting a lesson within the COP provided the space for teachers to reinvent their practice, take risks, make mistakes and offer suggestions for improvement (Dalgarno and Colgan, 2007). For example, reflecting on the lesson that they taught to Mia and Ava, Rose said she felt that students needed to *"know"* osmosis before they could propose a hypotheses for the applied experiment, so their design of the leap included a comprehensive lesson on osmosis. After the lesson, Pete offered the suggestion that the students did not need this lesson at all to make the connection between microscopy and osmosis. Rose and Pete were moving along the learning progression in the same direction but at different paces. Rose was transitioning from one belief system (knowledge as an end-in-itself) to another (knowledge as an end-in-view), while Pete was slightly further along in his learning progression:

> Rose: They'll have done the cell and then like what you said, they don't have to know anything about osmosis, and I never thought that
> Pete: Remember you put in about the hypotonic and all that, I wouldn't have put that in originally
> Rose: Ok yeah
> Pete: I would have just given them the investigation
> TP: Yeah, look at it and see
> Pete: And to come up with their own reasoning why, to link the osmosis with that, but it all depends on the class you've got in front of you
> *Microscopy Transcript*

This raises an important point about learning for teachers: not all teachers will effect changes at the same pace, but within a COP their learning can follow the same trajectory (Wenger, 2014).

Evaluating the leap worksheet they designed, Rose realised that she and Pete had different visions of how students would draw diagrams to represent osmosis, and neither of them predicted what students would actually draw, or that students would find this assignment particularly difficult. Dewey cautions against teaching from the position of one who already knows and advocates for teaching from the student perspective (Dewey, 1910/2012). Rose saw this first-hand in the worksheet she designed:

> Rose: So I think that's something that we actually need to improve on.
> Pete: I think even draw in the potato cubes
> Ava: Because you could draw that so many ways
> [Laughter]
> Rose: Exactly. I had in my head the way I think and then Pete's talking about what he wanted and then you're drawing it this way and I'm like ' how did she work this through'…….That's something we need to figure out

Microscopy Transcript

Both excerpts above advocate for professional development opportunities such as Micro-evaluations, to give teachers a place and a safe space in which to learn and refine their new craft (Luehmann, 2007).

6.5.2 Refinement of the FTEA

Refining the educational innovation following each design cycle is a part of the DBR methodology that ensures the innovation is usable in its target setting (McKenney and Reeves, 2018). Since Pete and Rose were now users of the innovation and are members of the COP, they were invited to share their opinions on the usability of the FTEA, following their 'test' (designing their own lesson). They used the Heart Dissection FTEA (Figure 6.9) as a template to design a microscopy lesson (Figure 6.11), but they did not find it as simple to use as expected. They were still unsure about the separation between the diagnostic experiment and the applied experiment, confusing the 'principle' with the 'inference'.

A professional conversation between them and the TP clarified the confusion about the meaning of the different terms in the FTEA and established that it needed to be more user friendly, taking into account the following:

a) There should be a clear delineation between the inductive and the deductive experiment

b) The leap needed to be identified on the FTEA, as it is the central tenet of the activity which separates the inductive and deductive experiments.

c) The FTEA would benefit from the addition of colour

This process of negotiation between the TP and Rose and Pete was a part of the work of COPs. Because all participants must engage with the FTEA, it's design was open to negotiation and alignment with the needs of its users (Wenger, 1998). The product of this mutual engagement and alignment was a newly designed, colourful FTEA, that clearly identified the Leap activity as a bridge between the inductive and deductive experiments. Figure 6.12 illustrates how it was used for the enzyme Micro-evaluation.

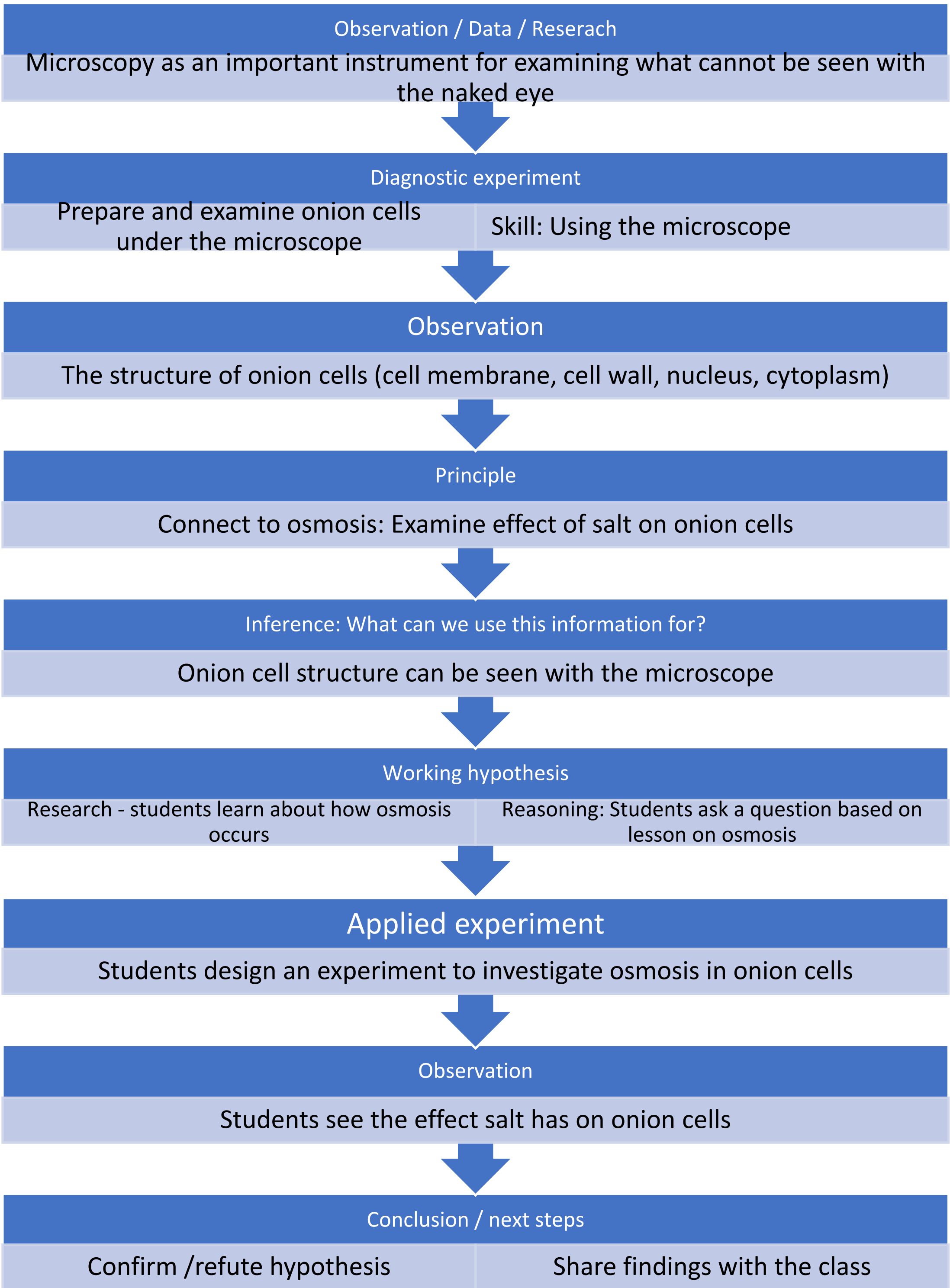


Figure 6.11: Rose and Pete’s FTEA for their microscopy/osmosis activity

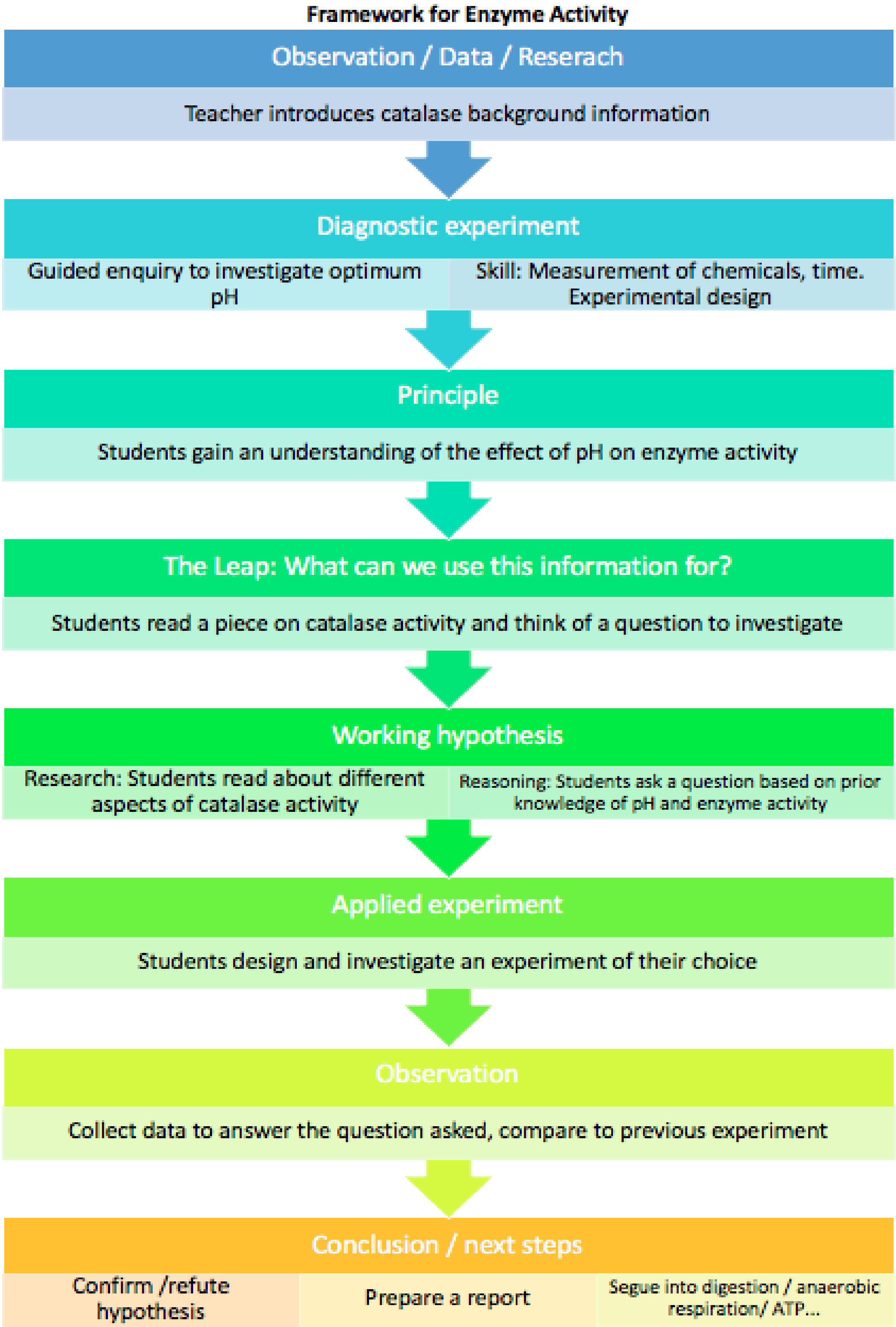


Figure 6.12: The newly re-designed enzyme FTEA.

6.6 Discussion

This chapter outlines how the development of a COP of enquiry-practitioners can be used to alter the signature pedagogy of biology teachers towards an enquiry-orientation. Loucks-Horsley et al. write that this change process, from one epistemology to another, requires teachers to act and think in new ways.

> "The conventional wisdom has been that changing teacher beliefs should be the primary work of professional development, for when one believes differently, new behaviours will follow"
>
> 2010, p.75

The bulk of the work of this professional development was in providing mastery experiences for teachers in a risk-free setting, so that they would feel empowered to go back to their own classrooms and effect changes in pedagogy there (Gregoire, 2003). Exposing teachers to a professional scientist (RP) and to an educational researcher (TP) in a university laboratory setting was instrumental in the provision of these mastery experiences. The findings from this cycle indicate the importance of providing stronger school-university links to allow biology/science teachers access to a scientific environment, within which to grow professionally by engaging in research-based laboratory activities with professional scientists and educational researchers. Working within a COP was shown here to be one way in which professional development thrives.

Teachers need opportunities to see an innovation successfully implemented if they are to change their beliefs and practice around teaching practical work (Guskey, 2002). They also need time and space to engage in professional development (Capps et al., 2012; Loucks-Horsley et al., 2010). The first design principle, increasing meaning through participation, was scaffolded using the WW and the Micro-evaluations, which enabled teachers to step away from the classroom context and which provided time, space and opportunity to engage in enquiry-teaching, using the FTEA as a reified object around which the experiences were organised.

The second and third design principles led to a COP approach to professional development. An important finding of this research cycle was that throughout both the WW and the Micro-evaluations, the core dimensions of a COP (mutual engagement, joint enterprise and a shared repertoire) addressed shortfalls in teachers' individual practice through the interdependence that is integral to a COP. For example, there were four aims of the WW, three of which – troubleshooting common issues, increasing subject content knowledge (including knowledge of laboratory skills), and increasing pedagogical knowledge of enquiry-teaching – were realised by achieving the fourth aim (development of a COP). This is because the practice of a COP has much in common with the theory and practice of enquiry teaching. Both are emergent, oriented towards the future by drawing on experiences of the past and present, and both are grounded in communal learning (Wenger, 1998; Dewey, 1938/2015). The view of knowledge therein is one of the end-in-view, it must be reached for, it cannot be already 'had'. Just as the theory underpinning this thesis espouses that knowledge cannot be handed down ready-made to students, teaching from an enquiry perspective means knowledge is not handed down ready-made to teachers either. Subject and pedagogical knowledge are to be shared, researched and negotiated within an interdependent community (Wenger, 1998). This finding answers the conundrum regularly cited in academia that teachers cannot teach through enquiry because they do not have the subject and pedagogical knowledge to do so (Jerrim et al., 2020; 2014; Kang et al., 2012; Osborne, 2015; Shedletzky& Zion, 2005;Yoon et al., 2012).

The WW was the first step towards opening the periphery of the COP for teachers to allow access at a level where they were not overwhelmed by an alternative signature pedagogy. Figure 6.13 represents the teachers' position within the COP by the end of the WW.

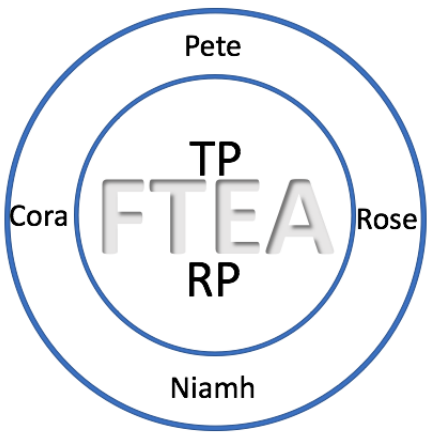


Figure 6.13: Teachers as peripheral members of the COP following the WW.

The Micro-evaluations were designed to engage teachers in learning about enquiry on a deeper level by scaffolding a move further into the COP, to enable them to competently participate in the practice (Wenger, 1998). The findings from this stage suggest that teachers need time and opportunities for learning about enquiry teaching from three different (and novel) perspectives – the student, the designer and the enquiry teacher. Doing this work away from the pressures of the classroom allowed teachers the space to make meaning of enquiry.

When teachers use a new practice and see the benefits to their students, then their beliefs begin to change (Ball and Cohen, 1999). Rather than use a high stakes setting, such as a senior cycle classroom, to see the benefits to students, the Micro-evaluation provided a very informal setting in which Rose and Pete could experience the transformative effect of FTEA designed lessons on students (Mia and Ava).

There was a reciprocal nature to the interactions between teacher, student and TP, which indicated another shift in the signature pedagogy towards teaching as facilitation (rather than transmission), and extended the communal learning in the COP to the students. Learning in this sense was based on mutual engagement, alignment with enquiry, and imagination, rather than memorisation of "ready-made" knowledge. Cogenerative dialogue between all participants contributed to the enquiry signature pedagogy by engaging students *and* teachers in their own learning process, providing opportunities for the student voice to be heard, and flattening the hierarchical nature of the teacher-student relationship associated with teaching as transmission (Siri and Lara, 2012). Designing and teaching their own lesson as a collaborative enterprise was a novel experience for Pete and Rose and this was where their understanding of enquiry gained real depth. For example, they realised that it was oxymoronic for students to know everything about a topic (osmosis) before they conducted an enquiry investigation. Crossing the boundaries of this nexus of perspectives was underpinned by the activation of three modes of belonging along which learning occurs - imagination, alignment with enquiry, and mutual engagement, none of which Pete or Rose was familiar with prior to joining the COP. In addition, crossing boundaries was supported by the FTEA as a boundary object around which each perspective was negotiated, and the passage from one perspective into another was scaffolded by the TP and RP, whose essential roles as brokers enabled the smooth movement of teachers between boundaries.

The micro-evaluations were an opportunity for Rose and Pete to continue their learning progression by deepening and building upon their nascent understanding of enquiry (Duschl et al., 2007). At the end of this research cycle Rose and Pete had moved further into the COP, while Ava and Mia gained a foothold as legitimate peripheral participants (Figure 6.14).

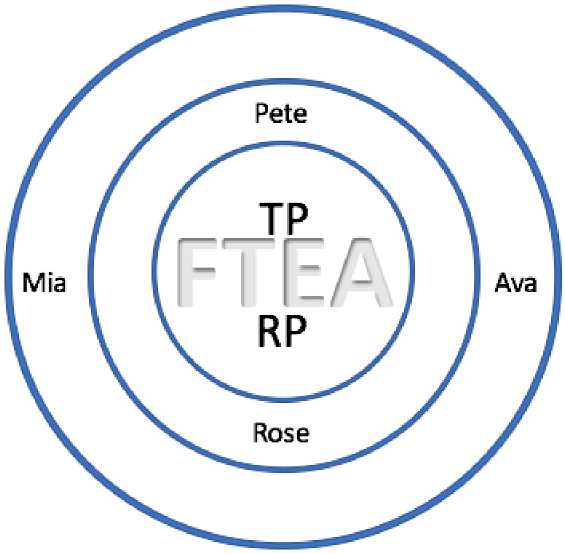


Figure 6.14: The evolution of the COP of enquiry practitioners following the Micro-evaluations.

Through the signature pedagogy of a COP, learning along the three levels of the signature pedagogy of enquiry teaching has been facilitated (Shulman, 2005). At the surface level, Rose and Pete learned to use the FTEA as a guide for designing lessons, at the deep level they learned to act as facilitators of enquiry, and at the implicit level their beliefs about teaching practical activities changed to embrace the uncertainty and forward looking view that thrives in social interaction.

This chapter also made a significant contribution to the refinement of the FTEA based on feedback from the Rose and Pete – the targeted users of the innovation. In the next chapter, the FTEA is enacted in two target settings. Based on the findings of this research cycle, PSTs are inducted into enquiry teaching on a larger scale, while in the secondary classroom, Pete and Rose bring enquiry to their own students, as fully participating members of the COP.

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Chapter 7

Fourth Design Cycle: Enquiry in the Target Setting

7.1 Introduction

The final stage of any DBR project sees the practicality and effectiveness of its output trialled in its target setting (Nieveen et al., 2012). This chapter brings the Framework for Teaching Enquiry Activities (FTEA) into two different target settings. In the first setting, the Practical Biology Teaching Module (PBTM), the FTEA was used as a reified object to assist novice teachers to begin their professional journey into enquiry teaching. From the perspective of a Community of Practice (COP), Pre-Service Teachers (PSTs) are at the very outer periphery, thus the Teacher Design Team (TDT) designed the module for learning at the periphery of enquiry teaching. The second setting, the In-Service Teacher (IST) classroom, saw the FTEA enacted in the senior cycle biology classroom by two ISTs, both of whom are practicing members in the enquiry-based COP. Figure 7.1 illustrates the positionality of participants within the COP. This chapter outlines and evaluates the effectiveness of the FTEA in both settings.

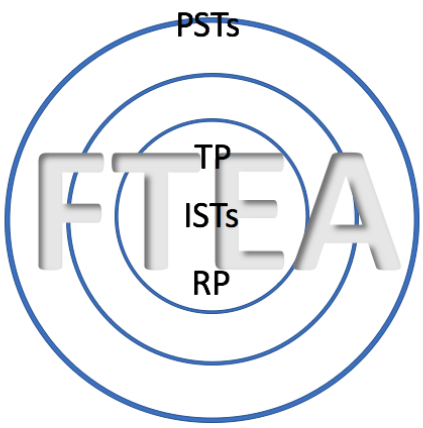

Figure 7.1: PSTs as legitimate peripheral participants and ISTs as fully participating members of the enquiry-oriented COP.

7.2 The PBTM

The group of pre-service teachers who took part in the third iteration of the PBTM had no experience of teaching senior cycle practical activities in a classroom situation. Therefore, it was important to consider that PSTs might have difficulty in seeing beyond the 'script' of their own classroom experiences (Loughran, 2014). Dewey points out that familiar patterns of teaching often persist, not on the merits of their rationale, but on the basis of tradition (Dewey, 1938/2015). This directly relates to Shulman's ideas about signature pedagogies, where future practitioners are educated for their new profession in ways that promote the traditions of the profession (2005). Without training underpinned by the signature pedagogy of enquiry-teaching, PSTs may model their practice after that which they received – confirmatory laboratory experiences (Kang, 2013), as evidenced in the previous iteration of the PBTM (Chapter 4). Guskey (2002) identifies one of the most neglected parts of professional development as sustaining change. PST beliefs need to be consistently (and sufficiently) challenged if they are to re-consider their assumptions about teaching science, and to effect changes in their practice (Loughran, 2014). Capps and Crawford (2010) add another dimension to the problem by suggesting that teachers with limited views of enquiry find it difficult to reach the "threshold" required to make gains in their understanding of enquiry, making it even more difficult to effect changes to practice.

One of the reasons regularly cited as to why PSTs views of enquiry are limited is that they do not have adequate subject content knowledge required to inform enquiry-based lessons (Luft and Hewson, 2014; Kang, 2013; Yoon, 2012; Capps and Crawford, 2010). Chapter 6 reported on how the dearth of subject content knowledge can be addressed by adopting an enquiry-oriented signature pedagogy within a community of practice. Therefore, the TDT approached the PBTM from the perspective that peripheral exposure to the practice of a COP would be the first step on their professional development journey and designed the module to enable PSTs to reach the threshold required to teach through enquiry. Figure 2 summarises the events of this iteration of the PBTM.

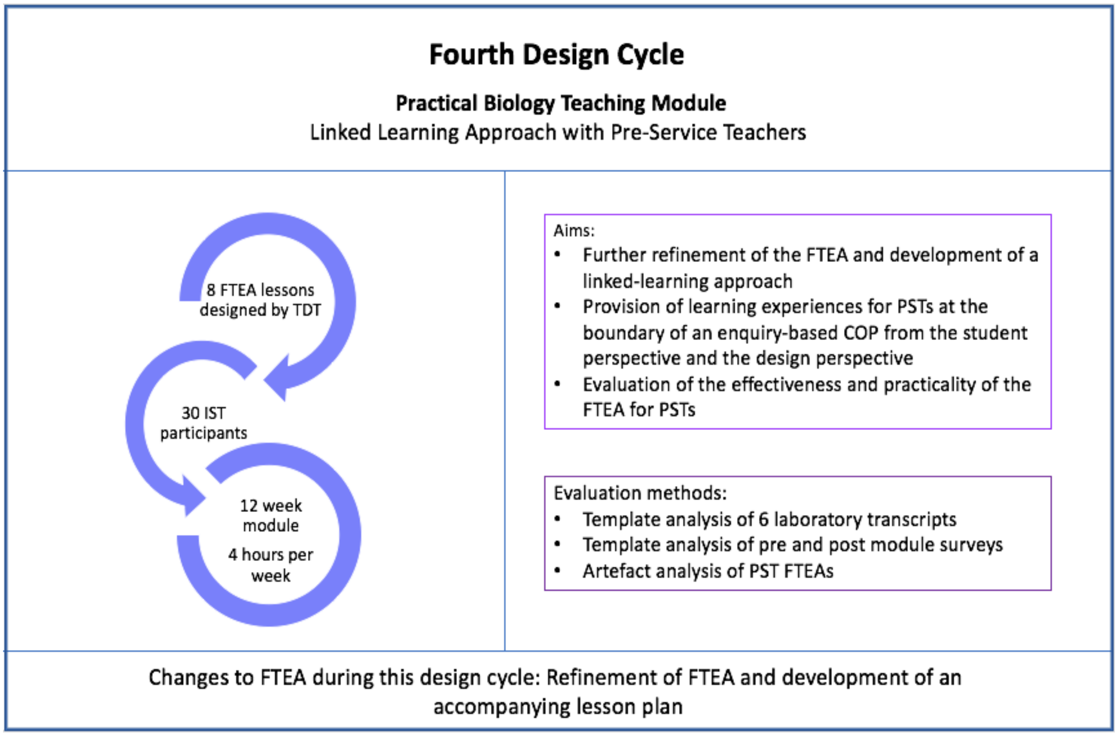

Figure 7.2: Events of the PBTM

7.2.1 Changes to the PBTM

Many teacher educators advocate for a teacher-as-learner approach that supports beginning teachers to experience how students learn, which leads to the development of a deeper understanding of the effectiveness of a pedagogical approach such as scientific enquiry, resulting in teacher development and change (Loucks-Horsley, 2010; Hamilton, 2018; Vasquez and Cowan, 2001; Loughran, 2014; Eick and Dias, 2005). Jones and Leagon (2014) recommend building in opportunities for PSTs to see successful teachers model new practices and experience success with the new practices. Therefore, the PBTM was redeveloped to allow 30 PST participants to take part as learners in 8 FTEA designed lessons, delivered by the TDT, over the course of 12 weeks. Towards the end of the module, PSTs were asked to design their own lesson using the FTEA. This approach is supported by Windschitl (2003) who highlights how providing real classroom contexts is important for PST training and that PSTs who had authentic experiences of enquiry in their undergraduate training were more likely to incorporate it into their practice.

In terms of a COP approach, this meant tempering the model of professional development from Chapter 6, to take into account that PSTs did not have any actual experience of teaching practical activities in a senior cycle classroom, and may not know enough to engage in a COP on the same level as ISTs. PSTs were afforded access to legitimate peripheral participation in the practice of enquiry-teaching at the very outer edge of the community boundary (Wenger, 2015). The COP was structured to incorporate three modes of belonging (hence learning), imagination, engagement and alignment, since it is in the intersection of all three, that an identity as enquiry practitioners is found (Wenger, 2015). Chapter 6 demonstrated that deep learning can occur at the boundaries of a nexus of perspectives, but here, PSTs were only exposed to one perspective at a time, and the nexus was limited to two perspectives – learner and designer (Wenger, 1998). Following Burgoon et al.'s (2011) claim that transformational change may not occur by challenging conceptions about science *teaching*, the teacher perspective was excluded in this case to allow for a focus on science *learning*, through peripheral participation as learner and designer.

Covid-19 restrictions at this time meant that laboratory sessions across the university were reduced to two hours maximum (previously there were three hours allocated to the laboratory session). The TDT developed and delivered a one-hour pre-lab online each week, where the FTEA for each weekly experiment, along with background subject content knowledge, were shared with PSTs. The laboratory sessions were designed in the same vein as the Walkthrough Workshop (WW) from the previous design cycle (Chapter 6), with PSTs acting as students each week, while the TP and RP modelled how to teach authentic enquiry experiences. The module culminated with PSTs designing their own lessons using the FTEA.

Following Luft (2001), who provided teachers with theoretical aspects of enquiry combined with practical approaches to teaching, over the course of 12 weeks, one hour each week was devoted to discussions of academic literature, including research-based evidence of why recipe-teaching does not support student understanding (Abrahams and Millar, 2008), and an introduction to the theoretical framework underpinning the FTEA. Appendix 7.1 provides the full reading list. Table 7.1 provides a summary of the weekly structure of the module.

Table 7.1: Breakdown of weekly schedule for the PBTM

1 hour (online)	Discussion of weekly academic reading
1 hour (online)	Pre-lab introduction to the weekly FTEA, subject content and laboratory technique
2 hours (in person)	Enquiry-led laboratory session

Data from this cycle took the form of

- Pre- and post-module surveys (Appendix 7.2)
- Six transcripts of laboratory audio recordings
- A sample of one TDT designed FTEA (Appendix 7.3)
- A sample of one PST designed FTEA with accompanying resources (Appendix 7.4)

Following on from the Micro-evaluation stage, the TDT collaborated on a re-design of the FTEA to make the Leap stand out as the bridge between the inductive and deductive steps. In addition, 'observation/data analysis' is identified on the FTEA as a part of both the diagnostic and the applied experiments, and it also clarifies that the hypothesis should be preceded by a question. Figure 7.3 illustrates the final design of the FTEA for the Leaf Yeast experiment.

For PSTs, an accompanying lesson plan was designed to mirror the format of the FTEA by clearly defining the three stages in the Complete act of Thinking – Induction, Leap, and Deduction (Dewey, 1910/2012), along with a section for each aspect of the FTEA (Table 7.2)

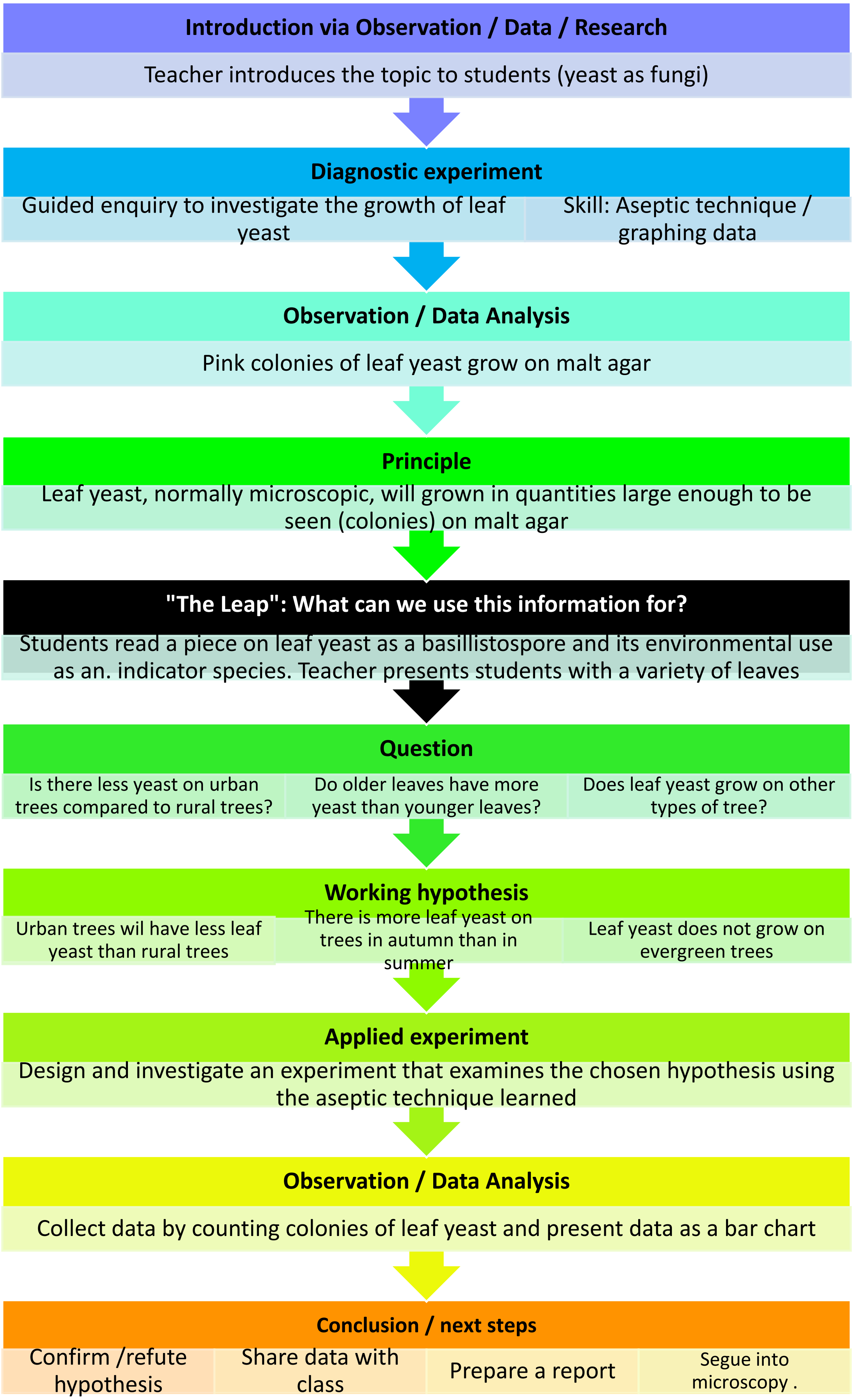

Figure 7.3: Final FTEA design for Leaf Yeast

Table 7.2: FTEA lesson plan for the Leaf Yeast experiment

<table>
<tr><td colspan="2">Title of Experiment: To investigate the growth of leaf yeasts using agar plates and controls</td></tr>
<tr><td colspan="2">Induction</td></tr>
<tr><td>Introduction</td><td>Students need some understanding of
leaf yeast and the conditions under which it grows
leaf yeast as an indicator species
leaf yeast basidiospores</td></tr>
<tr><td>Diagnostic experiment</td><td>Investigate the growth of leaf yeast using malt agar plates and controls</td></tr>
<tr><td>1. Preparation for Experiment</td><td>Reading comprehension for students (inc. tips for teachers) –
Make malt agar plates
Set up equipment
Plan for extension exercises and have the relevant supplies available
Prepare a relevant protocol for students
See also Tips for Teachers</td></tr>
<tr><td>2. Laboratory skill attainment</td><td>Teacher: Making up malt agar plates
Student: Aseptic technique, counting colonies</td></tr>
<tr><td>3. Risk assessment</td><td>Risk assessment carried out by teacher beforehand and sheet filled in and signed</td></tr>
<tr><td>4. List of equipment needed</td><td><u>To make agar</u>
Malt agar powder. Bunsen burner
Sterile petri dishes. Large beaker
Stirrer Deionised water

<u>For the experiment</u>
Ash Leaves – from a variety of areas (wood, country, town) and a variety of months (June, July, August, September)
Other leaves – sycamore, alder, oak, holly (evergreen)
Sterile malt agar plates Vaseline (in a syringe)
Disinfectant / 70% Alcohol Cork borer / scalpel
Chopping board or paper plates Bunsen burner
Lighter Forceps
Parafilm / tape Marker
Paper towels</td></tr>
<tr><td>5. Teaching methodology</td><td>1. Students can make their own malt agar plates (optional with guidance from teacher
2. Students learn aseptic technique using the method to investigate the growth of leaf yeast – (see also lab video and protocol)
Use the worksheet in conjunction with the procedure as</td></tr>
</table>

	an assessment for learning tool
Observation/ Data Analysis	Students observe the growth of pink colonies of leaf yeast on the agar plates Count the number of colonies produced by each leaf disc and record this number
Principle	Students see that leaf yeast, grows in pink colonies large enough to be seen on malt agar
Data presentation analysis	Each student works out the average number of colonies per leaf disc Students estimate how many colonies might be produced by an entire leaf (optional) Class data is collected
The Leap	
What can we use this information for?	Students are given a reading comprehension and are presented with leaves from different trees, ash leaves collected during different months, and ash leaves collected from urban and rural areas. This helps to scaffold their thinking.
Deduction – (real world application)	
Question and Working hypothesis	Based on what they have read and the leaves presented to them, students come up with a question and a working hypothesis, and share with the class. <u>Examples</u> • Does leaf yeast grow on trees other than ash? • Do trees from urban areas produce less colonies of leaf yeast (as it is an indicator of air quality)? • Is there is more leaf yeast on leaves in October than in June?
Applied experiment	Students design an experiment using the aseptic technique they learned during the diagnostic work, to investigate their question and assess their hypothesis
Observation	Collect new data to answer the question asked
1. Data collection	Students count colonies of leaf yeast growing on their agar plates. They record their results in a table
2. Data presentation and analysis	Students present their results in a bar chart and report on whether they can confirm or refute their hypothesis
3. Data reporting	Students create a comparative write up of the entire investigation (diagnostic and applied experiments) as a report/poster etc.
Evaluation	Teacher evaluates the teaching during the lesson under the following headings:

	What worked – what did students understand? What needs improvement- where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge? What will I do differently next time? Teacher evaluates the student learning by examining the student report or poster for evidence of understanding and by giving students LC exam questions

In keeping with Dewey's advocacy of learning along a continuum (Dewey, 1938/2015), the TDT not only designed FTEAs that formed intra-connections between inductive and deductive experiments, they actively sought to form inter-connections between one FTEA and another. These connections were developed as an act of imagination, engagement and alignment by the Teacher Practitioner (TP) and Research Practitioner (RP) within their COP (Wenger, 1998). A 'linked-learning' pathway across the eight FTEAs that could actively connect student learning across these activities so that students might better understand core biological principles was developed. Figure 7.4 provides a map of how these activities were inter-linked. Appendix 7.3 contains an example of the FTEA developed by the TDT for the Enzyme Immobilisation activity.

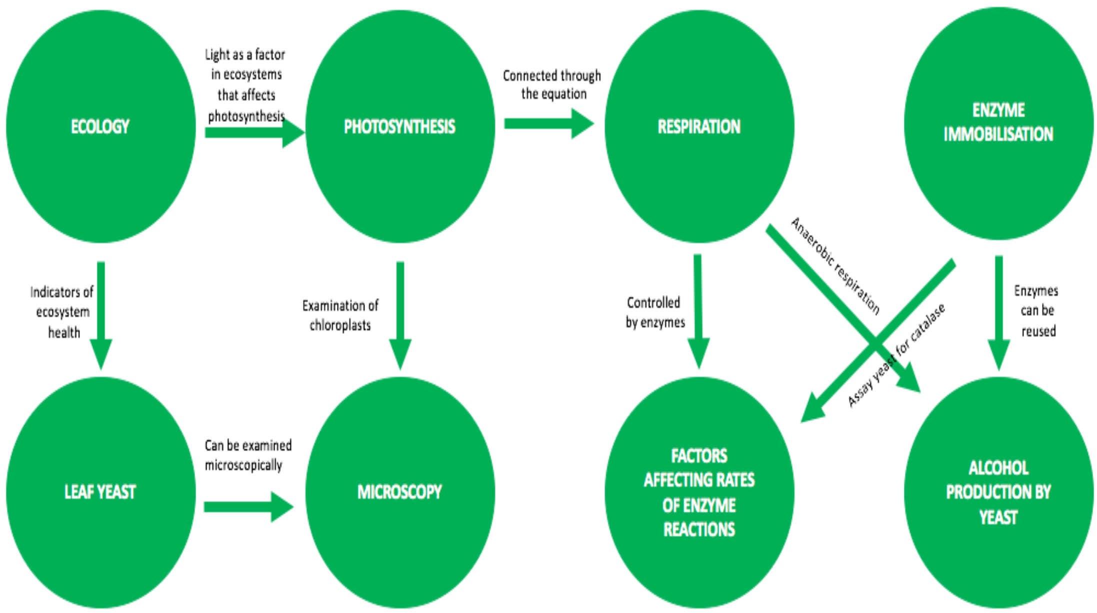

Figure 7.4: The linked-learning approach to the PBTM

7.2.2 Evaluation of the Student Perspective:

Using Template Analysis to analyse data from audio recordings of peer to peer conversations and conversations with the TP during the laboratory sessions, the following section presents evidence that the three modes of learning were embedded in the linked-learning approach to enquiry. PSTs clearly showed that from the student perspective, they were able to engage in scientific enquiry in a way that fostered understanding and promoted thinking as an integral part of the activity.

Engagement:

The first mode of learning, engagement, was a three-fold process which was found within the ongoing negotiation of meaning, the formation of trajectories and the unfolding of histories of practice. When all three of these processes were present, engagement "becomes a mode of belonging and a source of identity" (Wenger, 1998, p.174) which gave rise to a COP. The following excerpts show how a COP could be formed at the very periphery, when students were given experiences that blended meaning, trajectory and history.

Negotiation of meaning:

During the enzyme experiment PSTs were put in situations where they had to revise their hypotheses, because the data they collected contradicted their original predictions.

> TP: You had to change your hypothesis Ron?
> Ron: Yeah, I did the same experiment with potato and potato grows in acidic soil so my hypothesis was that the optimum pH would be a bit lower, but I found it was actually the exact same. It doesn't matter the soil pH it grows in the catalase always works at the same pH
> *Enzyme lesson*

The FTEA created a space in which students could make mistakes, refute hypotheses or repeat experiments because they had enough knowledge to confidently pursue the applied experiment, only conceding their hypotheses should be refuted *after* they had gathered evidence to that effect. Ron's comment showed not that he was wrong, but that he learned something by doing the applied experiment. This epistemological shift towards enquiry means that students can begin to realise a previously aspirational aim of working like 'real' scientists, when the focus of the activity is on the enquiry experience rather than the production of a phenomenon (Wei and Li, 2017).

Formation of trajectories:

This process aligns with Dewey's vision for learning along a continuum, where one learning experience informs the next (1938/2015). May and Jas were chatting as they work and Jas could be heard applying the technique for using the microscope, learned in the diagnostic experiment (moving to a higher power lens, adjusting the light), to the applied experiment (viewing chloroplasts in Elodea).

> May: It's looking good. Oh I can see them [excited]
> Jas: Oh, it actually doesn't look that bad. I don't know if it's good enough to see the chloroplasts. I think I need to go deeper [moves up to a higher power lens]. Oh you actually can [excited]. I need to adjust the light though. Yeah I can see like green dots.
> May: Yeah, that's what I'm looking at. I'm going to take a photo of that.
> Jas: Do it
> May: I'll send it into the chat [class social media group]
> Jas: Wow! I don't mean to brag but I'm very good at biology
> *Microscopy lesson*

May and Jas were so pleased with what they saw under the microscope that May decided to share a picture of it with her classmates and Jas joked about his biology prowess. This was another example of how the 'little things' were actually the 'big things' that led to learning. Jas's confidence in his ability was not accidental, it came about following a carefully designed FTEA, that allowed for him to experience an alternative way of sense-making, which reinforced his sense of confidence in himself as a student (Wenger, 1998). PSTs learned to use the microscope by staining and viewing onion cells(the mandatory experiment on the LC syllabus), but onion cells do not represent typical plant cells because they do not contain chloroplasts. The TDT crafted a Leap activity in which cytoplasmic streaming of chloroplasts could be observed in Elodea, providing an opportunity to observe plant cells with chloroplasts, which directed the trajectory of learning the next day towards photosynthesis.

Unfolding histories of practice:

A shared history is “a combination of participation and reification intertwined over time” (Wenger, 1998, p.87). The reified FTEA activities that Fin participated in were beginning to influence how she was thinking about practical activities. She identified how she had to think about what she was doing in the laboratory sessions and the importance of ‘hard’ peer discussions about potential hypotheses which can lead to further investigations:

> Fin: I find this more interesting than when we went into the biology labs and we were “right this is it, we’re doing this, that’s it” because you’re literally just copying it, whereas this way you actually have to think about it
> TP: And when you were chatting to other people today, were you chatting about “what I’m doing at the weekend or whatever” or were you chatting about this?
> Fin: Actually we were talking about this, “what question would you ask for this and what would you ask for this” because I was like “oh I don’t know if this is an actual question” or “is this actually something you’re able to do or not” so you find it hard talking about it and then you’re like “ok that is a good question” and you’re like “right I’ll do that”
> *Enzymes lesson*

Fin was able to compare recipe-based laboratory activities with her experience in the PBTM and indicated a preference for the experience that fostered thinking. Taking part in the 12 week module contributed towards a shared history of practice for Fin (and her classmates) and laid the foundation for an unfolding new history of enquiry-practice. Throughout the 12 weeks PSTs mutually engaged with the TDT and with each other to produce a local regime of competence at the very boundary of authentic enquiry for science teachers (ibid., 1998).

Alignment:

From the perspective of the TDT, the second mode of learning, alignment, entailed the ability to communicate the purpose, methods and criteria of enquiry to the PST group. In itself it was a creative process because it required crossing boundaries using boundary objects (the FTEA) to convince, inspire and unite diverging perspectives (Wenger 1998). The work of alignment can entail the process of “imposing one’s view, using power and authority” (ibid., p.186) and to some extent this was what the TDT did during this enquiry-based module, in order to breach strongly held PST beliefs.

This was evidenced below where Ann was trying to bring thinking into her own classes as a direct result of partaking in the module, because she recognised her own experience was devoid of thinking:

> Ann: I'm trying to do that with the classes I'm teaching now, is trying to get them to question it rather than just accept it as fact
> TP: And are you doing that because you've come to this module or are you doing this because this is the way you work anyway?
> Ann: I think because of this module, I see that it's a good way of learning and it's a good way of getting them to think
> TP: So, do you find that it has made you think?
> Ann: Yeah
> TP: Ok instead of just coming in and following instructions?
> Ann: It has. I would have just usually just learned things off, accepted it as fact and never actually thought about it or anything like that
> *Microscopy lesson*

May was asked if she thought this way of teaching would conflict with the leaving certificate exam and her answer directly correlated to Dewey's view of education as an amalgam of school experience and everyday experiences (1938/2015). Making the experience relevant to the student is an excellent way of promoting engagement and interest in the subject (Dewey, 1925/1958):

> May: Well I think it gives them a better application of applying it to everyday, so it's not just they're coming in and doing it and learning it and not knowing why they're doing it and the reasoning behind it. It gives a scientific reason, you know, so air pollution and all that, that's a big influence and a big factor today with global warming and everything anyway so they can see that it's having an effect on plants as well as humans as well if they apply it to something like that
> *Leaf yeast lesson*

There was one caveat to changing PST beliefs during the module, where PSTs indicated that they would revert to didactic methods for parts of practical activities that are commonly perceived to be difficult for students. Below is one example where two PSTs were talking during the heart dissection:

> Nic: It's quite hard to find the coronary artery. I can't imagine secondary school students finding it easy
> Ken: It would definitely be something that you'd be better off just showing them
> Nic: Yeah maybe demonstrate rather than ask them

> Ken: Because they'd find it very difficult to do it. You could try and let them do it but I'd say you're better off just to demonstrate because they'll find it very difficult.
> *Heart dissection lesson*

They both agreed that it would be better for the teacher to demonstrate this task rather than to ask students to try it themselves. From the scoping stages this approach was shown not to lead to meaningful understanding, rather it reduced learning opportunities for the students, by removing thought from their actions. 'Ability' was used here to pre-judge whether students would be capable of learning through enquiry or not, but it is grounded in a system that sees ability as an ability to memorise information (Burns et.al, 2018). It does not allude to a student's ability to think or to problem solve, which is the basis of enquiry. PSTs were straddling two epistemologies, one based on knowledge that is certain (the end-in-itself), and the other on knowledge that is uncertain (the end-in-view) (Dewey, 1925/1958).

Imagination:

Imagination is a creative process that reaches beyond direct engagement or, as Wenger (1998, p. 176) describes it, "looking at an apple seed and seeing a tree". The work of imagination is anchored in the social world, meaning it is not an individual process. In addition, creating connections in a future-oriented way is an essential part of it. Thus, every FTEA is a social enterprise, grounded in imagination; "generating scenarios and exploring other ways of doing what we are doing, other possible worlds" (ibid., 1998, p.185). The excerpts below were recorded following the Leap activity in different laboratory sessions. The first one, showed how Gal's group unintentionally conceived of an applied experiment that formed a connection between two mandatory LC experiments:

> Gal: We saw from this that the optimum pH was 7, so we were going to keep the pH and then vary the temperature, because the temperature is 25, to see if the temperature would have an effect on it.
> TP: And that's brilliant. Actually that's an experiment on the leaving cert course.
> Gal: Is it?
> TP: Yeah, so isn't it wonderful that you do this pH experiment and then-
> Gal: It leads into it
> *Enzymes lesson*

In the Enzyme Immobilisation FTEA, every group immobilised yeast in the gel beads and then assayed the beads for the enzyme sucrase during the diagnostic experiment. One Leap activity (as quoted by the TP, below) required that PSTs work together to develop an applied investigation into whether immobilised enzymes could be re-used:

> TP: So you have 20 minutes to prove that the beads can or cannot be re-used and to work with an enzyme that you have already come across, either todays enzyme or one from a previous experiment. You have all the equipment in front of you that you need. Please chat with the people at your desk, see what you come up with.
> *Enzyme immobilisation lesson*

Mol's group looked at the materials available to them on their desk and linked the materials to the assay for catalase that they had conducted the previous week:

> Mol: What enzyme? ……Obviously they can be re-used but I'm just trying to think what enzymes we've used…… We used catalase.
> Jan: Have we got catalase?
> Bob: Yeah because look we have the hydrogen peroxide and we have the washing up liquid…….. The buffer is in there
> *Enzyme immobilisation lesson*

Van's group developed the same hypothesis but the thought process behind it was very different. Val used his knowledge of the structure of a cell, and asked if yeast had the same particular cell organelle:

> Van: True. Wait do yeast have peroxisomes?
> TP: Well if it does then it must have what enzyme?
> Van: Catalase
> TP: Right?
> Van: Yeah
> TP: So are you testing for catalase?
> Van: We are testing for catalase
> *Enzyme immobilisation lesson*

Both of these extracts indicated the importance of the view of enquiry underpinning the FTEA which allows for students to think in different ways and still attain learning goals.

Data collection and analysis by students was identified in earlier research cycles as overwhelmingly absent from practical activities. The extract below shows that when decisions are left to the learners about collecting and presenting data, they were more than capable of communally developing creative solutions. May and Jas below were deciding how to collect data from the leaf yeast activity. They not only figured out that they should count colonies of Leaf Yeast but May showed a wonderful leap in imagination when she suggested that they could use the data to estimate the amount of yeast on the entire tree:

> Jas: You'd have to roughly measure the surface area that it covers.
> May: Could you measure the surface area?
> Jas: Yeah, well how else?
> May: I don't know…….. Could you try and count?
> Jas: Oh yeah, I suppose you could count the colonies actually
> May: Count the colonies and get a rough estimate
> Jas: That actually makes more sense
> May: And I wonder could you do it where, if that's the amount of colonies on one leaf, could you look up roughly, if you were to estimate how many leaves are on that tree, you could estimate how many colonies-
> Jas: -are on the tree, yeah
> *Leaf yeast lesson*

When imagination was built into learning, it generated new relations through time and space and created a very different sense of self for the learners who participated in it – they were not waiting for instructions about what to do, they were actively creating their own ways of doing in the present by projecting ideas into the future. Imagination levels the playing field, by making learning (not memorising) the goal, instead of looking at one student as more 'able' than another.

7.2.3 Evaluation of the Design Perspective

Having experienced all three modes of learning from the student perspective, the PST group were then tasked with creating their own FTEA for one Leaving Certificate mandatory activity from the design perspective. This section presents the design work of one PST, Nic, who designed an FTEA around the Food Tests experiment:

> Nic: I had some ideas about food spoilage. Not too sure, I'd have to do a bit of research on it first, that's this weekend's job. I already thought about linking it to enzymes or maybe the digestive system so I'm going to have to figure out how to link them. At least now I'm thinking of links
> TP: You're thinking about linking. And even when you're thinking about the food tests. "what can I use these tests for?". So here you see we've given some options, so you can also give options, it doesn't have to be-
> Nic: Yeah that's what I was thinking -
> TP: - and it can be a bit unrealistic at the moment. So what we do is we go 'oh that's a great question but we don't have that stuff, here's what we do have, can you work with this?' But when you're thinking of something, the world is your oyster.
> Nic: Could I think of something, maybe it's not on the course, but what about illnesses, you know people who are coeliac, could they eat this, could they not eat this?
> *Enzyme lesson*

The conversation, above, showed that Nic was employing the three processes of learning from the design perspective. Through mutual engagement with the TP she shared her ideas about the trajectory her design could take. The conversation helped her to negotiate a path through the meaning of the FTEA to create a continuum of learning. She was demonstrating alignment with the view of enquiry taught throughout the PBTM where she talked about figuring out how to 'link' her ideas together. She was also using imagination when she thought about how her FTEA could be connected to her students' everyday experience of diet and dietary diseases. The future-oriented nature of this discussion further indicates a potential solution to the issue of low subject content knowledge among PSTs (Capps et al., 2012). Nic specified that in order to fulfil the requirements of designing the lesson, she had to "do a bit of research on it first", where she would broaden her subject knowledge in the process. This research is evidenced in her FTEA design (Figure 7.5) which indicated that she researched and developed a Leap activity that leads to *four* potential applied experiments, some of which required content knowledge outside of the LC syllabus (e.g. the emulsion test). Nic also linked the starch test to food storage in plants, which formed a precursory link to photosynthesis. Appendix 7.4 contains Nic's resources for this lesson.

As an assessment task, all students were asked to present a portfolio containing their FTEA with an accompanying Lesson Plan, and lesson resources (risk assessment, worksheets, reading material, presentations). A sample of nine PST lesson design assessments is used here to determine how well PSTs developed their own FTEAs. Compared to the previous iteration of the PBTM, where practical activities were still mainly recipe-based, in this iteration there was a more enquiry-based focus to the lessons designed by PSTs. The overall strengths and weaknesses of the FTEA / Lesson Plan are summarised here:

Strengths

- All of the lessons developed were grounded in the concept of teaching a diagnostic experiment and expanding on that knowledge using an applied experiment, reflecting the Complete Act of Thinking underpinning the view of enquiry in this thesis
- For the Leap activity, all PSTs researched practical activities beyond the traditional mandatory experiments on the LC syllabus, indicating a potential increase in their practical subject content knowledge
- Most students demonstrated a good understanding of how to link concepts together using the FTEA/Lesson Plan

Weaknesses

- The Leap activity was underdeveloped for more than half of the sample of PSTs selected. This was mainly due to a lack of clarity around how the Leap was scaffolded to get students to ask their own questions, but if one considers that PSTs have very limited experience of teaching students in a practical setting, this finding is not surprising.
- While all PSTs used the Lesson Plan template, three did not use the FTEA to design their lesson

Given this was their first professional development opportunity for enquiry teaching, it is encouraging that so many PSTs were able to design enquiry-based lessons using the FTEA/Lesson Plan.

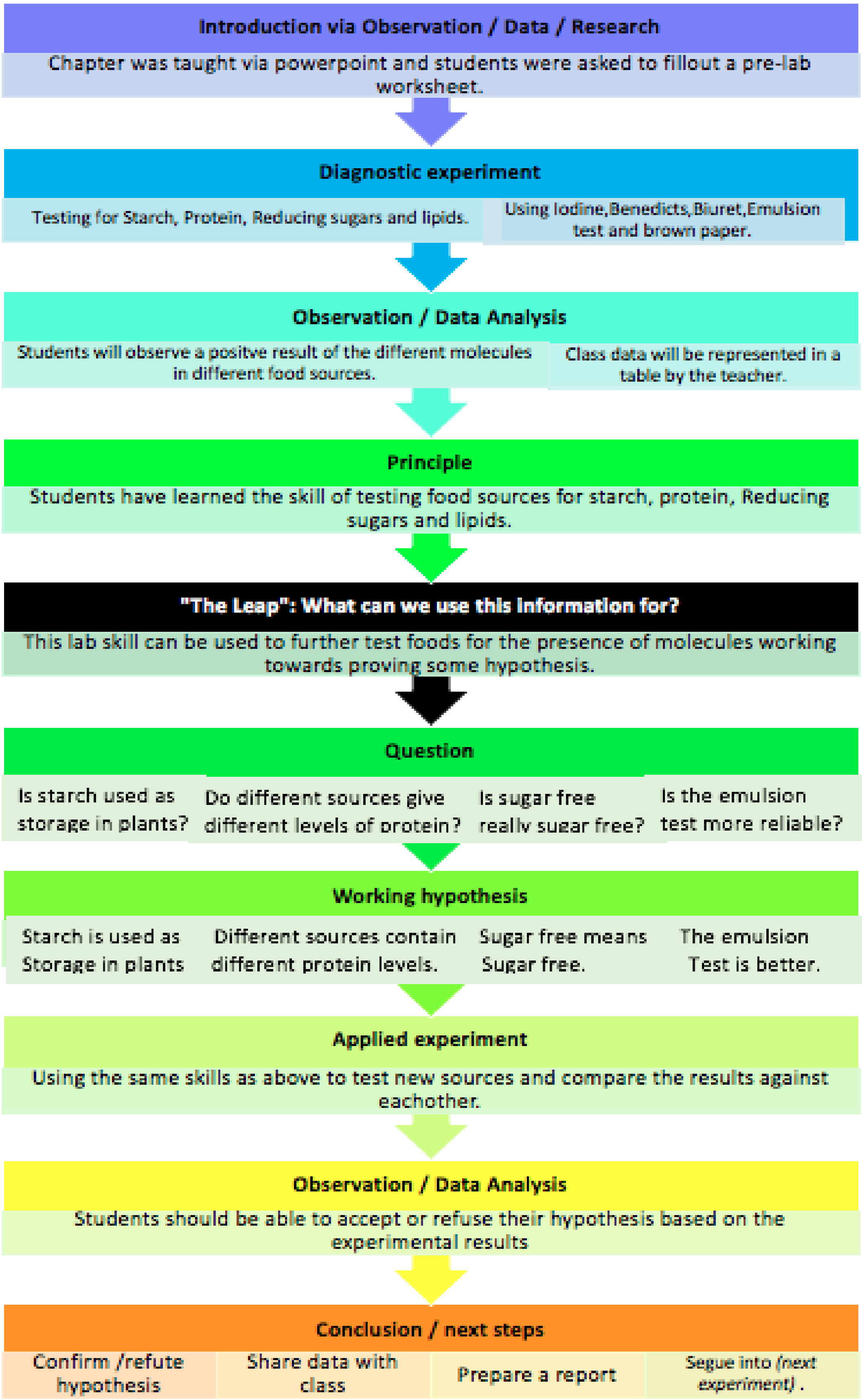

Figure 7.5: A PST designed FTEA relating to the food test activity

7.2.4 Evaluation of PST surveys

Students completed anonymous surveys before (22 respondents) and after (30 respondents) they undertook the module. The survey, adapted from the Structured Enquiry Observation Schedule (SEOS), was based on a Likert-scale PST assessment of whether the enquiry-based skills recommended in the syllabus documents were evident in the practical lessons taught. Appendix 7.2 contains the full set of data for this survey, with the most salient findings presented here.

Figure 7.6 illustrates that after taking part in the module, the majority (63%) of PSTs felt that they could ask a question and formulate an hypothesis with little-to-no assistance from the teacher. Pre-PBTM no PST had experienced hypothesis formation independently of the teacher, while for a large number this aspect of practical work was not evident or was conducted solely by the teacher. It is suggested here that the inclusion of a question and an hypothesis in the FTEA prompted difference in responses.

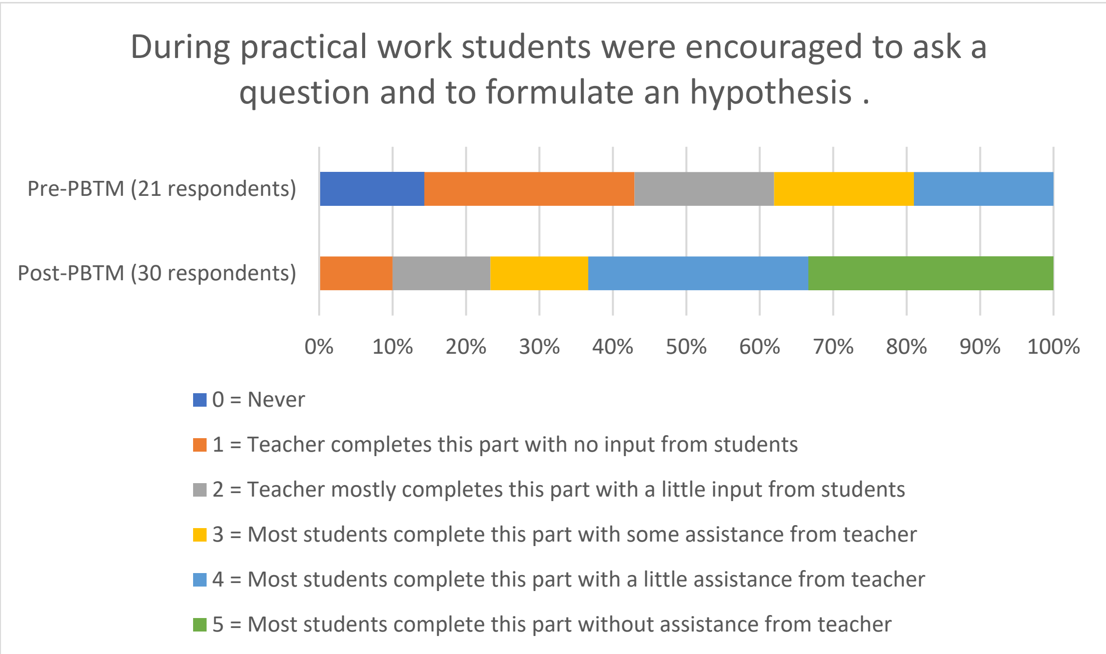

Figure 7.6: Likert scale responses of PSTs indicating their ability to ask a question and form an hypothesis

In the scoping stages, there was a dearth of collection, recording and analysis of data by students during practical work. Following the PBTM, over 70% of PSTs noted their own ability to perform all three skills with little-to-no assistance from the teacher. Figure 7.7 illustrates that PSTs ability to analyse data and draw conclusions with little-to no assistance from the teacher improved dramatically after the PBTM (73%), compared to beforehand (29%). Similar patterns were also seen in their ability to collect data and to record data appropriately as a table or graph. Within the lesson plan for the FTEA, the lesson designer has to stipulate how they will facilitate students to collect, record and present data, which may account for this increase in independent student participation.

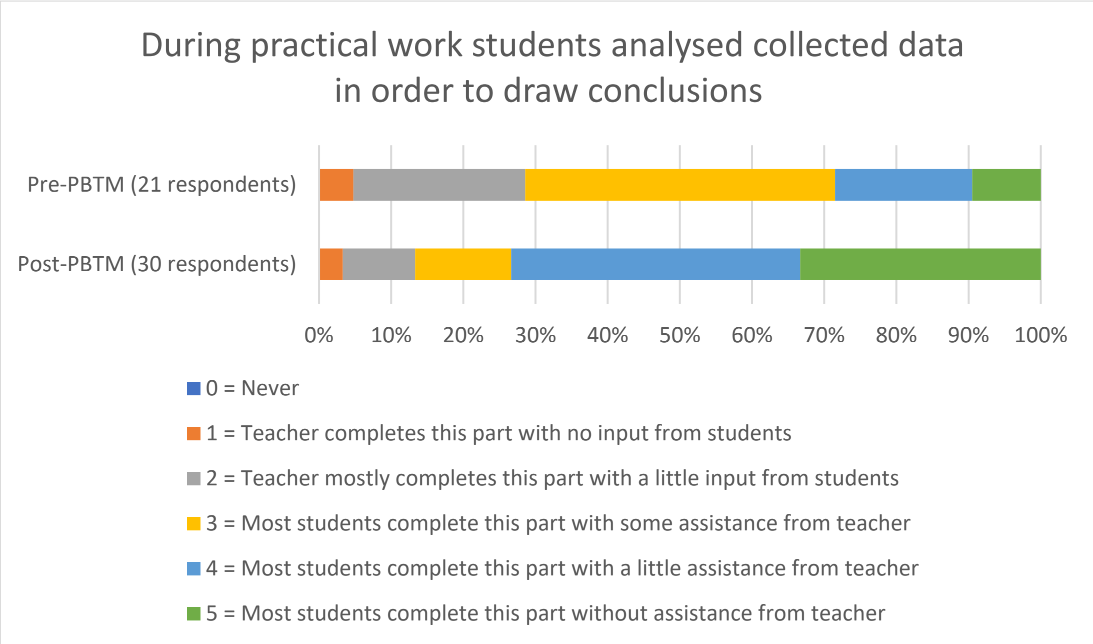

Figure 7.7: Likert scale responses of PSTs indicating their ability to analyse data and draw conclusions

In a reflection of the inclusion of a deductive experiment in each FTEA designed lesson, Figure 7.8 shows that 60% of students were able to conduct an applied experiment with little-to-no assistance form the teacher. Prior to the module, this number was 5%, with 38% of respondents indicating that application of experimental findings to further experiments was not a feature of the practical work they conducted.

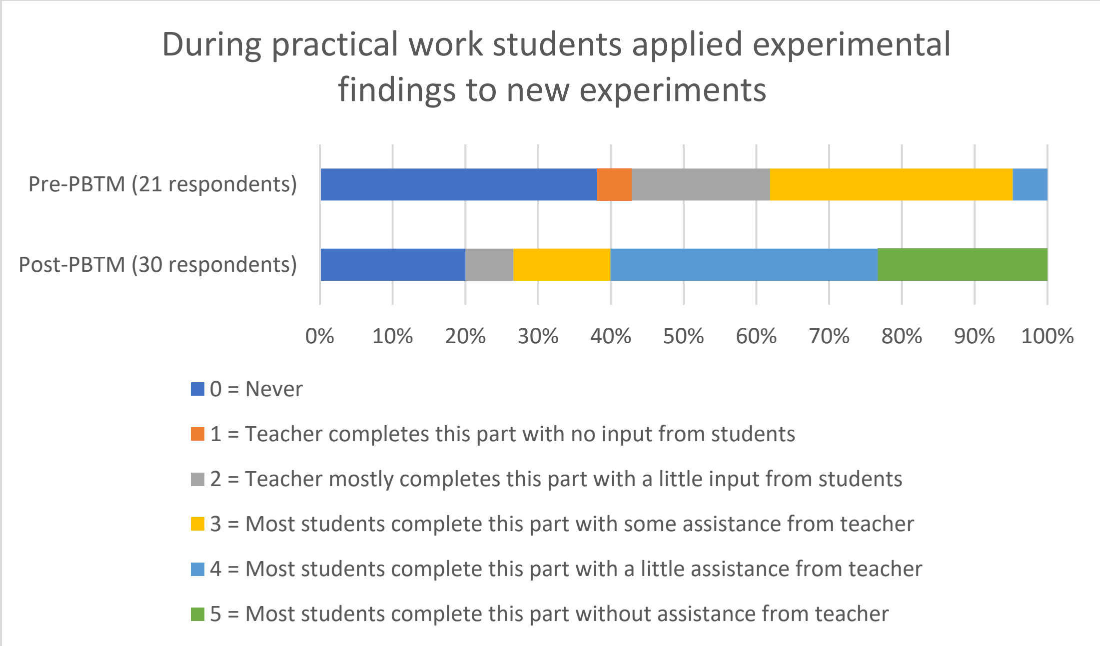

Figure 7.8: Likert scale responses of PSTs indicating their ability to apply experimental findings to new situations

Finally, Figure 7.9 indicates that pre-PBTM the majority (71%) of students never designed their own experiments during practical work. This compares to 53% of PSTs post-PBTM who designed their own practical work with little-to-no assistance from the teacher. Again, the FTEA is specifically designed so that students are scaffolded to design and conduct their own applied experiments.

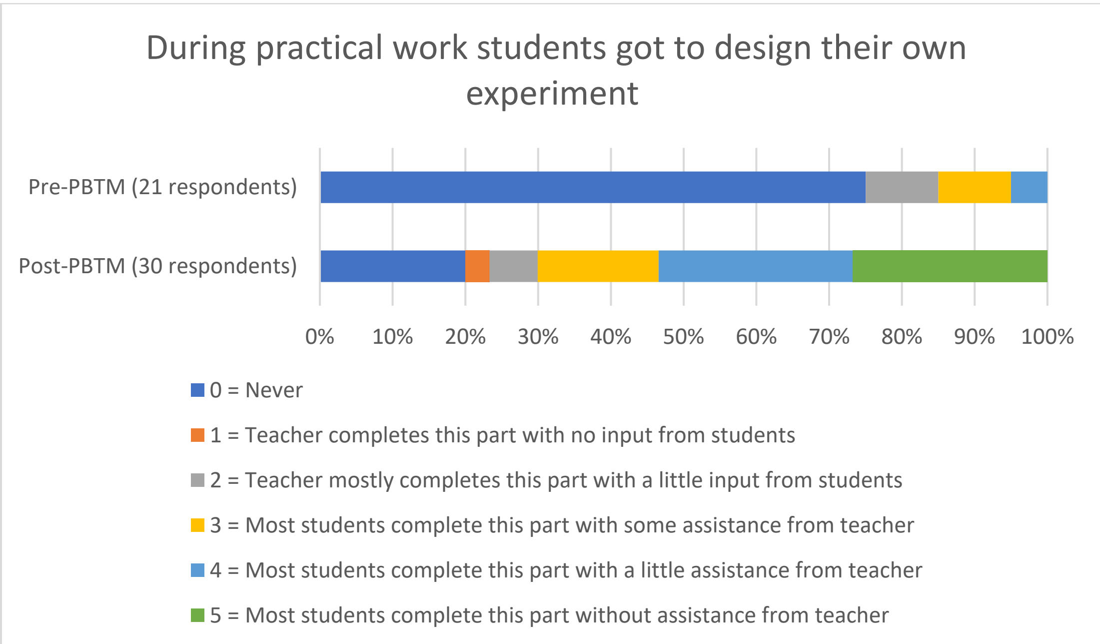

Figure 7.9: Likert scale responses of PSTs indicating their ability to design their own experiment

Overall, following the PBTM, a general trend emerged where, following the module, it was the student (and not the teacher) who was increasingly carrying out the skills listed. Worth noting also was the most common overall response rating before the module was 3 (students completed this part with some assistance from the teacher) and after the module was 5 (most students completed this part with no assistance from the teacher). Overall the module was successful in incorporating the enquiry skills, that had been absent during the scoping stages, into practical activities, and in improving the level of student engagement in the skills that were already evident for PSTs.

7.2.5 Discussion

Scholtz et al. (2004), cite the importance of matching the programme of development with the perceived needs of the teachers and the situations in which they work. This iteration of the PBTM matched the three outputs of DBR – the FTEA as an educational innovation, the Complete Act of Thinking as a research-informed theory for enquiry, and the Community of Practice approach to Professional Development– with the needs of PSTs. Salient findings of this design cycle are summarised here.

1. The PBTM was redesigned by the TDT to make understanding enquiry more accessible for novice teachers in the following ways:

- The FTEA, as an educational innovation and a reified boundary object, was adapted to the needs of the PST group by making the Complete Act of Thinking more pronounced in its design (See figure 7.3)
- Taking account of PSTs as newcomers to the practice of teaching practical work, a lesson plan was developed by the TDT to align with the FTEA so that PSTs could see how the FTEA was translated into a lesson by the TDT (see Table 7.2).
- The TDT also introduced academic reading into the module to support the work of changing the signature pedagogy to enquiry teaching, and to evidence the ineffectiveness of recipe-teaching.

• The TDT continued their work as at the boundary of the COP, using their different, yet complementary, skill sets to design each FTEA for this module (Wenger, 2015). Their work of constant negotiation of meaning that "generates new circumstances for further negotiation and further meanings" (Wenger, 1998, p.54) led to the linked-learning approach, where links are formed within *and* between each FTEA, creating a continuum of learning that realised the Complete Act of Thinking within each link (Dewey, 1910/2012; 1938/2015)

2. Teaching PSTs to teach through enquiry requires a preliminary induction into enquiry experiences as learners, rather than as teachers.

Following Loucks-Horsley et al. (2010) the primary work of the PBTM was changing the beliefs of PSTs around practical teaching. This was achieved by invoking a sense of belonging within the signature pedagogy of enquiry as legitimate peripheral participants. Teacher-as-learner experiences laid the foundation for tentative changes in beliefs about teaching practical work through exposure to the boundaries of two perspectives– the student and the designer (Wenger 2015). Levels of engagement, alignment and imagination (i.e. learning) all increased in the following ways:

Engagement

An examination of PST audio-recordings showed that in the laboratory environment, peer-to-peer discussions were centered around ideas and collaboration. In order to complete the activities, PSTs needed to work together, negotiating meanings in Leap Activities, learning along a continuum, and creating a shared history of practice together (Wenger, 1998). The excerpt below demonstrates how presenting enquiry as an alternative to recipe teaching, enabled PSTs to discern its merits over their previous experiences, to the point where Jas, below, indicated that he preferred to learn through enquiry:

May: I think the fact that it's making it more enquiry based, making it more relatable to the students, instead of just learning on and off, like 'oh I need to know this for the exam', at least they can apply it then
Jas: Yeah, they're being spoon-fed
May: Yeah exactly

> Jas: It was always like that when I was in school anyway. I prefer it this way
> *(Microscopy Lesson)*

Alignment

The results of the amended SEOS clearly show that PSTs saw how their experiences in the PBTM aligned better with enquiry. For the first time they were including enquiry skills such as asking questions and forming hypotheses (See Figures 7.5-7.9). PSTs working at the boundary of enquiry from the student perspective overwhelmingly preferred this form of learning even though it was more challenging:

> The practical work was very engaging, we got to take the initiative much more than ever before in a lab environment, this was daunting at first but once the fear of being wrong in front of a teacher passed it was very enjoyable to come up with our own hypothesis and ask our own questions. Overall it was very educational and fun and will stay with me as I go on in my teaching career.
> *Respondent 22 (Post-module survey)*

The comment above aligns with Windschitl's comments that PSTs are more likely to engage in enquiry teaching if they have experience of enquiry at undergraduate level (2003). PSTs were asked about their experiences of the module, and while the majority of students found it "insightful", "engaging" and "informative", one response provided an insight into how difficult aligning PST opinions with enquiry can be:

> The start of the labs were grand. The extension exercises will not be used in secondary schools realistically as the bio course is already so long there is barely enough time to do the bare minimum
> *Respondent 4 (Post-module survey)*

The PST experience of enquiry in this module was not sufficient to overcome the commonly held belief that enquiry-teaching takes up too much time. This comment was a useful reminder that successful professional development needs to be sustained over a lengthy period of time and within multiple contexts. (Lotter et al., 2014)

Imagination

Imagination cannot exist without future-oriented thought, that of the end-in-view (Dewey, 1958). PSTs were exposed to two separate forms of imagination, that of the student perspective, where they engaged in TDT-designed FTEAs, and that of the designer perspective, where they created their own FTEA. Again, for the first time, PSTs were actively engaged in thinking, which they overwhelmingly recognised as a positive outcome of the module:

> We learned a lot about getting students thinking and how to make classes more interesting and just getting involved and thinking more which was so helpful. In school I used to just sit there, barely participate, or just think 'what's she doing?'
> *Respondent 5* (*Post-module survey)*

The introduction of imaginative thought had three important consequences for PSTs.

1. It provided a solution to the issue of PSTs not having the content or pedagogical knowledge to reach the threshold where they could engage in enquiry-teaching (Capps and Crawford, 2010).

2. It bridged the gap between the work of science teachers and the work of real scientists because imagination is not concerned with getting a 'right' answer, it is more concerned with exploring the unknown, which is the basis of the work of real scientists (Wei and Li, 2017; Hodson, 2014).

3. PSTs saw that practical work can be used to enable students to explore 'at their own pace', since this was their experience of the PBTM. This ground-breaking epistemological realisation meant understanding that not all students need to learn the exact same thing at the same time:

> So that teachers can present students with the opportunity to explore scientific phenomena at their own pace and perhaps get a feel for how scientists actually do their research and how they present their findings
> *Respondent 24 (Post-module survey)*

As mentioned at the beginning of the chapter, this module should be seen as an inaugural foray into enquiry practices. PSTs were still at the very outer edge of the COP boundary because they had limited experience of actually teaching enquiry in a senior cycle classroom; however what they *do* have following the module is a significantly improved understanding of how to engage in authentic enquiry. For example, 12 out of 30 PSTs taught a practical lesson in their placement schools, the majority of whom found that participation in the PBTM informed their lessons. Four of the 12 found enquiry too difficult to implement in a classroom context, because of a lack of time or experience:

> It was most helpful with TY's but I found it hard to implement it when I'm only new to teaching.
> *Respondent 27 (Post-module survey)*

Another comment from a PST indicated that despite their experience of engaging in practical activities in the PBTM, and of reading academic literature critiquing traditional ways of teaching practical activities, their opinion of how practical work should be taught was not significantly changed at the end of the module:

> I think it is possible to have an effective teacher who makes students think and question what they are doing in practical work while still teaching in the traditional way.
> *Respondent 27 (Post-module survey)*

This ties in to Bourdieu's notion of habitus which consists of modes of thought that are resistant to change, acquired unconsciously, and are transferrable between different contexts (1990). Habitus explains why it is so hard to effect changes in how practical work is taught. PSTs, as novice learners, will go along with the form of teaching they experience in the module to a point, but when their experience conflicts with their beliefs about practical teaching, or when they perceive that a task has become too hard, they will resort to 'telling' students what to do, because that is their implicit and deeply held belief about how practical work should be taught. The COP approach used here challenged these unconscious ways of teaching science by explicitly focusing on changing the signature pedagogy of practical teaching through the negotiation of meaning. It required PST participation in the module as learners, using the FTEA as a reified object around which they could negotiate the meaning of enquiry (Wenger, 1998). PSTs are treading a line between the habitus of traditional practical teaching and the COP approach to becoming an enquiry practitioner. Changing teachers beliefs requires sustained professional development in a number of different contexts over a significant timeframe (Capps et al., 2012). This is why the PBTM is seen as the first of many professional development opportunities that PSTs will need if they are to develop a deeper understanding enquiry teaching.

The next section delineates the other end of the journey, where ISTs, following sustained professional development opportunities (the WW and the Micro-evaluations), implemented the FTEA in their own classrooms.

7.3 Enquiry in the Senior Cycle Biology Classroom

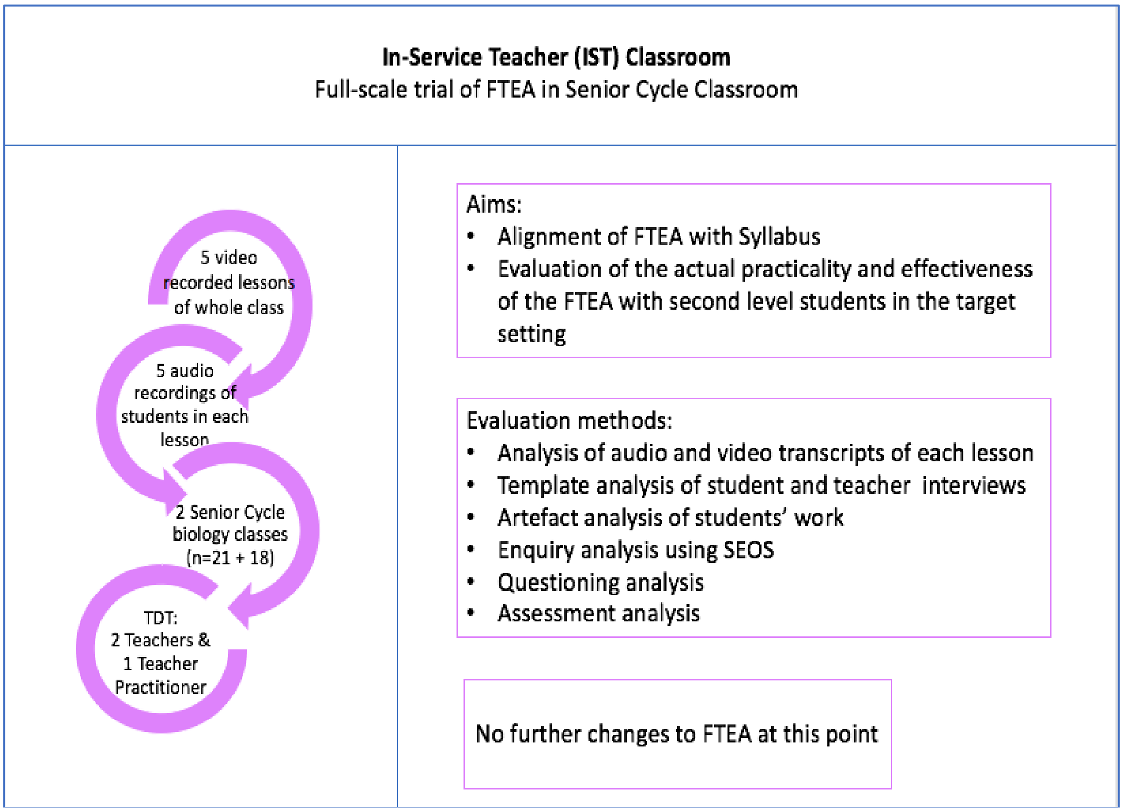

Figure 7.10: Summary of the events, aims and evaluation methods of the target setting

This section evidences how the application and evaluation of the FTEA in the senior cycle biology classroom led to improved understanding for students, compared to the lessons observed in the scoping stage observations. The same data collection techniques were employed in both iterations, to allow a comparative analysis of the impact of this research on students and teachers. Figure 7.10 summarises the events of this design cycle. A brief synopsis of the data collection is outlined below in section 7.4.1, followed by a re-examination of two overarching themes presented in the scoping stage analysis. The first theme, 'Reintegration of Hands and Minds' provides evidence that attests to the effectiveness and practicality of the FTEA in fostering action underpinned by thinking, through the delivery of enquiry-based lessons. The title of the second theme, 'Classroom Reality vs Syllabus Ideal', evidences how FTEA activities align with better with syllabus requirements.

7.3.1 Data Collection

Five lessons in total were observed in one second-level school, between October and December 2020, where Rose and Pete taught n=39 fifth year biology students in two different classes. Table 7.3 shows a breakdown of the practical activities from which data were gathered. Highlighted in yellow are the lessons that were video and audio recorded, all of which were transcribed and thematically categorised using MAXQDA software. Due to Covid-19 restrictions, in four of the lessons the diagnostic experiment was not observed, however, following Kew (2010), text message communication including photographs of student work, and discussions between the TP, Rose and Pete, proved very effective as a tool for collecting data for all of the experiments, providing further triangulation of research claims made here (Cohen et al., 2013). Interviews were carried out with Rose and Pete, and with four of their students, to elucidate the changes in teaching and learning. Each interview was transcribed and analysed using template analysis (King, 2012). Finally, research instruments from the scoping stages (the SEOS and the questioning analysis) were used to assess the enquiry skills that the students used and the level of thinking in the observed lessons (see appendices 7.5 and 7.6).

Table 7.3: FTEA lessons taught in the target setting

Title of FTEA	Diagnostic experiment	The Leap	Applied Experiment	Teacher	Students
Microscopy	Preparation and viewing of an onion cell	Oral / visual presentation by the teacher	Osmosis in onion cells	Pete	n=18
Enzymes *	Investigation of the effect of pH on the rate of catalase activity	Reading comprehension and investigation template	Investigation of other factors that may affect the rate of enzyme activity	Rose	n=21
Enzymes	Previous applied activity acts as diagnostic activity here	Students must present a 'shopping list' of materials before engaging in the applied activity	Investigation of the effect of temperature on the rate of enzyme activity	Rose	n=21
Enzymes *	Investigation of the effect of pH on the rate of enzyme activity	Reading comprehension and investigation template	Investigation of other factors that may affect the rate of enzyme activity	Pete	n=18
Enzymes/ Practical assessment	Preparation and application of immobilised enzymes	Teacher provides the question	Investigate the presence of catalase in yeast	Pete	n=18

*Same FTEA adapted to different classes

7.3.2 Theme 1: Reintegration of Hands and Minds

In the scoping stages this theme was entitled 'Separation of Hands and Minds' reflecting a common finding in academic research relating to the absence of thought from practice (See chapter 3). This section repudiates the hand/mind dualism by describing how teachers reintegrated thought into practice by adapting the FTEA to teach enquiry-based lessons. It is set out as follows:

7.3.2.1 Adapting the FTEA to the Target Learners

7.3.2.2 Changing the Mindset – the Value of the COP

7.3.2.3 Evaluation of the FTEA in the Target Setting

7.3.2.1 Adapting the FTEA to the Target Learners

Taking into account the learning within the COP during the Micro-evaluation, Pete decided to alter his microscopy lesson by changing his Leap activity from a PowerPoint presentation to a story about the effect of salt water on house plants, which he related to his students:

> Pete: I think the biggest thing was, how was I going to pitch it. I suppose in comparison with a standard leaving cert one, rather than just letting them do the microscope, I had to think of how I was going to pitch a story to them that was going to allow them to come up with the design of the investigation
> *Teacher Interview*

In creating this story as a Leap activity for his students, Pete endeavoured to make a connection between education and personal experience (Dewey, 1938/2015). He developed the "forked-road" situation for his students and then let them choose how to proceed with their own questions (Dewey, 1910/2012). He set the scene for students to investigate the effect of salt on cells using the microscope, as an applied activity which acted as a precursor for the subsequent topic in his scheme of work, osmosis. Figure 7.11 shows Pete's FTEA for this experiment. His new design removed the necessity to tell students everything they needed to know about osmosis, instead it used practical investigation to introduce the topic in a way that students could relate to it. When he was teaching osmosis at a later date, he could make the link back to this investigation.

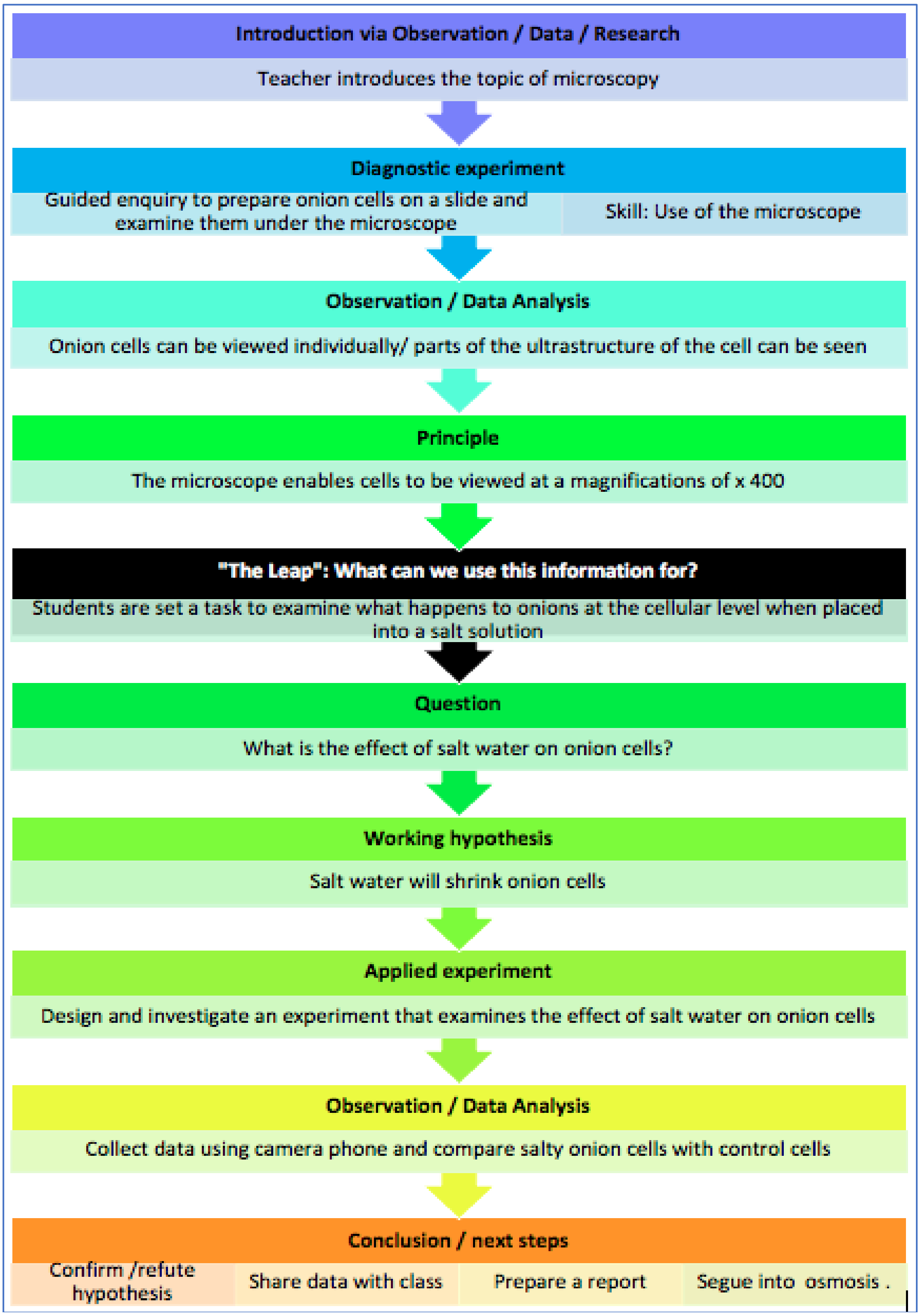

Figure 7.11: Pete's adaptation of the microscopy FTEA

The work of the TP and RP during the PBTM was carried out simultaneously to the work of Pete and Rose in the target setting (between October and December 2020). The crossover between the PBTM and the school classroom was negotiated by the TP who had access to both settings and orchestrated the shared repertoire of ideas for Leap activities in her role as a boundary spanner (Wenger, 2015).

Pete and Rose adapted their enzyme lessons from the FTEAs that were developed during the PBTM. Figure 7.12 illustrates how they merged a series of lessons pertaining to two separate enzyme-related principles (factors that affect enzyme activity & enzyme immobilisation) into a practical assessment, which links two strands of learning by incorporating two practical techniques; an assay for catalase with a technique for immobilising yeast. Pete and Rose were now acting as fully participating members of the TDT actively taking on imaginative roles within the COP (Wenger, 1998). They moved beyond designing enquiry-based lessons, into designing enquiry-based assessments, aligning the mode of learning with the mode of assessment.

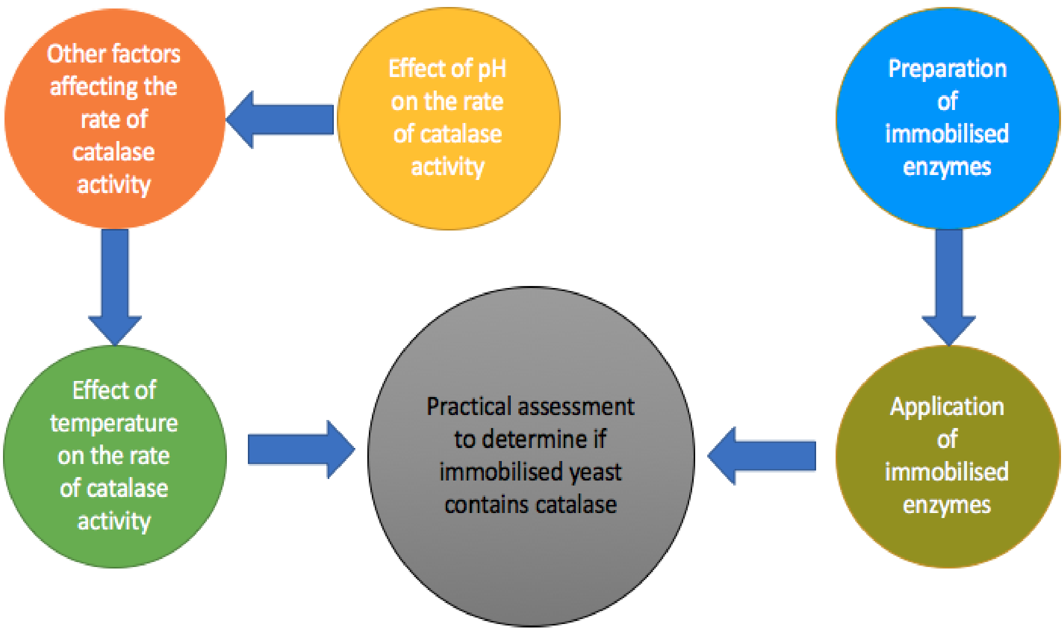

Figure 7.12: A summary of the sequence of enzymatic practical activities taught using the FTEA

The forward shifting nature of the inductive-deductive complete act of thinking, where what was learned inductively, later becomes deductive, is evidenced here

(Dewey, 1910/2012). The student inductively learns an experimental technique and then deductively applies the technique to a second practical activity. This second practical activity, shifts along the continuum of learning to become the inductive activity for subsequent investigations. Pete simply combined the learning from both experimental strands into an assessment by posing the Leap question himself, rather than scaffolding for students to ask the question. To answer Pete's question students needed to understand and combine the techniques from the two separate strands of learning. The next section provides evidence for the role of the COP as a site of continued learning in developing the enzyme activities.

7.3.2.2: Changing the Mindset – the Value of the COP

Reflecting on the time and preparation required for enquiry teaching, Rose commented that the biggest change was in the teacher's mindset:

> Rose: No, I think the only thing that's changing is the teachers head, the way the teacher presents at the start.
> *Teacher interview*

Pete rejected the notion, reported in the scoping stages, that enquiry teaching was too time-consuming, stating that the time spent preparing materials for the target setting lessons did not increase significantly compared to their pre-enquiry days. Rose concurred stating, "not if the ideas were there", acknowledging that the most difficult aspect of enquiry teaching was the imaginative aspect of creating ideas to act as scaffolding for Leap activities. She postulated that this should not be an individual task:

> Rose: You know, I think like, it would have to come from a department or come from a meeting of other teachers to come up with these ideas, but once you have the idea I don't think - the prep time is nothing more than what you'd be prepping for in a normal experiment.
> *Teacher interview*

Having worked within the enquiry COP, Rose understood the mutual learning that results from collaboration, and envisaged how this experience could be transferred to the entire science department in her school.

Over the course of this research as Rose and Pete's understanding of the view of enquiry that underpinned the FTEA grew, their development as full members of the COP meant that they required input from the TP and RP in more informal ways. For example, Pete created his own worksheet to act as a resource for his students to ask a question, develop an hypothesis, outline a design for investigating the hypothesis, and think about how to collate their data. Figure 7.13 shows one of these design templates, where the students have hypothesised that the enzyme (catalase) will work best at pH 4 because that is the pH of the soil in which the plant grows. Having worked together for two years, Pete and the TP communicate informally through text message to answer a query that Pete has regarding potential hypotheses (Figure 7.14a-c).

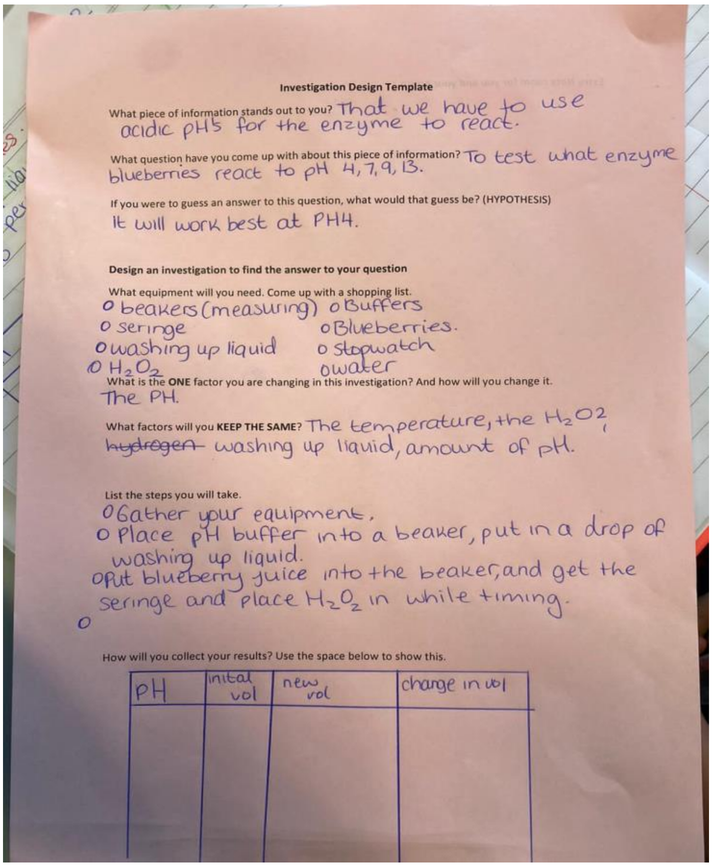

Figure 7.13: Investigation design template for the applied experiment for the effect of pH on the rate of enzyme activity investigation.

Pete consulted academic papers, which answered some of his questions but he could not find an answer to his query about soil pH and catalase activity (7.14a-b). Rather than give up, Pete asked the TP, whom he sees as another resource. Through working with the RP (a professional scientist) to co-design the enzyme FTEA, the TP knew the answer, which she related to Pete.

Figure (7.14c) indicated that Pete is comfortable with giving his students the freedom to propose an incorrect hypothesis, because the learning from it will be valuable. Pete built uncertainty, which is a part of the signature pedagogy of enquiry into his lesson design (Shulman, 2005).

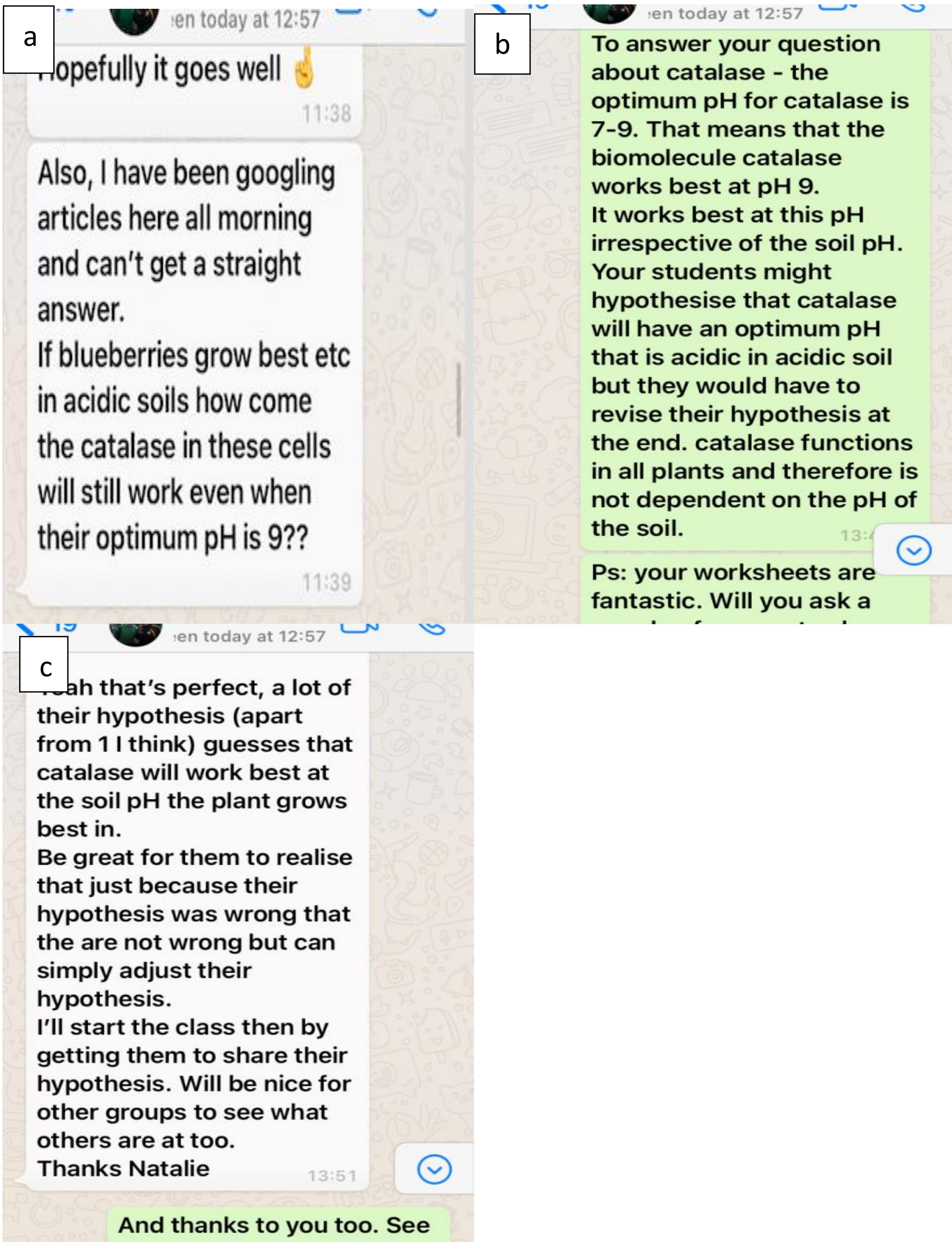

Figure 7.14: A series of text messages between Pete and the TP. Pete has a question for which he cannot find the answer (a). The TP answers the question (b) and Pete decides to let his students proceed with an incorrect hypothesis because they will learn from the investigation (c).

There are three salient findings from this exchange:

1. Pete's view of knowledge had transformed and aligned with authentic enquiry. He saw knowledge as an end-in-view, aligning how he prepared for practical classes with how he taught his lessons (Dewey, 1925/1958). Through this transformation Pete was broadening his subject content knowledge by asking his own questions, demonstrating that the method he used to prepare for experiments aligned with how he taught experiments and with how he wanted his students to learn from his lessons. This provided further evidence that teaching through enquiry increases subject content knowledge (Kurten and Henriksson, 2021; Nadelson, 2021)

2. By engaging with the COP, Pete built up relationships that extended beyond the intensive professional development of the third design cycle. Pete had access to the pooled resources of the COP as and when he needed it.

3. Pete's view of learning included imagination, which is future-oriented (Wenger, 1998). He foresaw and encouraged the Leap in thinking that his students must engage in to figure out that their hypothesis that was incorrect, and he valued what they learned from this experience.

Thus, the three modes of belonging to a COP (engagement, alignment and imagination) were embedded in how Pete prepared and taught his lessons. Through these three modes, Pete built an identity as an enquiry-practitioner (Wenger, 1998). In the next section the benefits of this new pedagogy are evaluated by examining the enquiry skills that students used and the type of questions asked during the lessons.

7.3.2.3 Evaluation of the FTEA in the Target Setting

Scoping stage use of Bloom's taxonomy to analyse of the level of questioning during practical lessons, indicated that a significant majority of questions asked by teachers over the course of the lesson were at the lowest level - recall. The majority of the remainder of questions were at the level of comprehension, with no questions at the highest three levels (Bloom, 1956). Rose's reason for asking so many recall questions was that she was endeavouring to prepare her students for the LC examination, where the level of questioning is predominantly at the level of recall (Burns et al., 2018). Pete and Rose began to question this approach to teaching because it does not leave room for scientific thinking:

> Rose: Before I was like… "What enzyme are we using?", "What substrate are we using?"
> Pete: I know we were only using recall on the bottom of….. Blooms
> Rose: But I was of the opinion that if I asked them at least 100 times they would write it down in an exam, [laughter] you know I just thought like, the more I ask the more it might actually eventually go into their head.
> Pete: You were approaching your classes as an educator more so than a scientist like, and that was the question, where you want people that were going to do well in exams or people who were going to be scientists like?
> Rose: Yeah, to think for themselves.
> *Teacher interview*

Both teachers made significant changes to their approach to questioning over the course of this final iteration. The differences between the type of questions asked in the scoping stages and the target setting illustrated are summarised here and illustrated in Figure 7.15:

1. The inclusion of the Leap and the Applied experiment led to an increase in the level of thinking required during practical activities, evidenced by the introduction of questions from the top four levels of Bloom's taxonomy; application, analysis, synthesis and evaluation. 30% of the questions asked were at the higher three levels of thinking. This was accompanied by a significant reduction in the number of recall questions asked by teachers.
2. The closure of each lesson incorporated a group discussion where students were asked to share their hypotheses, describe their experimental design and evaluate whether or not to revise their hypotheses, based on the data analysis they conducted. The questions asked by the teacher during these discussions occupied proportionally higher levels of thinking than those asked during the scoping stages. At the highest two levels of thinking (synthesis/evaluation) students answered 100% of questions correctly on their first attempt, which is not surprising, as they were answering questions about their own experimental designs and findings.

It is worth noting that this analysis only records questions asked by the teacher – however an integral part of the FTEA is that each group of students asks their own questions at the highest level of thinking (synthesis/evaluation) as a precursor to designing and carrying out every applied experiment, which embeds enquiry in the lessons, and elevates the level of thinking.

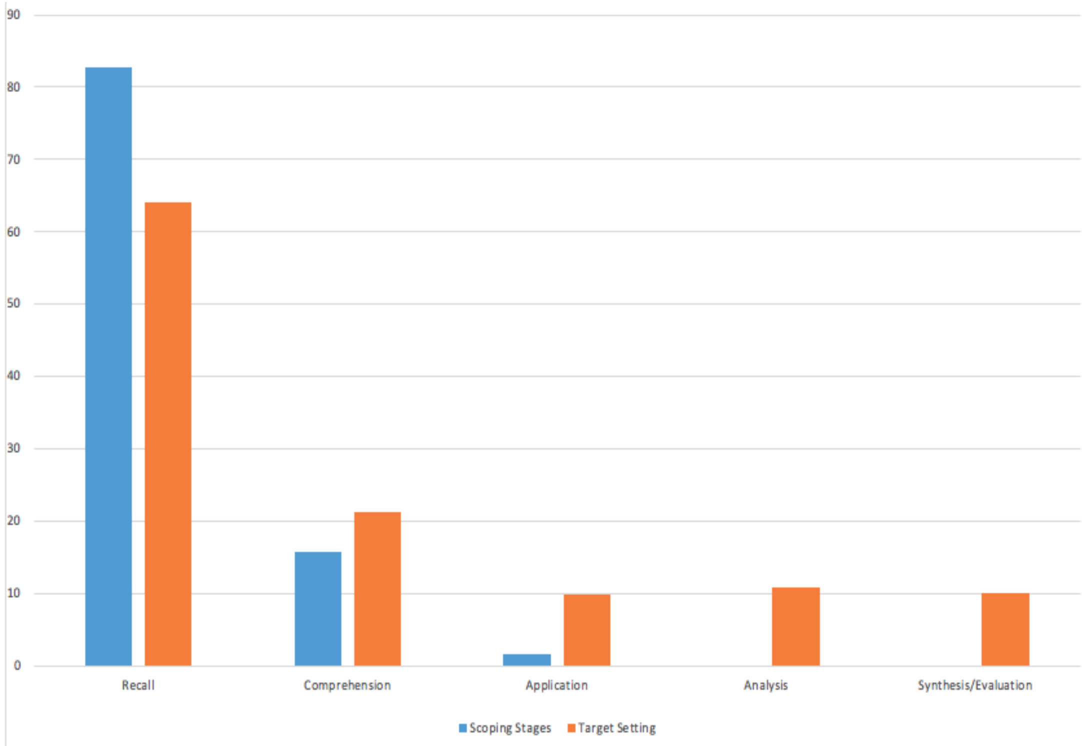

Figure 7.15: A comparison of the scoping stage lessons and the target setting lessons showing the percentage of questions asked at each level of Bloom's taxonomy.

Chapter 3 reported that, in line with international studies, students interviewed *during* the scoping stage, struggled to recall what they did with materials during experiment, to explain the purpose of the materials they used, and to identify and understand the scientific concepts underpinning their practical activities (Reiss, 2018; Osborne, 2015; Abrahams and Millar, 2008). In the target setting, two interviews with four students (two students per interview) conducted *almost three months after* target setting observations, indicated that scientific ideas were an integral part of practical activities.

The enzyme practical activities are used here to illustrate how students understood the purpose of the materials they used and the scientific concepts underpinning the activities.

When students were asked to explain the difference between the immobilised enzyme and the free yeast, both groups interviewed knew that they were examining the product of the reaction for the presence of glucose. One group knew that it took longer for the immobilised enzyme to convert the substrate to glucose:

> Carol: Yeah, didn't the immobilized one, I could be remembering this wrong, or we just done [sic] it wrong, but it took a bit longer I think to show up on the glucose strips.

When asked to explain why it took longer, Carol understood that the enzyme trapped in the bead takes longer to react with the substrate, indicating that she understood the scientific principle underpinning the experiment – i.e. she was capable of "doing" with ideas:

> Carol: It's also like in a bead, so like the sugar in it takes longer to get out of it [laughs] the bead.

In the scoping stages, all students asked believed they had learned that immobilised enzymes could be re-used, *even though* they did not actually re-use the gel beads containing the enzyme.

Students were also interviewed to assess if they were capable of "doing" with materials. Not only could they recall the materials they used but they also knew the function of those materials. Referring to the factors that affect the rate of catalase activity students knew:

- The source of the enzyme:

  Lia: We got it from celery or something

- The name of the enzyme:

  Katie: Catalase

- How to assay for catalase activity:

  Katie: Yeah from dish soap
  Carol: Yeah and if foam was standard, if foam was standard then you'd know that the enzyme catalyse was working.

- The substrate used- hydrogen peroxide, given as a chemical formula:

  TP: is there any chance that you remember the name of the substrate?
  Carol: Em, is it H2O2?
  Student interview 1

The practical assessment was perhaps the most insightful lesson in terms of integrating thought and action. Lia, below, explained how her group conducted the assessment. Note how she emphasised that the success of this activity was contingent on the group's ability to apply prior knowledge to a new situation; Lia terms this "thinking outside the box":

Lia: Because obviously we did the finding the pH of the catalase activity and then the immobilisation one, it is like we were combining the two experiments into one, so that's what I mean about thinking outside the box, because we had applied what we know already to create one experiment.
Student interview 2

Unlike the scoping stages, Joe recalls that the first thing his group did during the assessment was to engage in a group discussion about how they might proceed with answering the question, indicating how peer discussion has become an integral part of classroom activity.

Joe: First we sat and just talked it out, we didn't go straight in to it.
Student interview 2

Comments from Lia and Joe, above, emphasised how thinking through communication was an integral part of the work they do in practical classes. The three elements of learning were evident in the work that they did – they used imagination to "think outside the box", they mutually engaged in planning through discussion, and their understanding of what they were doing (applying what they already know to create a new experiment) aligned with the theory of enquiry underpinning the lessons (Wenger, 1998).

A conversation between the TP and Pete strengthened the claim made here that 'doing with ideas' was reintegrated into practical work. They were discussing how students use different, and equally valid, concepts to rationalise the temperature at which they chose to conduct one of the applied experiments.

TP: Well from talking to them, there was a girl here at the water bath and I said to her, "Sorry, can I just ask you, why did you put your stuff into the water bath?", and she goes, "Well, from last week that's the best temperature."
Pete: Ok.
TP: And I went, "Well, why didn't anyone else do it?"
Pete: Yeah.
TP: And she goes, "I don't know." [Laughter]
Pete: And that group there then I asked them, "Well, how come you didn't put it in the water bath?", and they were like, "But it's at the one temperature anyway."
TP: Yeah.

Pete: So, they had realised through the scientific method that they needed to keep that constant.
TP: Ok, so I mean that's good.
Teacher interview

Pete's comments indicate how his epistemological outlook had shifted in favour of the signature pedagogy of enquiry. He was comfortable with the uncertainty that knowledge as an end-in-view brings (Dewey, 1925/1958). Within the complete act of thinking Pete acknowledged that learning occurred within the experience that the student had (Dewey, 1938/2015). Pete was facilitating freedom for his students, which is "essentially the part played by thinking, which is personal" (Dewey, 1916/2011, p.165), by providing the conditions that had to be met in order to promote effective thinking (the diagnostic experiment, access to equipment) so that the students' own ideas could then direct their actions (the Leap and the applied experiment) (ibid., 1916/2011). Pete's FTEA design allowed for students to learn in personal, different, and equally valuable ways.

7.3.3 Theme 2: Syllabus Ideal vs Classroom Reality

This section outlines how the FTEA re-aligns with the rationale set out in the Biology Support Materials Handbook (GOI, 2003, p.4); that the scientific method of enquiry should be "applied" to practical activities, there should be an emphasis on the "process" of investigation, and that practical skills should be developed through experimentation. Evidence to this effect is presented as follows:

7.3.3.1 Classroom Reality Aligns with Syllabus Ideal

7.3.3.2 Practical Activities are Underpinned with Enquiry

7.3.3.3 Evaluation of Student Learning Through Assessment

7.3.3.1 Classroom Reality Aligns with Syllabus Ideal

The SEOS (Appendix 7.6) rated the five lesson video-recordings according to the skills set out in the syllabus and compared the rating with the average score for the 10 lessons observed in the scoping stages. Figure 7.16 presents a summary of the main differences between both stages.

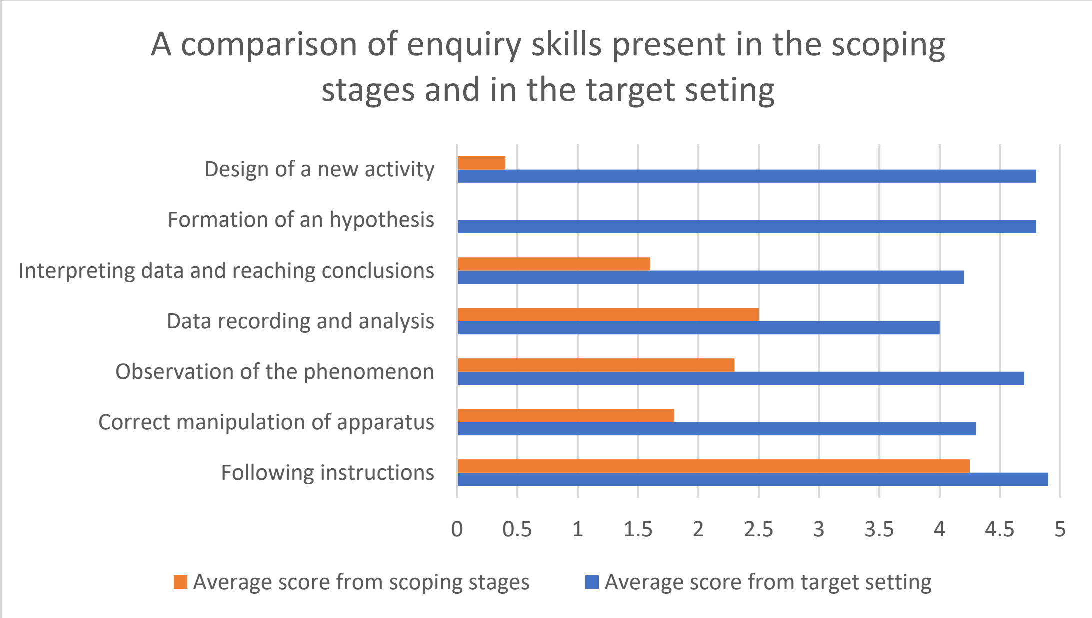

Figure 7.16: A comparison of enquiry skills present between the scoping stages and the target getting.

From Figure 7.16 following instructions, was common to both iterations, with average Likert scores indicating that students carried out this skill with little or no assistance from the teacher. In terms of manipulating apparatus correctly, while there was no focus on labelling equipment in three of the observations in the target classroom, in almost every other manipulative skill, the rating indicated a significant shift towards independent student work. Observation of the phenomenon was enhanced by the COP approach to sustained professional development, which fostered greater subject and pedagogical knowledge of the mandatory activities, meaning the diagnostic experiments "worked" and students saw the correct aspect of the correct phenomenon, mostly without assistance from the teacher. This was not evident in the scoping stages.

In every lesson in the target setting, students assumed most of the responsibility for recording, calculating, tabulating and graphically representing the results they observed. An even wider gap between the scoping stage and the target setting opened up when interpretation skills were examined. Students drew their own conclusions from their own experimental data, and related those conclusions back to an original hypothesis. Data recording, analysis and interpretation were not a feature of any practical activity in the scoping stages.

The double experiment aspect to the FTEA meant that all experiments had a practical application aspect to them and all students had the opportunity to repeat the diagnostic experimental technique by developing an hypothesis and designing an applied activity to investigate it. Hypothesis development was not a feature of any experiment observed in the scoping stages.

Finally, in the target setting students applied their learning to novel situations by designing an experiment to investigate the hypothesis that they proposed in each practical activity. In the scoping stages, there was very little evidence that students designed a new activity.

7.3.3.2 Practical Activities are Underpinned with Enquiry

This section supports the claims made in Table 2 above by providing evidence of how enquiry was integrated into practical activities. Scaffolding activities for thinking, consciousness, freedom, and personal connection to the material completely transformed the student experience of practical work (Dewey, 1925/1958). Evidence of this was found in the conversation below. Without any knowledge of osmosis, two students are trying to decide between two hypotheses – either the cells in the salt solution will change colour or they will shrink - by relating the concept to their everyday experience of putting salt on a slug (Dewey, 1938/2015):

> S4: It might change colour?
> S5: Yeah it might. Will it make the cell smaller no?
> S4: I have no idea
> S5: Will it change colour? I don't know. I'm just going to say, 'shrink cell'
> S4: Yeah, like do you know when you put salt on a slug and it sucks out all the moisture from it
> S5: Oh yeah, what would you call that?
> S4: Eh, like drying up?
> *Microscopy lesson*

During one of the enzyme Leap activities, students researched a range of factors that affected the rate of catalase activity. One group hypothesised that the rate of catalase activity in strawberries would be equal at all pHs (4,7,9,13) because strawberries are tolerant of all soil types. They designed an applied experiment to investigate this and discovered that the optimum pH was 9, but the results were hard to read so they decided to pick another pH tolerant vegetable and repeat the experiment. After the experiment they changed their hypothesis based on the results of both investigations. The following exchange occurred as part of a whole class discussion after the activity:

> Pete: Yeah the results were kind of poor in strawberries ……..You then went because you were annoyed with your strawberries you went and did a second experiment, what did you do?
> S7: Turnips
> Pete: What type of soil does turnip grow best in?
> S7: Any soil
> Pete: Yeah same as strawberries. So they tested again, what was the optimum pH for catalase in turnip?
> S7: pH9
> Pete: OK, so can you see the trend here? ….. Turnip grows in any type of soil. Catalase works best at pH9. Strawberry grows in any type of soil. Works best at pH9.
> *4th enzyme lesson*

Pete and the TP had discussed how having to change an hypothesis would lead to learning for the students (Figure 7a-c). This was a great example of how the Leap interrupted the flow of thought for students, and created uncertainty, which brought about genuine questions through conscious thought (Dewey, 1910/2012). This evidenced how the teacher was no longer 'telling' students what to learn, they were directing their own learning, albeit within the parameters of what the teacher could facilitate.

Unlike the scoping stage observations, in the target setting, students were gathering their own data, learning how to represent it graphically, linking it to what they knew, and using it to reach for what is yet-to-be-known. The class discussion at the end of each practical activity, afforded students the opportunity to share and discuss their learning. Carol below, discussed how she and her peers were asked by Pete to explain the thinking behind the activities they do, which allows other groups to evaluate their own thinking in terms of how it aligns with the group data:

> Carol: Yeah, the way we do it, like we kind of go from group to group so like we go to one group – "what did they do, how did they do it, what they thought",

and then like as the group is speaking everyone else is thinking about "oh is this the same? Did we get that?"
Student interview 1

An interesting outcome of giving students freedom to collect and interpret data occurred when a student asked Pete how he should gather data in the microscopy experiment. Pete deflected the decision back onto the student, who decided to take photographs (Figure 7.17):

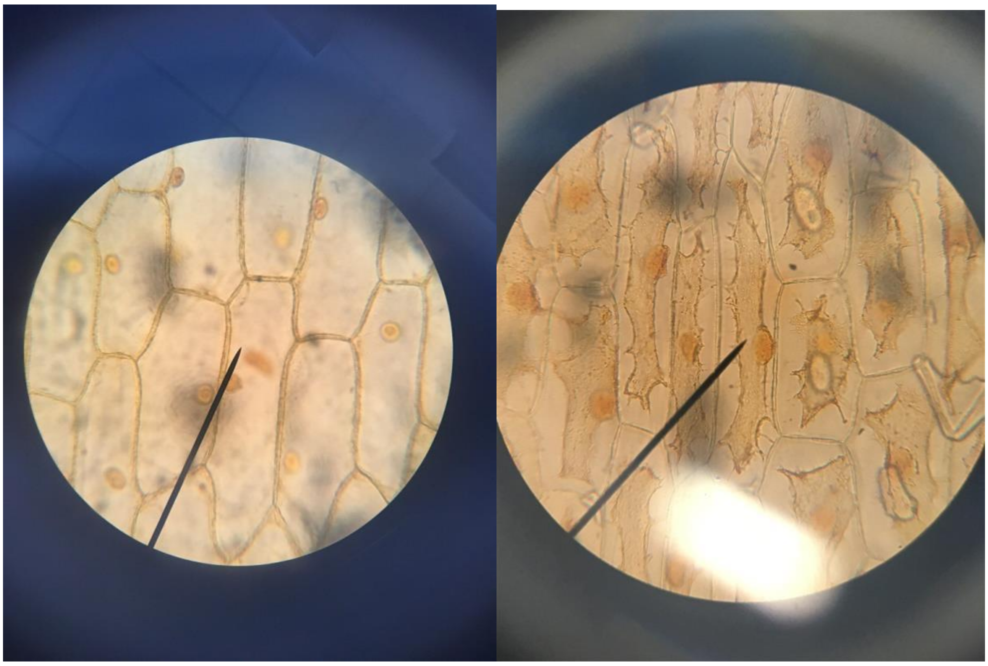

Figure 7.17: Photographs depicting (A) onion cells under the microscope and (B) the effect of salt solution on onion cells

These photographs confirmed the hypothesis of the two students (above) who proposed that adding salt would shrink the cells. Pete later remarked to the TP that allowing students to use their cameras to take pictures, rather than asking them to draw diagrams was "after completely blowing it out of the water" in terms of data analysis:

Pete: … and they can flick over and back like. I don't think that would have maybe been as good if you couldn't have seen those pictures side by side. It was so hard to explain it to them if they didn't have them
Microscopy Experiment

While Pete was the teacher in the room, he could still learn from his students. The signature pedagogy of enquiry reflects this approach to teaching and learning, where the student is respected as an active contributor to the collective knowledge of the class group. Knowledge in this context flows dynamically between student and teacher, rather than being imposed by the teacher, leading to a more equitable and interesting experience for the student (Dewey, 1916/2011)

By the time Rose taught her third enzyme lesson, her students were using the experimental technique with fluency. She scaffolded the Leap by asking students to write a shopping list of all of the equipment they would need to "find out about temperature using catalase".

This led to a student discussion about the chemicals and equipment they would need, which was connected to an understanding of the ideas underpinning the materials; keeping the pH constant, choosing pH 9 as it was the optimum pH previously, and temperature as the variable. The TP made the following observation to Rose during this exercise:

> TP: There's nobody asking you what to do
> Rose: No, they've done quite well
> TP: That's a massive difference
> *2nd Enzyme Lesson*

Compare this to the scoping stages, where teachers reported their frustration at students constantly asking them what to do, even when the instructions were on the class board.

So far in their senior cycle experience, Carol and Katie have not conducted a recipe-style experiment and they rejected the idea of following instructions, as they believed it would negatively impact their learning by excluding thinking from their actions:

> TP: So it didn't really matter, you didn't need a list of instructions to follow
> Katie: If you're just given a list of instructions, like, I feel like it wouldn't even be beneficial because you're literally just getting told what to do and you're not being allowed the opportunity to bring your own opinions and what you think might work or won't work.
> Carol: Yeah, you're not thinking about why you're doing it, like if you're just given like this and this, you're not saying like oh why am I doing this, how does it work in the experiment.
> *Student interview 1*

Both Carol and Katie articulated a view of learning that aligned with the signature pedagogy of enquiry, expressing a preference for knowledge as an end-in-view and learning though personal experience. It seemed anathema to them that someone would "tell them what to do", because that would exclude thinking from their actions. Following Dewey (1925/1958, p.247), they saw the self as the "tool of tools", "the means in all use of means" without which learning is incomplete.

7.3.3.3: Evaluation of Student Learning Through Assessment

Pete's practical assessment provided an alternative approach to the traditional written test. In order to complete the assessment, students had to link two separate strands of learning by answering a question that Pete posed to them. He integrated thinking into the practical activity, as "a power of following up and linking together the specific suggestions that specific things arouse" (Dewey, 1910/2012, p.39).

The conversation between the TP and Student 5, below, indicated the student understood the enzyme was in the immobilised yeast, the purpose of the materials they must use to assay for catalase, and the inclusion of a suitable control:

> TP: How are you going to test for that enzyme?
> S5: With washing up liquid and hydrogen peroxide, we'll see if the product of it is water and oxygen. So if we add the washing up liquid it will create bubbles so you'll see it.
> TP: Very good. And what's your control going to be? Have you thought about that?
> S5: We'll just try it with water
> *5th lesson, practical assessment*

In the scoping stages teachers and students were left frustrated by procedural instructions that did not lead to the production of the expected phenomenon. Dewey would argue that there were non-existent social conditions in which the individual mind could think, which resulted in teachers and students finding themselves at odds with their environment, and rather than adopt a searching, imaginative approach to learning, they held on to the recipe-style, "instituted under the influence of custom and tradition" and, extremely hard to break away from (Dewey, 1925/1958, p.219). In this design cycle, the FTEA facilitated teachers and students to troubleshoot experiments that did not "work" because of procedural errors that need to be rectified. Here the students realised they made a mistake (not letting the beads harden for long enough) so they repeated the procedure to rectify their mistake:

TP: What part are you on?
S10: Well we're immobilizing the enzyme but it didn't really work so we have to do it again
TP: Did you leave them harden for long enough?
S9: No, that's the mistake
TP: Is that what happened?
S9: We washed it too hard
5th lesson, practical assessment

The conversation below occurred between students from two different groups; one student (S11) is reassuring the other students that their immobilised yeast beads were adequate despite their concerns to the contrary:

S9: How much more do you put in of this?
S11: A lot more than you did. I think we added too much
S9: I don't know what we added
S11: But like, you can always add more water. Your beads look fine though
S9: It's too thick sure
S11: Are they turning into beads?
S7: Yeah
S11: Then its fine. You're grand.
5th lesson, practical assessment

This approach to assessment was completely different from the approach of summative written tests which are characterised by silence and competition. During this assessment, students used discussion to plan and conduct their enquiries. The excerpt above indicates that students from different groups assisted and reassured each other in a collaborative atmosphere.

The practical assessment, evaluated on the basis of the poster produced by the students, was allocated 25% of the overall Biology grade (the other 75% was for a written examination). Figure 7.18 shows a poster created by one group which outlined the process they undertook to determine that yeast does indeed contain catalase.

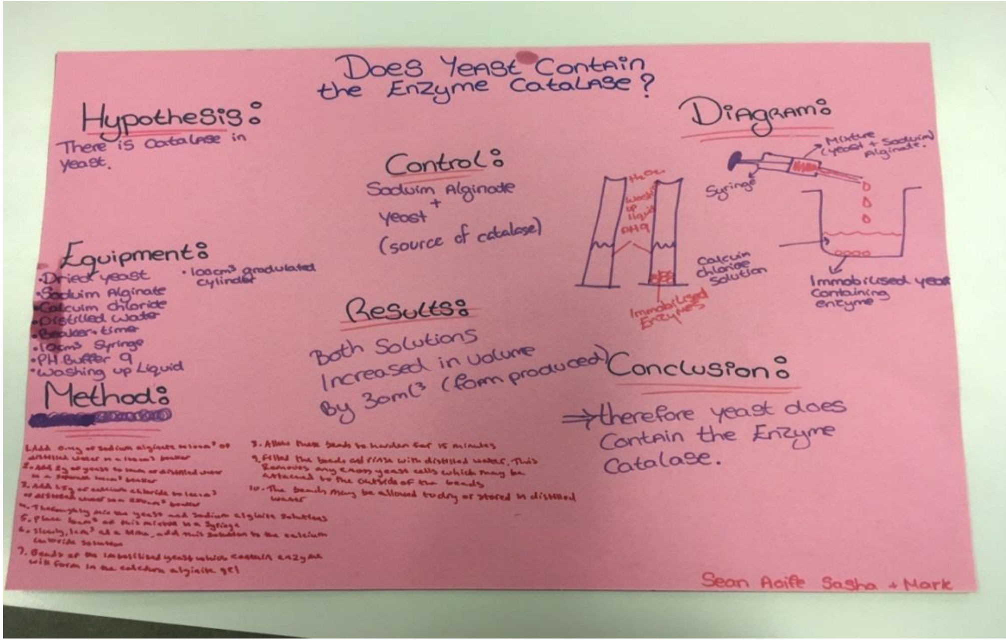

Figure 7.18: Poster presentation for the practical assessment

Their assessment of their own work portrayed confidence in what they presented to Pete at the end of the lesson:

> S10: That's a solid 25% there
> S8: Well like you know catalase!
> S10: To be honest the conclusion says it best.
> *5th lesson, practical assessment*

This type of assessment follows Dewey's (1925/1958) belief that each student has the capacity to learn in social relationships that are "heterogeneous and expansive" and where there is a demand for "initiative, invention and variation" that connects individuals with thought. The pedagogy of enquiry attends to the "individual mind", which is free to initiate, adventure, experiment, dissolve, and alter when it finds itself at odds with its surroundings, in order to arrive at new truth and vision. A new self is formed in this manner, one that is dependent on the unforeseeable result of the adventure. Wenger would call this the formation of an identity of enquiry (1998).

Pete also gave his students a written examination using Leaving Certificate questions from past examination papers. His analysis of the exam results allays scoping-stage concerns about enquiry teaching disadvantaging students in the LC examination (See Appendix 7.5). Average student scores conveyed almost double the marks on experiment questions (60.4%) compared to long theory-based questions (35.2%). While it may not be surprising that students scored higher on the experiment questions, what surprised Pete was how well students he considers “weak” performed on the experiment questions, compared to the other questions they attempted.

Pete illustrated his point by sharing some of his data with the TP via text message (Figure 7.19). He details how one of his ‘weak’ students failed the short question section (33%), while scoring quite a high mark on one of the experiment questions (80%).

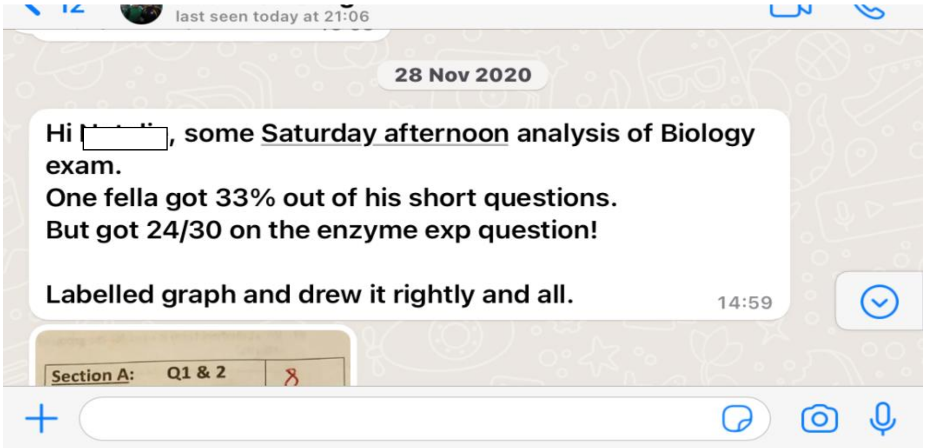

Figure 7.19: Text message communicating assessment scores of a ‘weak’ student

Figure 7.20 illustrates another example of a student that did not perform well on short questions 1-6 (average 35.8%) or long questions 9-10 (average 10%), but passed the exam overall, because of the high marks on the experiment questions 7-8 (average 85%).

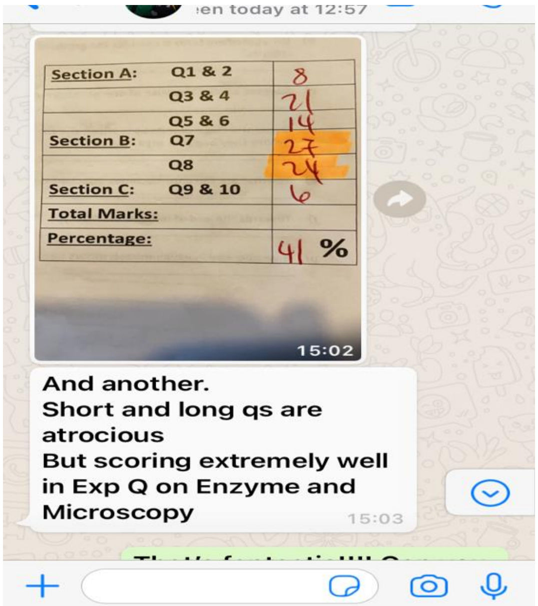

Figure 7.20: Text message highlighting high marks in the experiment questions (in orange)

Pete illustrates his point by sharing a photograph of an experiment question (Figure 7.21), where it is clear the student achieved a high score, despite being unable to answer what would generally be considered ‘easy’ questions elsewhere on the exam paper.

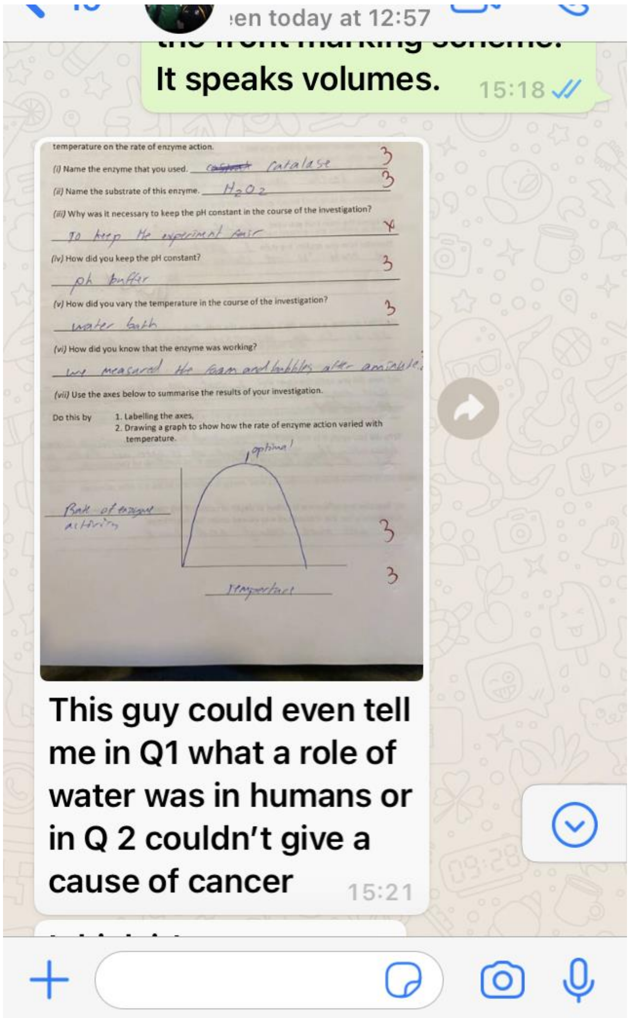

Figure 7.21: Text message illustrating how a student scored high marks in the experiment question

It is proposed here that teaching practical activities using the FTEA benefitted all students, evidenced by the higher average marks scored on the experiment questions compared to long and short theory questions. What cannot be ignored is that the student-centered style encompassed by the FTEA engaged students traditionally considered “weak”, and pushes teachers to reconsider the benchmarks for what they consider a weak student to be. Teaching practical activities in this way fostered genuine learning through engagement in the process of investigation, creation of opportunities for imaginative thinking, and alignment with the signature pedagogy of enquiry, ironically enabling students labelled "weak" to perform at the same level as the "bright" students (Wenger, 1998).

7.3.4 Discussion

This final iteration of the research illustrated how changing the signature pedagogy of practical teaching, brought about corresponding improvements in the quality of thinking in the biology classroom. Evidence presented here established the vastly different experience of practical activities for students, compared to that of the scoping stages, as thinking became synonymous with practical activities. This discussion encapsulates how an appropriate balance of each dimension of the signature pedagogy of enquiry (intellectual, technical, moral), was embedded in the lessons taught by Pete and Rose, and how these changes led to a new and more responsible pedagogy in situ, a pedagogy of *thinking* (Shulman, 2005).

1. The intellectual dimension, which refers to professional ways of thinking, was grounded in the use of the FTEA to prepare for practical lessons. This preparation draws on theory around the inductive-deductive nature of Dewey's complete act of thinking, where teachers must teach students to learn to use materials and equipment to produce a phenomenon during the inductive experiment, and then they put this learning to use during the deductive experiment. This was a process of learning for the teacher as much as for the student, evidenced by findings from this design cycle that indicate that it brings about improvements in teachers' subject and pedagogical knowledge during the planning process, which has been shown to have a direct impact on student learning (Voogt et al., 2016). Including thinking in lessons required thought on the part of the teacher. This included researching ideas, sharing ideas with other teachers, and incorporating new ideas into lessons.

The COP approach to enquiry has undoubtedly supported Pete and Rose in this endeavour, fostering a pedagogy of thinking around finding collaborative ways to "make thought prevail in experience, not just the results of thought by imposing them upon others, but the active process of thinking" (Dewey, 1925/1958, p.120). This was done through participation in the COP and reification of the FTEA as an object around which the meaning of enquiry was negotiated (Wenger, 1998).

2. The technical dimension refers to how members of the profession perform and is undergirded by a set of assumptions about how knowledge is imparted (Shulman, 2005). Incorporating a Leap into each practical activity draws on Dewey's interpretation of consciousness as focused thinking through action, where teachers must find a way to present the familiar in an unfamiliar setting, necessitating student activity *in thinking*, not apart from it (Dewey, 1925/1958). The teacher's role in the lessons above has been transposed into one that plans for intellectual growth via the forked-road situation presented to students during each Leap, giving students choices around the pursuit of ideas that were facilitated by the teacher's preparation (Dewey, 1938/2015). Through this lens, the teacher became a knowledgeable other (Vygotsky, 1978), guiding the students to find proof from inference, both parties involved in the search for knowledge.

Dewey expresses distaste for the type of questioning observed in the scoping stages because it "leads to an accumulation of disconnected details all on the same level"(Dewey, 1910/2012, p.186). When teachers reduced the number of recall questions asked and increased questions at higher levels of Bloom's Taxonomy (1956), students could access higher levels of thinking. Even better, having students ask the questions and convert them into hypotheses occupied the highest levels of thinking (synthesis and evaluation) - *thinking in action*, reintegration of hand and mind, and was a part of every lesson observed in this iteration.

Since ready-made knowledge was no longer imparted to the students by the teacher, collaboration and engagement among students through discussion was essential to the work that students did. Meaningful student discussion was evident throughout all aspects of the lesson, enabling students to establish connections between the materials they were using and the concepts the teacher wanted them to understand (Tanner, 2009).

> Carol: Em, I personally prefer talking to other people about it, cause I feel like it would benefit you more, not in a way for someone else to tell you you're doing it wrong, not in that way, but to feel like you can get what they're thinking, then get what you're thinking and just put it together.
> *Student interview 1*

Students preferred lessons that allowed for discussions in which they could negotiate meaning by sharing thoughts and ideas (Wenger, 1998). Teachers learned the difference between telling students what to think and teaching them how to think.

3. The moral aspect of a signature pedagogy refers to the beliefs and professional values of teachers. Working within an enquiry COP had the biggest impact in this area. Within the COP Pete and Rose built identities as enquiry practitioners, developing an ability to learn along three dimensions - imagination, alignment and engagement – which they incorporated into their FTEA lesson designs.

Abbott et al.'s observation (2018) that participation in professional learning communities, increased teachers' ability to question practice and provided increased confidence in applying new ideas, was evidenced in this chapter. Pete and Rose engaged with a pedagogy that values the socially constructed nature of knowledge as an end-in-view (Dewey, 1925/1958). Through this lens, they designed enquiry lessons for their students with a future oriented epistemology, where uncertainty was integral as students "maintain a state of doubt and carry on systematic and protracted inquiry" (Dewey, 1910/2012, p.13). There was no one "right" answer in the enquiry classroom because learning came about as a result of engaging in the enquiry process, making the "leap" in consciousness to connect one idea to another, trying out ideas, making mistakes, learning from mistakes, and sharing new knowledge with the class. Alternative ideas were encouraged, respected and (within reason) facilitated in the enquiry classroom.

> Katie: Em, I mean if we're doing an experiment where we have a bit more of our like own control over it, I feel like most of the time is taken up by talking about the experiment, cause obviously we're all trying to figure out what to do and who does what, and what will work and what won't.
> *Student interview 1*

Katie, above is describing how Pete and Rose successfully distinguished between external imposition of information onto students by a teacher and internal control of information by students (Dewey, 1916/2011). Students made informed choices over what to investigate, what data to collect, how to present their data, and how to share their findings and as a result, they were more invested in the outcome.

One final outcome of the enquiry-oriented approach to learning came in the form of Pete's practical assessment which he aligned with the future-oriented enquiry ethos. Completion of the group assessment meant that students were required to reach for the end-in-view by doing an experiment they had not previously done (so they could not memorise the answer), but that was achievable if they linked two separate strands of learning that they had experienced in class. Pete developed an assessment for thinking that aligned with the pedagogy of thinking, and in doing so his perception of student ability changed. This change was further solidified when he gave his students a traditional test containing LC exam questions. Students that were considered weak performed at the same level as "bright" students on the questions that related to the practical activities. For questions that did not relate to practical work, the weak students did not score well. A consequence of adopting the moral dimension of the enquiry signature pedagogy is that it requires a revision of how student ability is evaluated. There is an argument to be made that adopting an enquiry-oriented pedagogy of thinking is a more equitable form of teaching, and that it should apply to all biology lessons, not just practical lessons. In Dewey's words:

"Were all instructors to realise that the quality of mental process, not the production of correct answers, is the measure of educator growth, something hardly less than a revolution in teaching would be worked."

(1916/2011, p.98)

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Chapter 8

Discussion

8.1 Introduction

This chapter discusses curricular change in biology teaching using the findings from the study to illuminate the complex layers involved in changing practice. The outcomes of the three research mesocycles are discussed, beginning with the first mesocycle, which initiated a scoping cycle of research to identify the problem. In the second and third mesocycles, the solution to the problem meant going deeper under the layers of teaching and learning at senior cycle, uncovering and identifying the enquiry vacuum, and finding a solution to the wicked problem of practical teaching in the form of an artefact (the FTEA) grounded in a pragmatic theory of enquiry which was utilised during successive professional development micro-cycles to effect change in thinking and practice through enquiry. The penultimate section of this chapter identifies where this research is situated in terms of current STEM policy in Ireland and is followed by a final section that recognises the limitations of the research.

8.2 Outcomes of the Research Process

8.2.1 First Mesocycle – Needs and Content Analysis

This stage of the research saw an alignment between the Irish upper secondary biology practical classroom and a vast body of international research that identifies the recipe-based nature of the majority of practical lessons taught in science-based subjects (Sharpe and Abrahams, 2020; Millar 2004). Across the board, classroom enactment of recipe-style practical work directly conflicts with enquiry-based policy intentions. In Ireland those intentions conjure an image of biology as providing students with laboratory skills, enquiry-skills and preparation “for further education, training and employment in science related areas" (GOI, 2003, p.2). The policy intentions have trickled down into the consciousness of the collective teacher/student body since, when asked, interviewees reiterated the policy dogma around the value of practical activities for learning. Their comments speak more to their aspirations for practical work, as evidenced by an acknowledgement by teachers that within their own classrooms, while their students enjoyed it, they were not learning from it (Chapter 3). This was confirmed by data from student interviews where students had difficulty connecting scientific ideas underpinning practical work to the practical activities they were doing in class. Students identified practical work as their favourite part of biology lessons, specifically because it was an opportunity to engage socially with their peers in class, echoing previous research (Abrahams, 2009; Toplis, 2012). The social nature of learning was not harnessed into any kind of meaningful discussion about scientific ideas during practical activities, which is reflected in audio-recordings of students chatting about the materials they were using or about their personal lives. The lively nature of practical classes observed while students were carrying out tasks stood in stark contrast to the lack of discussion immediately before and after every practical activity. This period of the lesson was conducted either in silence (with students writing in laboratory manuals) or by the teacher asking mostly recall questions. There was no evidence of student thinking during these periods (Chapter 3).

The expectation that students will understand scientific concepts underpinning an experiment if they can produce the phenomenon has been repeatedly refuted in academia but in second level classrooms it is still the most common method of teaching practical work (Abrahams, Reiss and Sharpe, 2014; Abrahams, 2017; Langley and Mytum-Smithson, 2022). In this particular study there was an extra layer of frustration for teachers and students, because in six out of the ten practical activities observed, the students could not produce the phenomenon with the materials they were given, resulting in teachers telling them what "should" have happened, and leaving students confused as to the purpose of the practical activities. Students were only able to grasp at "pseudo-ideas" and "half-perceptions", which restricted their ability to think and to learn (Dewey, 1916/2011, p.80). Following Abrahams and Millar (2008), this scoping cycle uncovered how teacher preparation for practical work, revolved around preparation for what they wanted students to do with materials but not for what they wanted them to do with ideas.

8.2.2 Second and Third Mesocycles – Design and Development

First Prototype: Theory and artefact

The first prototype for an educational intervention to improve the level of thinking in practical activities was based on a “humble theory” adapted from Abrahams and Millar’s method of assessing the effectiveness of practical lessons in two domains; the level of doing and the level of thinking (2008). If a lesson incorporates activities in both the hands-on (doing) and minds-on (thinking) domain, and if students do and learn what the teacher intended for them to do and learn, then the lesson can be described as effective.

Integrating the humble theory and the design principles led to the development of the first prototype (the Framework for Teaching Practical Activities FTPA) lesson plan that teachers could use to prepare practical activities. The main premise of it is that practical activities follow an experiment-extension format where students learn a laboratory technique first and then apply it to a real world situation. Minds-on thinking is integral to this approach and the lesson plan allowed teachers to specifically identify where it is included in the lesson. Following a dearth of data collection, presentation and analysis in the scoping stage observations, the FTPA contained sections dedicated to planning for these. The overall structure of the FTPA roughly followed the scientific method of enquiry, which was notably absent from Leaving Certificate (LC) practical activities, despite being written into the curriculum as a method for teaching practical work.

Observation of PSTs and IST attempts to teach enquiry-based lessons revealed that the FTPA was not sufficient to address the enquiry vacuum that opened up during this mesocycle. The culturally ingrained, recipe-based nature of practical activities was masking a much bigger ‘wicked’ problem within the senior cycle biology curriculum – that the enquiry-oriented focus of the syllabus documents was undermined by a general inability of teachers to understand and apply scientific enquiry to their practical lessons. This situation is not unique to Irish biology teachers, it merely reflects what has already been internationally documented (Capps et al., 2013; Kidman, 2012). Essentially, teachers did not have the epistemic knowledge required to effect changes in their teaching practice (Zohar and Hipkins, 2018).

The washback effect of the leaving certificate system of assessment has been made culpable for much of the focus of teachers on rote learning and recipe-style tasks during practical work (Burns et al., 2018; Lehane, 2016). However, it also provides a convenient smokescreen behind which the ineffectual epistemology of conventional recipe-based 'mandatory experiments' (which have been proven by research, and recognised by teachers in this study, to be ineffective in promoting critical thinking skills) can continue unchallenged. This led to two design principles for the next cycle: development of a theory of enquiry to underpin the educational artefact, and establishment of a programme for professional development as a liminal space in which teachers could cross the epistemic divide between recipe-teaching and enquiry-teaching (Land et al., 2014).

Second prototype

There were three outputs of the research within this meso-cycle of research. A solid Theory of Enquiry was developed, followed by an educational innovation – the Framework for Teaching Enquiry Activities (FTEA), which was used as a reified artefact to underpin a Programme for Professional Development.

Theory of Enquiry

In line with modern curriculum development practices, a change in epistemology towards enquiry needs to be supported with a sound theoretical frame of reference (Priestly and Minty, 2013). A turn to academia for a theoretical solution, revealed another conundrum that exacerbated the wicked problem faced by anyone seeking to promote enquiry-based practical activities. There is a lack of agreement in academia around a clear definition of 'enquiry', equivalent to a literary minefield through which one has to burrow to extract a meaning for enquiry that is suitable for this particular situation (senior cycle practical activities), i.e. a theory specific to practical activities that supports an epistemological move towards knowledge-building processes.

A turn to the work of Dewey (1910/2012) in the form of the Complete Act of Thinking provided a theoretical lens through which a re-designed Framework for Teaching Practical Activities was reified. The Complete Act of Thinking is underpinned by a double movement between inductive and deductive thinking. Induction involves using different forms of partial data to uncover a whole meaning or principle, which is then further investigated through deductive application and testing of that principle in new situations. The combination of inductive and deductive reasoning brings the thinking back to the scientific principle and reinforces its meaning for students (ibid., 1910/2012).

The fulcrum of this theory rests on Dewey's concept of inference which bridges the space between induction and deduction. This is the space where thinking, understanding and learning occur. It is the space where the mind-body dichotomy dissipates as the focus of the lesson embodies consciousness (Dewey, 1925/1958). Consciousness occurs as there is a need and demand for filling out what is indeterminate, it makes the familiar unfamiliar, causing the student to stop and think about what they are physically doing, using hand and mind synergistically as one tool for thinking. Knowledge, through this epistemological lens, it is seen as an end-in-view, its future-oriented nature makes it is tangible, yet just out of reach. It cannot be "had" by transmitting information from teacher to student, it must be searched for by the student, the thinking is rooted within the practical, within the movement, this end in view is about the practice in the moment (Dewey, 1925/1958). Instead of teaching practical work as isolated incidents of activity, each activity is connected to previous, present and future activities along a continuum of learning. Deductive learning in one situation becomes the starting point for inductive learning in the next situation. Through this theoretical frame, senior cycle practical activities no longer focus solely on the inductive aspect of producing a phenomenon, students must now learn how to use an experimental technique and the data it produces, as a vehicle to project where their learning can take them in the deductive realm. This requires a pedagogy of uncertainty, curiosity and possibility which is contingent on teachers' ability to scaffold for consciousness by creating "forked-road situations" in which students must use inference to make a "leap" from what they have learned to what they could *potentially* learn with the information available to them (Dewey, 1910/2012). This pedagogy of uncertainty supports Biesta's (2014) argument in favour of shifting our understanding of knowledge and the curriculum from the domain of certainty to the domain of the possible. Biesta queries "whether it is possible to think about knowledge and reality in a different way, starting from different assumptions" by asking different questions (2014, p.36). In the Irish classroom context, it is the teacher who traditionally asks questions, the answers to which are generally known in advance and are either 'right' or 'wrong'. This research has demonstrated that when students are supported to ask their own questions, the need to be right or wrong dissipates. This is because not all students ask the same question and not all questions will be anticipated by the teacher when she prepares the lesson. Questions are converted to hypotheses which are investigated deductively, the outcomes of which are shared among the class group, reinforcing the scientific principle under investigation as "warranted assumptions" rather than "truth". The transferability of warranted assumptions from one situation to another strengthens their claims and can suggest possibilities for resolving further problems, which in turn can only be realised by acting upon them (ibid, 2014). This pragmatic approach taken to knowledge-building supports a move away from traditional transmission of information from teacher to student and becomes a democratic coming to knowledge, through intelligent trial and error (Dewey, 1929).

The Framework for Teaching Enquiry Activities (FTEA) Artefact

Academics working within curriculum studies have called for an awareness that students cannot work within the pragmatic sphere of knowledge-building processes that can be used to justify warranted assertions and lead to deep knowledge, without a focus on knowledge production and the nature and depth of thinking within practical activities (Zohar and Hipkins, 2018). However, the implementation of student-centered reforms that adopt "inquiry" pedagogies can actually have the opposite effect on learning because they are open to multiple interpretations (see Chapter 5 for a description of the difficulty of defining inquiry), and they conflict with teachers own personal beliefs about knowledge construction (ibid., 2018).

Curriculum reforms have consistently failed to address this lack of epistemological awareness among teachers, regardless of whether those reforms have been "tight" (top-down) or “loose” (bottom up) (ibid., 2018). Zohar and Hipkins (2018) compared the structure of the loose New Zealand curriculum and the tighter Israeli curriculum and found common implementation difficulties caused by a “looseness associated with a lack of clear criteria for teaching, assessing, and designing interventions that include a focus on knowledge-building practices in the disciplines (i.e., an epistemic focus)” (2018, p.44).

The FTEA is one such educational intervention with a set of clear epistemological criteria, designed for the biology curriculum, that fills the unoccupied niche in enquiry-based pedagogy. It allows teachers to make decisions that fit within the context of their own classrooms, while still fulfilling the requirements of the curriculum, thereby providing a solution to Fullan’s (2007) call to strike the right balance between tight and loose policy settings.

Dewey’s (1910/2012) Complete Act of Thinking is integrated into a Framework for Teaching Practical Activities (FTEA), which teachers can use to plan and prepare for inductive initiation of practical activities, by teaching students an experimental technique that guides them towards a scientific principle, followed by deductive investigation of that principle in a novel situation, by scaffolding a Leap activity that enables students to ask a question, develop an hypothesis and use the experimental technique to investigate it. Recognising that learning occurs along a continuum and is always future-oriented, each FTEA ends by indicating the direction of successive practical activities. For PSTs and teachers new to enquiry, the FTEA can be expanded into a Lesson Plan which further supports teachers in designing enquiry-based lessons. The FTEA, has demonstrated its potential in closing the enquiry vacuum for biology teachers, because it is underpinned by a theory of enquiry that considers how people think and how knowledge is constructed, both of which are embedded in its design (Dewey 1910/2012).

Osborne contends that an epistemic shift in enquiry practices in school to a focus on what scientists actually do (i.e. their knowledge-building practices) has been hampered by the conflation of “inquiry” with recipe-style confirmatory exercises (2014). The FTEA has shown its worth as an educational intervention that promotes a focus on knowledge-building, and assists teachers (and as a consequence, students) to think within the future-oriented, uncertain realm within which the epistemology of enquiry thrives.

Chapter 7 evidenced how PSTs and ISTs successfully used the FTEA to design practical activities. As an educational tool, it supported teachers to use enquiry as a realistic option for teaching practical work. Teachers thought and acted differently and the effect of this on student learning was profound. For example, in the scoping stages, teachers were worried that enquiry was a distraction from the real business of preparing students for the Leaving Certificate examination, but when students took part in FTEA-designed lessons, many performed beyond their “ability” on summative evaluations based on LC examination questions. This directly challenges the view that intellectually demanding learning is not suitable for all students (Yanto et al., 2019).

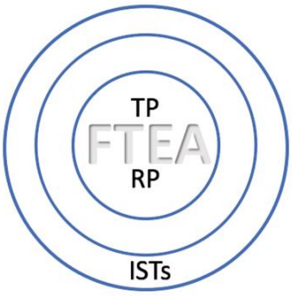
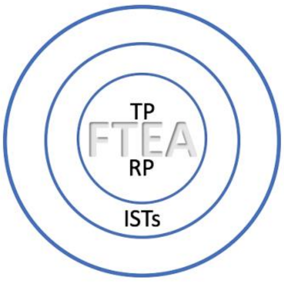
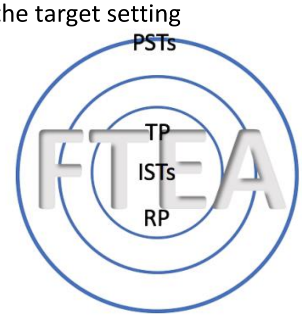
Designed specifically for practical activities, it is preferable to more popular enquiry-based heuristics such as Bybee’s (Bybee et al., 2006) 5E learning cycle, which by the admission of Bybee himself, has decreased effectiveness when used over shorter periods of time, such as one practical lesson (2014). Capps et al. (2013) have also criticised learning cycle approaches to practical work because teachers can have their students engage in all five stages of the cycle outside of the context of scientifically oriented questions and without engaging meaningfully with data. The FTEA also offers a more realistic framework for teachers than other enquiry frameworks (e.g. Pedaste et al., 2015) because it supports the teacher to *design* an enquiry-based lesson (rather than to follow a process of enquiry). In addition Pedaste’s (2015) inquiry-based learning framework, which represents a generic framework complied from a review of 32 other inquiry cycle designs, downplays the role of deductive application of knowledge in novel contexts. The pragmatic underpinnings of the FTEA promote deductive application of knowledge as an important means of enabling students to learn through action, keeping knowledge in the domain of the possible (rather that the domain of certainty), and keeping the pedagogy in line with its theoretical underpinnings (Biesta, 2014). Knowledge is an outcome of this process of enquiry.

One final advantage of the FTEA over other enquiry-based frameworks is the inclusion of the Leap which requires that teachers specifically think about and plan for how they can incorporate inference (the pedagogy of uncertainty) into their lessons. Teachers must use inference to plan for how their students will use inference – much like a Leap within a Leap. In this way, the method of designing the curriculum aligns with the enactment of the curriculum.

Programme for Professional Development

The final output of this research centered on finding a way to support teachers to understand and use the FTEA as a tool for planning practical activities. It is notoriously difficult to change teachers' practice long-term because it requires a change to their belief systems, which are deeply held and culturally embedded (Loucks-Horsley et al., 2010; Guskey, 2002). The success of this research in doing just this points to the need to provide the liminal space in which teachers could be supported to cross the epistemic divide between recipe-teaching and enquiry-teaching through a Community of Practice approach (COP) (Wenger, 1998). Table 8.1 summarises the scaffolded approach to professional development taken here.

Table 8.1: A summary of the Programme for Professional Development

Stage	Position within COP	Methodology
First stage: Planning and preparation 	RP and TP form the core of the COP using the FTEA as a boundary object. Each brokers access to educational pedagogy for enquiry (TP), and scientific content knowledge (RP) for the other.	Collaborative design and development and trialling of FTEA lessons. Generation of data for the WW.
Second stage: introduction to FTEA lessons 	High support/low accountability environment, brokered by the TP and RP, in which ISTs can develop an understanding of enquiry-teaching. ISTs occupy the periphery of the COP, participating in FTEA designed lessons as learners.	A Walkthrough Workshop provides the informal environment in which teachers are brought together to experience FTEA designed lessons and evaluate their potential practicality as senior cycle lessons
Third stage: FTEA lessons in a small scale setting 	Medium support / medium accountability environment. ISTs move further into the COP and develop a deeper understanding of enquiry by crossing the boundaries of three different perspectives-participating as student, designer and teacher. The TP brokers access to these three perspectives.	Multiple Micro-evaluations trial FTEA-designed lessons with a small group of users (teachers and students) in a small scale laboratory setting. The actual practicality and effectiveness of the FTEA is evaluated here.
Fourth stage: FTEA lessons in the target setting 	Low support / high accountability for ISTs who are now fully participating members at the core of the COP.	ISTs trial FTEA-designed lessons in the senior cycle classroom
	High support / low accountability environment. PSTs begin their PD journey at the periphery as learners	PSTs take part in a Walkthrough Workshop approach to the practical biology teaching module

The Walkthrough Workshop was preceded by a planning stage in which two people with expertise in the science education field – a Teacher Practitioner (TP) and a Research Practitioner (RP) worked collaboratively to design and develop lessons that they would model for ISTs. Their particular professional skillsets made them ideal leaders in the change process. The TP, as a former biology teacher-turned-teacher-educator and educational researcher had the pedagogical expertise to develop the FTEA underpinned by an epistemology of genuine enquiry, and the RP, as a research scientist and teacher-educator, had the technical and scientific knowledge to support and inform the design of FTEA activities. There have been instances in the literature of pairing teachers with research scientists to improve their understanding of enquiry, which have had mixed success (Drayton and Falk, 2006; Hughes et al, 2012). A scientist working with a teacher to improve their understanding of enquiry pedagogy is under researched. This research attests to the benefit of attending to the two-way engagement in the design process, where the TP and the RP worked together in a dynamic process of design and development using the FTEA as a guide, allowing pedagogical and scientific knowledge to flow back and forth between them. Dolfing et al. (2021) discuss the importance of collaborative curriculum design by teachers as a vehicle for supporting effective teacher learning in contexts such as this, where teachers are working within a new epistemology. This research shows how collaborative curriculum design should also extend to teachers working with other professionals in the field of science, where those professionals have an interest in pedagogy and a scientific skillset to complement that of the teacher.

The design perspective was also introduced to teachers as an element of the PD programme during the Micro-evaluation stage, where teachers worked together to design curriculum materials and student activities, with the support of the TP. This teacher-as-curriculum-designer approach rests on the nurturing of the "Design Mind" in PD programmes and represents a move away from the popular view of the teacher-as-curriculum-deliverer (Priestly et al., 2021). As evidenced in Chapter 5, policy around a clear definition of enquiry is not currently available, thus it cannot be translated into practice by teachers. Becoming a curriculum designer within a community of enquiry practitioners, on the other hand, enables teachers to bring a clear understanding of enquiry practices into the local context of their own classrooms. This provides an example of how creating clear criteria that tighten the "looseness" within teaching, assessing and designing interventions, can focus on epistemic knowledge within science education (Zohar and Hipkins, 2018). With this nexus of perspectives (learner, designer, teacher), along with a design tool (the FTEA) and specific ways of thinking about design (the Complete Act of Thinking), teachers were then ready to bring enquiry to their own classrooms as fully participating members of the COP.

At each stage of the PD journey, teachers move closer to the core of the COP as the level of support they receive is reduced, while the level accountability at each stage is increased.

The real success of this study came to fruition when ISTs enacted their own curriculum for enquiry teaching in the everyday, messy, social context of practical teaching. Dewey advocates for this type of "reality as a whole", but this research argues that it should only be attempted after teachers have been introduced to the signature pedagogy of enquiry and are comfortable within its epistemology. Only then can an understanding of what it is to be a teacher as curriculum maker can be fully realised. Deng (2017) contends that for too long, curriculum discourses and processes have been operating in different arenas of reality, leading to a situation where there is no connection between the written curriculum and the enactment of that curriculum through pedagogical practices. The problem is that the curriculum is made independently of its users (teachers and students) resulting in "a tendency to overlook the social and institutional contexts in which teaching is embedded and takes place and the (institutional) curriculum that, as indicated earlier, is intended to frame and guide teaching" (ibid, 2017, p.7). To ameliorate this situation, he proposes a form of curriculum concerned with curriculum making that accounts for the socially mediated nature of teaching and learning within classrooms (ibid, 2017, p.9).

Within this view, the teacher as the curriculum maker has the responsibility for transforming the written curriculum into everyday learning experiences for their students, thus addressing the challenge of finding a balance between curriculum freedom and regulation (Kuiper, Nieveen, and Berkvens, 2013; Nieveen, Sluijsmans, and Van den Akker, 2014).

As already outlined, the Irish senior cycle biology system is, at present, far removed from the idea of teachers as curriculum makers (Chapter 3 and 4) however the COP approach to professional development used within this research has demonstrated a how a move towards curriculum making can be achieved within the demands of freedom and regulation that Irish biology teachers contend with. Furthermore, as a new biology specification is currently under development (NCCA, 2019), calls for greater alignment of teaching, learning and assessment between the written and enacted curriculum (Hyland, 2014) cannot be answered without acknowledging that an epistemic shift should be at the root of any curriculum reform efforts. Assisting teachers to make this shift requires sustained and long-term professional development (Loucks-Horsley et al, 2010). The approach to professional development taken in this research has demonstrated how it is possible to make these changes through a scaffolded, collaborative approach to curriculum making and enquiry-based teaching and learning.

8.3 Policy Implications for STEM Education

It is incumbent upon curriculum developers and policy makers to acknowledge the enquiry vacuum in which most science teachers operate at senior cycle. Teacher participants came to this study with no understanding or experience of enquiry teaching and were rooted in a rigid system of recipe-style activities and assessment based on rote-learning, from which they could not envisage alternative modes of teaching. Another issue facing teachers was their utter isolation within their own classrooms. They had never had the opportunity to take part in professional development around teaching practical activities and they were not in the habit of collaborating with other teachers, even within their own subject departments, which may explain why they could say on one hand that practical work was important and meaningful (because that is the view in the syllabus documents), and on the other hand admit that their own students were not learning from it (Chapter 3). This section examines the characterisation of enquiry and professional development in Irish and European policy documents and proposes where this research can offer insights for policy makers, particularly in the Irish context as new STEM curricula are about to be implemented at senior cycle (NCCA, 2019).

8.3.1 Policy Implications for Enquiry

An examination of the Irish STEM Education Policy Statement 2017-2026 (DES, 2017). which outlines a vision for STEM education, shows a very limited understanding of enquiry, with vague guidelines such as, "teachers and early years practitioners will adopt an inquiry-oriented approach to their teaching and learning, and their practice will be informed by their engagement in and with relevant research" (ibid p.15). This thesis points to the highly complex nature of enquiry and to the lack of consensus in "relevant research" around what enquiry is and what it looks like. It is unhelpful to make a statement such as this placing the onus on teachers to adopt an enquiry-oriented approach without providing a clear definition of enquiry, underpinned by sound theory which can be applied to the intended enquiry-based pedagogy for teaching and learning (Priestly and Minty, 2013). This policy document draws on American STEM policy, which has faced its own criticisms from academic quarters for failing to reform the recipe-based nature of most practical work, specifically because teachers do not understand how to teach through enquiry (Capps et al., 2013; NRC, 2012).

The NCCA review of leaving certificate science subjects (NCCA, 2019) refers to enquiry as inquiry-based learning (IBL). This review is informed by a commissioned review into the Irish Leaving Certificate curriculum by Kind (2012), which perpetuates the notion that enquiry-based practice equates to categorising enquiry into three levels: structured, guided and open enquiry (Eastwell, 2006; Llewellyn, 2013). At the lowest level of enquiry (structured), students learn basic scientific skills such as observation of a phenomenon and formation of conclusions. At the second level (guided) students focus on data collection. Development of higher cognitive processes is confined to open enquiry (Zion and Mendelovici, 2012). This view of enquiry feeds into the separation of hand and mind, excluding minds-on thinking from lower levels of enquiry, which leads to a situation where academics have associated the level of enquiry with student ability, perpetuating the notion that only "bright" students would be able for open enquiry (Yanto et al., 2019). This progression through levels of enquiry is widely researched in academia but it has almost no uptake at second level (Capps et al., 2013). The problem with characterising enquiry in this way is that it fosters a misconception that the ideal goal for enquiry is open-enquiry (Hofstein and Kind, 2012), which has a negative association with student achievement in science (Jerrim et al., 2019; Sheil et al., 2016), and is therefore avoided by teachers. It also assumes that teachers understand enquiry, when clearly, they do not (Capps et al., 2013; see also Chapter 4).

The vision for STEM Education in Ireland is not a modest one, aiming to deliver "the best" education and training service in Europe by 2026:

> "In line with our ambition to have the best education and training service in Europe by 2026, Ireland will be internationally recognised as providing the highest quality STEM education experience for learners that nurtures curiosity, inquiry, problem-solving, creativity, ethical behaviour, confidence, and persistence, along with the excitement of collaborative innovation"
> (DES 2017, p.12).

Within the vision for the highest quality STEM education experience, "inquiry" is seen as one of a number of characteristics that can assist in achieving excellence – even though this understanding of inquiry as an IBL approach is problematic (Jerrim et al., 2019). Rather than looking at student development through levels of enquiry, the focus of the research in this dissertation is on encouraging teachers to use knowledge of how people learn, to design and practical activities for thinking (Deng, 2017; Osborne, 2015).

This view of enquiry is seen as an umbrella term that encompasses all of the other characteristics that fulfil the vision for excellence in STEM education– curiosity (Chapter 6), problem-solving (Chapter 6), creativity (Chapter 5, 6, 7), ethical behaviour (Chapter 7), confidence (Chapter 6, 7), persistence (Chapter 7) and the excitement of collaborative innovation (Chapter 6,7). Since enquiry and science education are inextricably linked, it would seem reasonable that the first step towards improving the learning experience is to provide a clear theoretical understanding of enquiry for teachers that can bridge the gap between policy and practice. This thesis proposes such a theory and reifies it into a signature pedagogy for enquiry-teaching that supports the STEM policy aspirations.

Furthermore, the ultimate purpose of the NCCA review was to "decide what knowledge is worth learning by students" (NCCA, 2019, p.20). It seeks to strike a balance between propositional knowledge, which is currently overrepresented at senior cycle, and procedural and epistemic knowledge which are currently underrepresented at senior cycle (SEC, 2013, p.18). The view of knowledge within this thesis as future-oriented, fallible, and situated in the relationship between actions and their consequences is a perfect representation of how this balance can be achieved in the realm of practical activities.

In wider European policy and practice, the term Inquiry-Based Science Education (IBSE) is used to denote a student-as-scientist approach to enquiry, where student engagement in science classes means "diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments" (European Commission, 2007). However European STEM teachers themselves report that they predominantly use "traditional direct instruction", with IBSE as their second least used methodology (Scientix, 2018a). It is interesting to note that teachers also reported a high incidence of "teaching with experiments", which indicates that transmission of information is what happens inside the practical classroom. The lack of IBSE, in particular as students approach upper secondary is concerning, and this paper calls for innovative approaches to STEM teaching practices grounded in enquiry-based science (ibid., 2018a).

Inquiry is seen as an innovative pedagogical approach written into policy in most European countries, yet it is rarely put into practice in classrooms. The pragmatic approach to knowledge in this thesis can answer calls from university and private company stakeholders to "drop the "how to" state of mind – applying "recipes" to already known problems – to adopt a "why?" state of mind, inquiring about problems that are not yet documented" (Scientix, 2018b).

8.3.2 Policy Implications for Professional Development

Turning to the second policy implication of this research is the recognition for the need to improve STEM education in Ireland through "a quality assured programme of STEM professional development" built on collaboration (DES, 2017, p.14). The policy points to the development of "robust relationships between schools and HEIs, research agencies, business and industry, professional bodies, science centres, media and government agencies" (ibid., p.15). This partnership approach to STEM education is mirrored in European policy with collaboration between university, industry and schools to develop STEM teacher skills promoted as an effective means of professional development (Scientix, 2018b). Indeed, there is a two way sharing of resources where policy makers commission outside agencies to develop resources for teaching and learning in the classroom, and teachers themselves can provide curriculum content to education ministries. This form of upskilling STEM teachers had created its own difficulties with teachers feeling "lost in the maze of STEM resources", with those resources created by industry partners being the least likely to be used by teachers in the classroom (ibid., 2018b, p.21). The aspirations of policy makers in Europe around professional development and partnerships do not translate into practice–for example, most teachers surveyed had done no professional development around STEM teaching in the two year period prior to the Scientix survey (2018a). This paper raises concerns about a lack of STEM professional development that supports teachers' content and pedagogical knowledge and confidence in using innovative technologies. The deficits in fostering a culture of innovative PD can be balanced by capitalising on the fact that the majority of teachers turn to their colleagues for professional support.

The COP approach developed in this thesis provides a solution to the question of how to encourage teachers to engage with innovative PD in partnership with each other and other stakeholders. Developing the "inquiry identity" cannot be achieved with PD designed using cognitive paradigms (focusing on content and pedagogy), since these have consistently failed to bring about transformations in teachers' practice (Bryce et al., 2016). Instead, grounding PD in a social practice approach to enquiry-based teaching, recognises that participation within a community of practitioners shapes how teachers learn to teach, and enables teachers to shape the learning of other members of the community (Holland and Lave, 2009). In other words, the inquiry identity is socially situated, teachers gain knowledge of enquiry content and pedagogy from mutual engagement in a community of other enquiry practitioners. Chapter 6 provided powerful evidence of how PD focused on the three modes of learning (hence identity) within a COP provided a solution to the commonly raised issue of a lack of content and pedagogical knowledge among science teachers (Capps et al., 2012; Yoon et al., 2012). Entering the COP as peripheral members, teachers recognised the value of coming together, away from the school context, to experience scientific knowledge construction through investigations from a learner perspective, which began the process of identity transformation (Luehmann, 2007). Part of this process was the development of more sophisticated ways of connecting scientific content knowledge with practical activities, and the realisation that teachers themselves were sources of knowledge and could learn from each other. Gee (2003) suggests that taking on a new identity (because the existing identity misaligns with the desired practices) requires “repair work” to support those new to or uncomfortable with a new identity. Aside from the scaffolded approach to membership of the COP, the repair work that teachers needed to effect a new identity came in the form of a boundary object (the FTEA) and was mediated by two brokers (the TP and RP), who provided the place and the safe space in which to negotiate the meaning of enquiry. In this way teachers were brought across the boundaries of the COP, from one level of participation to the next.

Finally, to develop their craft in designing and teaching practical activities through enquiry, it is important that professional development is seen along a long-term continuum, beginning during initial teacher education and continuing throughout a teacher’s early career. It took two years for the teachers in this study to achieve full membership status within the COP. It is recommended here that professional development should begin as a scaffolded approach during initial teacher education and should continue into early-career professional development opportunities. As teachers develop their enquiry identity inside COPs, they can in turn become “coaches” or mentors for other members of the COP who are further out on the periphery (Lotter et al., 2014). Vygotsky would see this as teachers acting as knowledgeable others, bringing other teachers across zones of proximal development that they themselves have already crossed (1978).

8.3.3 Policy Implications for the FTEA

Within the STEM Policy (DES, 2017),there are numerous references to teachers as designers, underpinned by the simplistic view that having sufficient pedagogical content knowledge (PCK) will be enough to support them in this endeavour. This view sees PCK as something that teachers “have” or “do not have” and is akin labelling students based on their perceived “ability”. The FTEA has proven its worth as a sense-making object that teachers can use to negotiate the meaning of enquiry and to design enquiry-based lessons collaboratively.

It bridges the gap between written and enacted policy by espousing a view of enquiry as a forward looking, future-oriented, end-in-view approach to learning, (Dewey, 1925/1958), as it leads to more ethical views on teaching and learning as written in the vison for STEM education in Ireland (DES, 2017).

8.4 Limitations of, and Potential Future Directions for Research

The effect of the Covid-19 pandemic placed strict limitations on the number of teachers who could take part in professional development during this research. The research claims made here are therefore restricted to the experience of the two teachers who took part in enacting FTEA-designed lessons in the target setting. However, the aim of this DBR project was to investigate the conditions under which a deeply complex concept (enquiry) could be reified in the senior cycle classroom, an aim that was achieved. The final aspect of DBR research projects concerned with curriculum innovation is to upscale the research with a larger number of research participants in a variety of school settings to assess its impact on a broader scale (Nieveen, 2006). Potential future research cycles could investigate this process of upscaling enquiry-based teaching at senior cycle on a regional or national level. In the Netherlands, curriculum innovation has turned towards Teacher Design Teams (similar to a COP approach) which focus on the teacher as the curriculum maker (Huizinga et al., 2015). The work of Teacher Design Teams is very similar to the work of the COP in this study and warrants further investigation for its potential to provide a framework for upscaling curriculum change in the Irish context.

Bassey (1999) emphasises the importance of piloting to develop research instruments that are consistent and well tested because it increases confidence in the trustworthiness of the data collected. Malmqvist et al. (2019) echo Bassey’s assertions but concede that there are instances, such as small-scale exploratory investigations that may not require a piloting process because their focus is on whether an issue is suitable for more substantial research.

In this small-scale research study it is acknowledged that there was a lack of piloting carried out on data collection instruments, which may have impacted the refinement of some of those instruments and therefore the quality of the data that was collected. Part of the lack of piloting can be attributed to the small-scale nature of the research, but there was also the difficulty of finding research participants during the global pandemic which meant that any one recruited to the project was maintained as a research participant rather than a piloting participant whose data could not be used. Three instruments in particular are discussed here in terms of the trustworthiness of the data they collected – interview, Structured Enquiry Observation Schedule (SEOS) and questionnaire.

Interviews often provide interviewers with “introductions to unknown worlds” (Sampson, 2004, p.400), and there is a sense that in order for the interview to be effective, a pilot is necessary to allow the interviewer to become familiar with the material and to fine tune any questions that may be misunderstood or misinterpreted. However, there are those who identify cases where pilots are not necessary with qualitative interviews because there are gradual improvements in interview schedules which occur over the course of the interviews (van Teijingen and Hundley, 2001). Harding argues that this is exactly why piloting is essential in qualitative interviews, so that the interview schedule can be adjusted prior to embarking on the main study rather than during it (2018). The quality of interview data has been reported to be dependent on the interviewer’s competence, familiarity with the subject and the interview techniques used. In this case the interviewer was very familiar with the subject and had developed skill in interview techniques, given her role as a biology teacher-turned-researcher (Malmqvist et al., 2019.). Notwithstanding, the interview process would have been improved though a piloting process that incorporated feedback sessions from interviewees and other researchers.

The SEOS was developed for use by this researcher only, and in that sense, its use across the PhD study was consistent and the data collected could be considered to be reliable. However, a lack of piloting makes it difficult to assert that it would be utilised in the same manner by other researchers or practicing teachers, hence, the level of confidence in it as a tool that could be used to assess the level of enquiry in a practical lesson remains untested. Given the lack of understanding of enquiry-learning, it is not assured that another researcher would use the SEOS in the way in which it is intended to be used (Capps and Crawford, 2013). However the SEOS does have potential to fill a niche as a self-, student- or peer-assessment tool, that could be used by teachers to measure the level of enquiry in their classrooms, and bring them to an understanding of the role of the student in enquiry-based learning. A future direction for this research is to conduct a pilot study in which the SEOS is refined for use by practicing teachers, as a precursor to a wider study to assess its effectiveness as a tool to improve enquiry practice in biology as Ireland transitions to a new biology curriculum.

Gudmundsdottir and Brock-Utne, 2010 discuss the importance of piloting questionnaires before employing them on a larger scale. Their piloting process identified issues that one group of participants had interpreting the questions. They recognised the lack of familiarity, (on the part of the researcher) with the research context, and the risk of question misinterpretation (of the participants) as two of the limitations of questionnaires. The questionnaire used in this doctoral thesis was adapted from the SEOS and was peer reviewed. The researcher was acutely familiar with the educational context in which it was intended to be distributed. However, it was not piloted, which may have impacted on its refinement because it was not screened in advance for misinterpretation errors.

Interview and Questionnaire data were analysed according to Template Analysis guidelines which specify refinement of the template until all of the data are accounted for within a structure that can be applied across multiple cases (King, 2012). A scientific approach to data analysis means that data are subjected to every possible test in an attempt to falsify the initial assumptions about the data. Only if data cannot be falsified can we speak to the objectivity and hence credibility, of the data (Popper, 1959). In terms of reliability, Silverman argues that qualitative data can be made reliable when the analysis is made transparent through a detailed description of the process. In addition, the researcher must be transparent about the theoretical stance from the interpretation takes place (Silverman, 2014). Both of these stipulations were adhered to within this research

(Chapter 2). However, in terms of template analysis, there were certain procedures omitted from the data analysis that would have enhanced the reliability; for example, standardising the categories (or codes) used to analyse each interview text by employing inter-rater reliability checks. This entails giving data to a number of analysts and asking them to analyse them within an agreed set of categories (Silverman, 2014). Given the small-scale nature of this doctoral thesis, this was not an option and it is acknowledged here that this would have enhanced the reliability of the data analysis.

In terms of the validity of the data analysis, the data should accurately represent the social phenomenon to which they refer (Hammersley, 1990). It should be specified that the low number of cases used in this research allowed for an intensive analysis of limited but rich data. One of the issues with how template analysis represents data is it is possible to lose sight of the local context within which that data sits, when specific pieces of data are selected for reporting (Bloor et al., 2000).

The analysis of the SEOS and the level of questioning in each lesson was not dissimilar to Content Analysis, where researchers establish a set of categories (SEOS- categories derived from the syllabus requirements; questioning analysis- categories derived from Blooms Taxonomy) and then count the number of instances that fall into each category. A crucial aspect of this method is to ensure that the categories are sufficiently precise so that different analysts could arrive at the same result when the same body of data is being analysed (Silverman, 2014). Again, the small-scale nature of this research did not allow for this process to occur thus it cannot be said that the SEOS or the questioning analysis are completely reliable or valid until different researchers use them in the same way and produce the same results.

The level of ambition in this research was to demonstrate to the educational community that there is a more successful way to teach practical work that supports students in understanding the scientific concepts that underpin the activities they conduct in practical lessons. The findings of the scoping stages of this research (Chapter 3) align with international evidence that there is an enquiry vacuum at upper secondary level in biology. Given the high level of support that a small number of teachers required at the beginning of the research, and the lack of any theory to underpin enquiry teaching, it would appear that much greater investment is required from government bodies and educational leaders to prepare teachers for the transition to a new curriculum. A good starting place would be to effectively refine and trial the SEOS on a larger scale to create regional and national awareness of the lack of enquiry skills utilised by second level teachers and students during practical lessons. This would provide a segue for research around the refinement of FTEA as an instrument that could address the issue. Dewey (1986) contends that an experience should be educative, but that there is always the risk that it can be mis-educative. This points to the need for the refinement of both artefacts to focus on whether teachers use them as they are intended to be used.

Aligning with the ethos of the DBR methodology, the FTEA was successfully implemented in its target setting, but only on a small scale (Csikszentmihalyi, 2013). However, in accordance with the final stages of DBR, the artefact can only make a significant difference in education if it is utilised on a wider scale (Serdyukov, 2017). Some of the conditions that promote the favourable implementation of educational innovations are outside of the control of this researcher. For example Polka and Kardash (2013) refer to the need for a "change zone" within the educational system, which provides the space and conditions in which the artefact can be disseminated. In Ireland, the transition between the old and new biology curriculum has the potential to be a change zone, provided policy makers and educational leaders are aware of and support the ability of the FTEA to bring about change. Within any change zone, "we need an army of implementers together with favorable [sic] conditions for the invention to spread and produce a result. Implementers in turn have to be creative and motivated to do their job; they must also have freedom to innovate in the implementation, security on the job to take risks, and control of what they are doing." (Serdyukov, 2017, p.18). This small-scale project had only two implementers (Pete and Rose), and it took time for them to understand the meaning of enquiry and how to develop the creativity and imagination required to implement enquiry-led lessons using the FTEA. While not impossible, there is a significant challenge to engaging an “army of implementers”, given the challenge of recruiting the small number of participants who took part in this research. A post-research study should be conducted to establish whether both teachers are still using the FTEA to teach enquiry-based lessons. Therefore, the next logical step for this research is to re-connect with the two teachers and determine what supports they need (if any) to continue to implement enquiry-based lessons. This follow-up study would gauge the extent of the Hawthorne effect relating to the use of the FTEA. The stance of this researcher aligns with that of Ann Browne (1992) that a Hawthorne effect is an acceptable aspect to educational innovation; i.e. a change in the behaviour of the participants caused by the presence of the researcher is a part of the process. However, if the change cannot be maintained in biology classrooms in the absence of the researcher, then the FTEA does not fulfil the requirements of any DBR artefact; that it must be practical and usable in its target setting. Following on from an initial study with the two original participants, a larger cohort of teachers could be engaged theoretically and practically to upscale and refine the use of the FTEA as a supporting artefact for enquiry-based lessons.

For this study it was not practical to undertake a longitudinal study of PSTs over a longer period of time. The WW experience during the Practical Biology Teaching Module was not supported by further PD around teaching practical work through enquiry at senior cycle, because this was the only laboratory module they undertook as part of their initial teacher education. Future research would benefit from profiling and supporting a group of PSTs as they move into the early career stage of teaching. Sustaining a COP approach beyond third level is a new avenue of exploration that would maintain a strong connection between second level teachers and third level educational research.

The final potential future direction for this research is to establish links with other stakeholders around developing a curriculum for practical activities grounded in the inquiry identity, as a more equitable way of teaching STEM subjects. STEM policy indicates an appetite for reform of teaching learning and assessment practices and calls for national bodies to work together to effect research informed changes to practice (DES, 2017). This research provides a viable alternative for teaching learning and assessment and therefore, could potentially become part of the national conversation around STEM teaching practices.

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Appendices

Appendix 2.1: Origin of Questions for the Student and Teacher Interviews

Origin of Questions for the Student interviews

Theme	Questions	Origin of theme
Interest in biology	How is practical work enacted in biology classrooms? (B) Why did you choose biology? (M)	Warm up questions about the subject (Kvale, 2011)
Interest in biology	How is practical work enacted in biology classrooms? (B) What is the best thing about doing biology? (M)	Warm up questions about the subject (Kvale, 2011)
This question was not gleaned from the literature but it seemed prudent to include it	Do the syllabus requirements and classroom enactment align? (B) Why do we teach practical work? (M)	To see why students think we teach practical work and compare their perception of it to what actually happens in the classroom
Students like practical work for its social and affective aspect	How is practical work enacted in biology classrooms? (B) What do students like about practical work? (M)	The affective social aspect of practical lessons engenders enjoyment for students – i.e. students like being with their friends (D'Costa & Schleuter, 2013). Is that also the case here?
Looking for aspects of enquiry	Do the syllabus requirements and classroom enactment align? (B) Describe the routine of practical classes in general (M)	To investigate if the practical lessons are conducted using a 'recipe' method or not (Abrahams & Reiss, 2012; Kind et al, 2011; Lunetta et al., 2007)
Preparation for practical lessons is generally confined to equipment and materials	Does the academic literature apply in the Irish context? (B) What kind of preparation do you / teacher do before a practical class? (M)	To see if there is any evidence of a pre-lab lesson (Lunetta et al., 2007) or to see if preparation for the experiment is seen as a part of the experiment.
The scientific method is a part of the syllabus but is not a part of practical work	Do the syllabus requirements and classroom enactment align? (B) Is there a hypothesis / question posed / any aspect of the scientific method (M)	Checking for aspects of the scientific method as stipulated in the syllabus documents (Llewellyn, 2013; Hofstein et al., 2005; Government of Ireland, 2003)
Students follow instructions to reach a pre-determined outcome	Does the academic literature apply in the Irish context? (B) Do students know what to do with materials – can they follow the procedure? (M)	Part of recipe teaching is following instructions. Literature reported that students can follow instructions (Kind et al., 2011; Abrahams & Millar, 2008; Hofstein & Lunetta, 2004). Observations and audio transcripts revealed that (in this study) students had difficulty following instructions. Interviews confirmed this.
Student understanding is diminished by recipe teaching	What effect does the enactment of practical work have on student understanding? (B) Do students know why they were doing what they were doing? (M)	Following Abrahams and Reiss (2012), this study used students' comments during interviews to make claims about their thinking.

By omitting preparation for how to teach the scientific concepts underpinning practical work, students are left confused as to the purpose of experiments	What effect does the enactment of practical work have on student understanding? (B) Can students connect theory with practical work? (M)	Teachers expect that by doing an experiment, the scientific concept underpinning the experiment will become clear to the student. Research indicates this is not the case (Hodson, 2013; Solomon, 2005; Millar, 2004). Observations and audio of lessons confirm this.
Getting the 'right' answer means producing the phenomenon	What effect does the enactment of practical work have on student understanding? (B) What do students consider to be a 'successful' experiment? (M)	Is producing the phenomenon considered the main goal of the experiment? (Abrahams & Millar, 2008)
The outcome is pre-determined for students. There is no leeway for deviating from the recipe	Does the academic literature apply in the Irish context? (B) Are students aware of the outcome before they do the experiment? (M)	Checking to see if students are working towards a pre-determined phenomenon – part of recipe style teaching (Kind et al., 2011; Abrahams & Millar, 2008; Hofstein & Lunetta, 2004)
Teachers feel they are disadvantaging their students if the students do not 'see' the phenomenon	What effect does the enactment of practical work have on student understanding? (B) Are students told what 'should' have happened if the experiment doesn't work? (M)	Teachers often feel they should either manipulate an experiment to make it 'work' or else they tell students what should have happened (Milllar, 2004)
Students are not familiar with enquiry learning	What effect does the enactment of practical work have on student understanding? (B) What do students understand by enquiry? (M)	To compare student perception of enquiry with literature (Llewellyn, 2013; Pardo & Parker, 2010)
Lessons do not incorporate enquiry	Does the academic literature apply in the Irish context? (B) Is there any enquiry in lessons? (M)	Practical work should be taught through enquiry as stipulated in the syllabus documents (Government of Ireland, 2003)

(B) = Big question (M) = Mini question

Origin of questions for teacher interviews

Theme	Questions	Rationale
Teacher experience	How does teacher experience affect the nature of practical lessons? (B) Question regarding background: college attended, subjects read etc. (M)	Warm up questioning (Kvale, 2011)
Teacher experience of enquiry	How does teacher experience affect the nature of practical lessons? (B) How are teachers prepared (college & CPD) for teaching practical work (M)	Literature reports a lack of professional development in teaching through enquiry (Dillon, 2008)
Teacher experience of enquiry	How does teacher experience affect the nature of practical lessons? (B) Secondary school experience of practical work (M)	To check for continuity at third level. Is there a culture of recipe teaching?
This question was not gleaned from the literature but it seemed prudent to include it	Do the syllabus requirements and classroom enactment align? (B) Why do we teach PW? (M)	To see why teachers think we teach practical work and compare their perception of it to what actually happens in the classroom and to students' perceptions of practical work

Students do not understand scientific ideas underpinning practical work	What effect does practical work have on student understanding? (B) Do students learn by doing PW? Why do students like doing PW so much? (M)	Evidence from research indicates that students like doing practical work because they do not have to write or think (Abrahams, 2009)
Focus on materials and equipment – not on ideas	How does teacher experience affect the nature of practical lessons? (B) What are the challenges around teaching practical work? (M)	To see what teachers focus on as challenges to practical work – does it revolve around equipment? (Nivalainen et al., 2010)
Collaboration is informal – no structure in place	How does teacher experience affect the nature of practical lessons? (B) Do teachers collaborate around doing practical work? (M)	Is there any structure in place for teachers to collaborate specifically to improve practical lessons (Jones et al., 2013)
Preparation focuses on materials and equipment	Does the academic literature apply in the Irish context? (B) How do teachers prepare for practical work (M)	Is there any emphasis on a pre-lab lesson (Lunetta et al., 2007). Do teachers prepare for what they want their students to think about? (Abrahams & Reiss, 2012)
Focus is on materials and equipment	Does the academic literature apply in the Irish context? (B) How do teachers get students to prepare for practical work (M)	Is there any emphasis on a pre-lab lesson (Cann 2016; Basey et al., 2014; Lunetta et al., 2007)
Method of assessment influences pedagogy	How does teacher experience affect the nature of practical lessons (B) How does the Leaving Certificate influence pedagogy? (M)	Research in the Irish context identified the Leaving Certificate exam as one of the reasons recipe teaching continues (Cullinane & Liston, 2016; Kennedy, 2012)
Conceptual understanding must be explicitly taught	What effect does the enactment of practical work have on student understanding? (B) Are students learning by doing practical work? (M)	Research indicates there is no conceptual understanding of scientific concepts when practical work is taught by recipe (Hodson, 2014; Abrahams & Reiss, 2012; Millar, 2004). Lesson observations and audio confirm this for this particular study
Recipe teaching disables students' ability to think and act	Does the academic literature apply in the Irish context? (B) Can students follow instructions? (M)	Part of recipe teaching is following instructions (Abrahams & Reiss, 2012; Kind et al., 2011; Abrahams & Millar, 2008; Hofstein & Lunetta, 2004) Observations and audio transcripts revealed that students had difficulty following instructions in this study. Interviews confirmed this.
Practical lessons focus only on following the recipe to produce the phenomenon	Does the academic literature apply in the Irish context? (B) Do students understand the what the materials are for? (M)	Research evidence claims that students cannot connect the materials and objects they use to do practical work with scientific ideas (Abrahams & Reiss, 2012; Abrahams & Millar, 2008). Observations and audio of lessons confirmed this.
Practical lessons focus only on following the recipe to produce the phenomenon	What effect does the enactment of practical work have on student understanding? (B) Do students understand the concepts behind the experiments? (M)	Teachers expect that by doing an experiment, the scientific concept underpinning the experiment will become clear to the student. Research indicates this is not the case (Hodson, 2014; Solomon, 2005; Millar, 2004). Observations and audio of lessons confirm this.
The notion of an experiment 'working' is tied to producing the phenomenon	What effect does the enactment of practical work have on student understanding? (B) How well do experiments 'work'? (M)	Most of the experiments observed in this study did not produce the phenomenon – this question was to check with teachers how common it is for experiments not to 'work' (Taken form lesson observations)

The notion of an experiment 'working' is tied to producing the phenomenon	What effect does the enactment of practical work have on student understanding? (B) How do students know when an experiment has been 'successful'? (M)	Is producing the phenomenon considered the main goal of the experiment? (Abrahams & Millar, 2008)
The scientific method is part of the syllabus bit not part of practical lessons	Do the syllabus requirements and classroom enactment align? (B) Are elements of the scientific method incorporated into practical lessons? Hypothesis, data collection, analysis, presentation etc. (M)	Check if syllabus documents align with practice (Government of Ireland, 2003). See what aspects of the scientific method are incorporated into practical lessons (National Research Council, 2012; Grunwald & Hartman, 2010)
Practical laboratory skills are neglected with the recipe method	Do the syllabus requirements and classroom enactment align? (B) Are practical skills taught? (M)	Literature reports practical skills not developed (Abrahams, Reiss & Sharpe, 2013). Classroom observations corroborate this report.
Literacy	What effect does the enactment of practical work have on student understanding? (B) What is the level of student literacy like? (M)	Evidence from literature indicates a lack of focus on scientific terminology and literacy (Fotou & Abrahams, 2015; Abrahams & Reiss, 2009)
Lessons do not incorporate enquiry	How is practical work enacted in biology classrooms? (B) Is there any enquiry? (M)	Check for alignment of practice with policy (Government of Ireland, 2003; Lunetta et al., 2007)
What do teachers think?	How does teacher experience affect the nature of practical lessons (B) What changes could be made to LC biology? (M)	To see what changes to teachers would like to make to the leaving cert exam.

(B) = Big question (M) = Mini question

(B) = Big question (M) = Mini question

Appendix 2.2: Consent forms for students, teachers, parents and principals

INFORMATION AND CONSENT FORM FOR STUDENTS

Information Sheet

Research project on how biology practicals are taught in Leaving Certificate.

What is this study about?

There are two parts to this study. The first part is about looking critically at how practical work is taught to leaving cert biology students. The second part of the study will investigate whether there is an alternative way of teaching practical work that benefits students and leaves them with a better understanding of the subject. You will be learning biology like you always do in 5th year and in 6th year you may be doing practical work in a different way. This will in no way have a negative effect on your learning, it will only enhance your understanding of the experiments.

Who am I?

My name is Natalie O'Neill and I am a researcher from Maynooth University. I am also a biology teacher with 20 years of experience teaching leaving cert students.

What will I be asking of you?

I will be asking your permission to video record 4 practical classes taught by your biology teacher this year and next year. The recording will be to examine the type of teaching and learning that is taking place in the classroom. You don't have to take part in the recording if you don't want to and the only people who will be looking at the videos are me and a small group of 10 other biology teachers who are co researchers in this project.

I may also ask 3 students from your class to take part in an interview together for 30 minutes this year and next year. Again, you do not have to take part if you don't want to. The interview will not be video recorded but will be audio recorded.

Who will see the information from the classroom videos and who will hear the information from the audio tapes?

The only people who will see the classroom videos are me and a small team of 10 teacher-researchers. We will be looking at the teaching and learning that happens in the classroom.
Before the audio interview, I will give you a Study Identity number and only you will have access to this number. When the interview is over, I will be replacing student names with these numbers so that everything you say will be anonymous. Your interview will be put together with interviews from other people and schools and you will not be identifiable in any way. I will return to your school with the transcribed focus group interview from your school and you are entitled to read this transcript to see if you are happy with what you said. You will be able to identify yourself from you Study Identity Number. If you are not happy with any statement you may ask for it not to be included in the final write up.
All information about the research will be stored on the projects laptop, which only Natalie O'Neill has access to. The laptop is password protected.

What happens to the information about the research once it is complete?
The information will be stored safely up to ten years in Maynooth University and it will then be destroyed. It must be recognised that, in some circumstances, confidentiality of research data and records may be overridden by courts in the event of litigation or in the course of investigation by lawful authority. In such circumstances the University will take all reasonable steps within law to ensure that confidentiality is maintained to the greatest possible extent

If you are stressed or anxious about the study, who can you contact?

Your classes will not be affected by this study. For the first part of the study the only difference will be that I will be sitting in the back of the room for 4 classes which will be video recorded. The questions that will be asked in the focus group interview will not be of a sensitive nature. However, if you are nervous about taking part, the school principal, Ms Jefford, or your biology teacher would be more than happy to have a chat with you.

Looking forward to working with you.

A study to examine and improve on how experiments are taught to leaving cert biology students.

Student Assent Form

Please complete as appropriate:

		Y	N
1	I have read the information sheet		
2	I understand that my taking part is totally voluntary		
3	I understand I am free to withdraw from the study at any time		
4	I assent to being videoed during my practical biology classes for this year and know I will be asked again next year if I want to be recorded		
5	I understand that I am not obliged to answer any question I don't want to		
6	I have had an opportunity to ask questions and all my questions have been answered		
7	I assent to participating in this study		

If you have any further questions about this research you can contact me, Natalie O'Neill at natalie.oneill@mu.ie or at

Participants name (in block letters) ______________________________

Participant's signature ______________________________

Researcher's name (in block letters)

____

Researcher's signature ______________________________

If during the participation in this study you feel the information and guidelines that you were given have been neglected or disregarded in any way, or if you are unhappy about the process, please contact the secretary of the Maynooth University Ethics Committee at research.ethics@nuim.ie or 00353 1 7086019. Please be assured that your concerns will be dealt with in a sensitive manner.

INFORMATION AND CONSENT FORM FOR RESEARCH PARTICIPANTS

Information Sheet

Purpose of the Study.

My name is Natalie O'Neill, and I am a doctoral student in the Department of Education at Maynooth University.

As part of the requirements for my PhD, I am undertaking a research study under the supervision of Dr. Majella Dempsey and Dr. Jackie Nugent.

The study is concerned with investigating current practice in the teaching of practical work in biology at senior cycle level. Part of the study will be the collaborative design and implementation of improvements in how practical work is taught and you will be a member of the team that designs these innovations and brings the new design into practice in the classroom.

What will the study involve?

This research project will be carried out using Design Based Research as the methodology. This means that you, as the teacher, will have a collaborative role in designing and implementing new innovations in the classroom. The study will involve a two-year commitment on your part. During the first year, I will be observing 4 practical classes that you teach. Part of the observation will involve video and audio recording the lessons. You will be interviewed at the end of this phase. There will be other teachers participating in the study and I will also be observing the same practical classes in their classrooms. Once this initial phase is complete, I will share my findings with the research team and we will begin the second phase of the research which is the design phase. As a team we will take each of the 4 practical classes in turn and design, implement and evaluate innovations that we hope will improve the students' conceptual understanding of the experiments they are doing. You will be interviewed after each of the 4 practical classes. During the design phase you will be asked to meet with the team as a whole and this may involve a time commitment outside of school hours. There will be no more than 6 of these meetings within any school year.

Who has approved this study?

This study has been reviewed and received ethical approval from Maynooth University Research Ethics committee. You may have a copy of this approval if you request it.

Why have you been asked to take part?

You have been asked because you are a biology teacher and you are a suitable candidate to provide data for this study.

Do you have to take part?

No, you are under no obligation whatsoever to take part in this research. However, we hope that you will agree to take part and allow me to observe you teaching, participate in a one-to-one interview and meet with the research team. It is entirely up to you to decide whether or not you would like to take part. If you decide to do so, you will be asked to sign a consent form and given a copy and the information sheet for your own records. If you decide to take part, you are still free to withdraw at any time without giving a reason and/or to withdraw your information up until such time as the research findings are analysed. A decision to withdraw at any time, or a decision not to take part, will not affect your relationships with your school or Maynooth University.

What information will be collected?
Your name, personal email and personal contact number will be collected by me. The only people who will have access to them are my supervisors and me. In any of the data that is published your name will be anonymised so that neither you nor the school you are working in can be identified.

Will your participation in the study be kept confidential?
Yes, all information that is collected about you during the course of the research will be kept confidential. No names will be identified at any time. All hard copy information will be held in a locked cabinet at the researchers' place of work, electronic information will be encrypted and held securely on MU PC or servers and will be accessed only by Natalie O'Neill, Majella Dempsey or Jackie Nugent.
No information will be distributed to any other unauthorised individual or third party. If you so wish, the data that you provide can also be made available to you at your own discretion.

'It must be recognised that, in some circumstances, confidentiality of research data and records may be overridden by courts in the event of litigation or in the course of investigation by lawful authority. In such circumstances the University will take all reasonable steps within law to ensure that confidentiality is maintained to the greatest possible extent.'

What will happen to the information which you give? All the information you provide will be kept at Maynooth University in such a way that it will not be possible to identify you. On completion of the research, the data will be retained on the MU server. After ten years, all data will be destroyed (by the PI). Manual data will be shredded confidentially and electronic data will be reformatted or overwritten by the PI in Maynooth University.

What will happen to the results?
The research will be written up in my doctoral dissertation. A summary report will be prepared and given to you and your school. The findings may be presented National and International conferences and may be published in scientific journals. A copy of the research findings will be made available to you on request.

What are the possible disadvantages of taking part?
I don't envisage any negative consequences for you in taking part in this study.

What if there is a problem?
At the end of each meeting I will discuss with you how you found the experience and how you are feeling. If you experience any distress following any meeting or interview or if you feel the research has not been carried out as described above, you may contact my supervisor (Dr. Majella Dempsey, majella.dempsey@mu.ie)

Any further queries?
If you need any further information, you can contact me:
Natalie O'Neill, 086 8586280, natalie.oneill@mu.ie

If you agree to take part in the study, please complete and sign the consent form overleaf

Thank you for taking the time to read this

Consent Form

I……………………………………agree to participate in Natalie O'Neill's research study titled "Is current practice in teaching practical work an effective means of developing secondary students' conceptual understanding of Leaving Certificate biology?"

Please tick each statement below:

The purpose and nature of the study has been explained to me verbally & in writing. I've been able to ask questions, which were answered satisfactorily. ☐

I am participating voluntarily. ☐

I give permission for my lessons, interviews and meetings with Natalie to be audio/video recorded ☐

I understand that I can withdraw from the study, without repercussions, at any time, whether that is before it starts or while I am participating. ☐

I understand that I can withdraw permission to use the data right up to submission of the thesis ☐

It has been explained to me how my data will be managed and that I may access it on request. ☐

I understand the limits of confidentiality as described in the information sheet ☐

I understand that my data, in an anonymous format, may be used in further research projects and any subsequent publications if I give permission below: ☐

I agree to quotation/publication of extracts from my interview ☐

Please sign the form overleaf

Signed…………………………………. Date……………….

Participant Name in block capitals ……………………………………………..

I the undersigned have taken the time to fully explain to the above participant the nature and purpose of this study in a manner that they could understand. I have explained the risks involved as well as the possible benefits. I have invited them to ask questions on any aspect of the study that concerned them.

Signed…………………………………. Date……………….

Researcher Name in block capitals ……………………………………………..

If during your participation in this study you feel the information and guidelines that you were given have been neglected or disregarded in any way, or if you are unhappy about the process, please contact the Secretary of the Maynooth University Ethics Committee at research.ethics@mu.ie or +353 (0)1 708 6019. Please be assured that your concerns will be dealt with in a sensitive manner.

For your information the Data Controller for this research project is Maynooth University, Maynooth, Co. Kildare. Maynooth University Data Protection officer is Ann McKeon in Humanity house, room 17, who can be contacted at ann.mckeon@mu.ie. Maynooth University Data Privacy policies can be found at https://www.maynoothuniversity.ie/data-protection.

Two copies to be made: 1 for participant, 1 for PI

INFORMATION AND CONSENT FORM FOR PARENTS/GUARDIANS

Information Sheet

Purpose of the Study.

I am Natalie O'Neill, a doctoral student in the Department of Education at Maynooth University and a biology teacher with over 20 years of experience in the classroom.

As part of the requirements for my PhD, I am undertaking a research study under the supervision of Dr. Majella Dempsey and Dr. Jackie Nugent.

The study is concerned with investigating current practice in the teaching of practical work in biology at senior cycle level. I would like to investigate how practical work is being taught in school and to see if there is a way that it can be improved upon. The involvement of your son/daughter as a student of biology would be very much appreciated.

What will the study involve?

This study will take place over a two-year period. Classes for your son/daughter will continue as normal during the period that the research is being carried out. In the first year I will be in her/his classroom observing 4 experiments that the class carries out. The classes will be video/audio recorded for the purpose of data collection. Your daughter/son may be randomly selected to take part in a 3 person focus group interview after the fourth experiment is completed. If you or she/he is uncomfortable with being interviewed, she/he does not have to take part.

In the second year, I will contact you again to remind you of this consent and that you can withdraw at this stage. I will observe a further 4 experiments in the same manner as before. These experiments will be designed differently following research carried out by a group of biology teachers and me. Your daughter/son may be asked to take part in a focus group interview after each of these 4 experiments and again, she/he does not have to do this if she/he does not want to.

Who has approved this study?

This study has been reviewed and received ethical approval from Maynooth University Research Ethics committee. You may have a copy of this approval if you request it.

Why has your son/daughter been asked to take part?

Your son/daughter has been asked to take part because her/his teacher is willing to assist in research that aims to improve on the teaching and learning of biology. This type of research requires student participants and he/she is a suitable candidate to provide research evidence for this study.

Does my child have to take part?

No, there is no obligation whatsoever to take part in this research. However, I sincerely hope that you will agree to your child taking part. If you decide to allow your son/daughter to take part, you are still free to withdraw him/her at any time without giving a reason and/or to withdraw his/her information up until such time as the research findings are analysed. A decision to withdraw at any time, or a decision not to take part, will not affect your child's relationships with his/her teacher, school or Maynooth University.

What information will be collected?
There will video and audio evidence of practical classes recorded for research purposes. If your child participates in a focus group, there will be an audio recording of this as well.

Will your son/daughter's participation in the study be kept confidential?
Yes, all information that is collected about your child during the course of the research will be kept confidential. No names will be identified at any time. All hard copy information will be held in a locked cabinet at the researchers' place of work, electronic information will be encrypted and held securely on MU PC or servers and will be accessed only by Natalie O'Neill, Dr. Majella Dempsey or Dr. Jackie Nugent.
No information will be distributed to any other unauthorised individual or third party. If you so wish, the data that your child provides can also be made available to you at your own discretion.

'It must be recognised that, in some circumstances, confidentiality of research data and records may be overridden by courts in the event of litigation or in the course of investigation by lawful authority. In such circumstances the University will take all reasonable steps within law to ensure that confidentiality is maintained to the greatest possible extent.'

What will happen to the information which your son/daughter gives? All the information your child provides will be kept at Maynooth University in such a way that it will not be possible to identify him/her. On completion of the research, the data will be retained on the MU server. After ten years, all data will be destroyed (by the PI). Manual data will be shredded confidentially and electronic data will be reformatted or overwritten by the PI in Maynooth University.

What will happen to the results?
The research will be written up in my doctoral dissertation. A summary report will be prepared and sent your school if you wish to access it. Alternatively, you can contact me by email and I will send the report to you. The findings may be presented at National and International conferences and may be published in scientific journals. A copy of the research findings will be made available to you on request.

What are the possible disadvantages of taking part?
I don't envisage any negative consequences for your child in taking part in this study.

What if there is a problem?
If you feel the research has not been carried out as described above, you may contact my supervisor (Dr. Majella Dempsey, majella.dempsey@mu.ie)

Any further queries?
If you need any further information, you can contact me:
Natalie O'Neill, 086 8586280, natalie.oneill@mu.ie

If you agree to take part in the study, please complete and sign the consent form overleaf

Thank you for taking the time to read this

Consent Form

I………………………………………. agree to allow my son/daughter ……………………………………….. to participate in Natalie O'Neill's research study titled "Is current practice in teaching practical work an effective means of developing secondary students' conceptual understanding of Leaving Certificate biology?"

Please tick each statement below:

The purpose and nature of the study has been explained to me in writing. I have been able to ask questions, which were answered satisfactorily.
☐

My son/daughter is participating voluntarily.
☐

I give permission for my son/daughter's lessons to be audio/video recorded
☐

I understand that my son/daughter can withdraw from the study, without repercussions, at any time, whether that is before it starts or while he/she is participating.
☐

I understand that I can withdraw permission to use the data right up to submission of the thesis ☐

It has been explained to me how my son/daughter's data will be managed and that I may access it on request.
☐

I understand the limits of confidentiality as described in the information sheet
☐

I understand that my son/daughter's data, in an anonymous format, may be used in further research projects and any subsequent publications if I give permission below:
☐

I agree to my son/daughter taking part in focus group interviews and to the quotation/publication of extracts from those interviews
☐

Please sign the form overleaf

Parent/Guardian signature…………………………………. Date………………

Name in block capitals ……………………………………………..

Student's name in block capitals………………………………….

I the undersigned have taken the time to fully explain to the above participant the nature and purpose of this study in a manner that they could understand. I have explained the risks involved as well as the possible benefits. I have invited them to ask questions on any aspect of the study that concerned them.

Signed…………………………………. Date………………

Researcher Name in block capitals ……………………………………………..

If during your participation in this study you feel the information and guidelines that you were given have been neglected or disregarded in any way, or if you are unhappy about the process, please contact the Secretary of the Maynooth University Ethics Committee at research.ethics@mu.ie or +353 (0)1 708 6019. Please be assured that your concerns will be dealt with in a sensitive manner.

For your information the Data Controller for this research project is Maynooth University, Maynooth, Co. Kildare. Maynooth University Data Protection officer is Ann McKeon in Humanity house, room 17, who can be contacted at ann.mckeon@mu.ie. Maynooth University Data Privacy policies can be found at https://www.maynoothuniversity.ie/data-protection.

Two copies to be made: 1 for participant, 1 for PI

INFORMATION AND CONSENT FORM FOR SCHOOL PRINCIPALS

Information Sheet

Purpose of the Study.

My name is Natalie O'Neill, and I am a doctoral student in the Department of Education at Maynooth University.

As part of the requirements for my PhD, I am undertaking a research study under the supervision of Dr. Majella Dempsey and Dr. Jackie Nugent.

The study is concerned with investigating current practice in the teaching of practical work in biology at senior cycle level. Part of the study will be the collaborative design and implementation of improvements in how practical work is taught. Each biology teacher in your school will be invited to become a member of the research team that designs these innovations and brings the new design into practice in the classroom.

What will the study involve?

This research project will be carried out using Design Based Research as the methodology. This means that the biology teacher will have a collaborative role in designing and implementing new innovations in the classroom. The study will involve a two-year commitment on his/her part. During the first year, I will be observing 4 practical classes that he/she teaches. Part of the observation will involve video and audio recording the lessons. The biology teacher will then be interviewed at the end of this phase. A focus group of no more than three students will also be interviewed. There will be other teachers in other schools participating in the study and I will also be observing the same practical classes in their classrooms. Once this initial phase is complete, I will share my findings with the research team and we will begin the second phase of the research which is the design phase. As a team we will take each of the 4 practical classes in turn and design, implement and evaluate innovations that we hope will improve the students' conceptual understanding of the experiments they are doing. Each biology teacher will be interviewed after each of the 4 practical classes. During the design phase he/she will be asked to meet with the team as a whole and this may involve a time commitment outside of school hours. There will be no more than 6 of these meetings within any school year.

Who has approved this study?

This study has been reviewed and has received ethical approval from Maynooth University Research Ethics committee. You may have a copy of this approval if you request it.

Why has your school been asked to take part?

You have been asked because the biology teachers in your school are suitable candidates to provide data for this study.

Does your school have to take part?

No, you are under no obligation whatsoever to take part in this research. However, we hope that you will agree to take part and allow me to observe you teaching, participate in a one-to-one interview and meet with the research team. It is entirely up to you to decide whether or not you would like to take part. If you decide to do so, you will be asked to sign a consent form and given a copy and the information sheet for your own records. If you decide to take part, you are still free to withdraw at any time without giving a reason and/or to withdraw your information up until such time as the research findings are analysed. A decision to withdraw at any time, or a decision not to take part, will not affect your relationships with your school or Maynooth University.

What information will be collected?

There will be no personal data collected about students.

The names, personal emails and contact numbers of teachers taking part will be collected by me.

The only people who will have access to them are my supervisors and me. In any of the data that is published the names will be anonymised so that neither you, the teachers you work with nor the school you are working in can be identified.

Will your participation in the study be kept confidential?

Yes, all information that is collected about you during the course of the research will be kept confidential. No names will be identified at any time. All hard copy information will be held in a locked cabinet at the researchers' place of work, electronic information will be encrypted and held securely on MU PC or servers and will be accessed only by Natalie O'Neill, Majella Dempsey or Jackie Nugent.

No information will be distributed to any other unauthorised individual or third party. If you so wish, the data that you provide can also be made available to you at your own discretion.

'It must be recognised that, in some circumstances, confidentiality of research data and records may be overridden by courts in the event of litigation or in the course of investigation by lawful authority. In such circumstances the University will take all reasonable steps within law to ensure that confidentiality is maintained to the greatest possible extent.'

What will happen to the information which your teachers and students give? All the information provided will be kept at Maynooth University in such a way that it will not be possible to identify anyone taking part. On completion of the research, the data will be retained on the MU server. After ten years, all data will be destroyed (by the PI). Manual data will be shredded confidentially and electronic data will be reformatted or overwritten by the PI in Maynooth University.

What will happen to the results?

The research will be written up in my doctoral dissertation. A summary report will be prepared and given to you and your school. The findings may be presented National and International conferences and may be published in scientific journals. A copy of the research findings will be made available to you on request.

What are the possible disadvantages of taking part?

I don't envisage any negative consequences for you or your school in taking part in this study.

What if there is a problem?

At the end of each meeting I will discuss with you how you found the experience and how you are feeling. If you experience any distress following any meeting or interview or if you feel the research has not been carried out as described above, you may contact my supervisor (Dr. Majella Dempsey, majella.dempsey@mu.ie)

Any further queries?

If you need any further information, you can contact me:

Natalie O'Neill, 086 8586280, natalie.oneill@mu.ie

Thank you for taking the time to read this

Consent Form

I……………………………………agree to participate in Natalie O'Neill's research study titled "Is current practice in teaching practical work an effective means of developing secondary students' conceptual understanding of Leaving Certificate biology?"

Please tick each statement below:

The purpose and nature of the study has been explained to me verbally & in writing. I've been able to ask questions, which were answered satisfactorily.
☐

My school is participating voluntarily.
☐

I give permission for lessons, interviews and meetings between Natalie and the science teachers in this school to be audio/video recorded
☐

I give permission for focus group interviews and between Natalie a small group of senior cycle students in this school to be audio recorded
☐

It has been explained to me how the data will be managed
☐

I understand the limits of confidentiality as described in the information sheet
☐

Please sign the form overleaf

Signed……………………………………. Date……………….

Participant Name in block capitals ……………………………………………..

I the undersigned have taken the time to fully explain to the above participant the nature and purpose of this study in a manner that they could understand. I have explained the risks involved as well as the possible benefits. I have invited them to ask questions on any aspect of the study that concerned them.

Signed……………………………………. Date……………….

Researcher Name in block capitals ……………………………………………..
If during your participation in this study you feel the information and guidelines that you were given have been neglected or disregarded in any way, or if you are unhappy about the process, please contact the Secretary of the Maynooth University Ethics Committee at research.ethics@mu.ie or +353 (0)1 708 6019. Please be assured that your concerns will be dealt with in a sensitive manner.

For your information the Data Controller for this research project is Maynooth University, Maynooth, Co. Kildare. Maynooth University Data Protection officer is Ann McKeon in Humanity house, room 17, who can be contacted at ann.mckeon@mu.ie. Maynooth University Data Privacy policies can be found at https://www.maynoothuniversity.ie/data-protection.

Two copies to be made: 1 for participant, 1 for PI

Appendix 3.1: The Practical Activities Analysis Inventory for 10 Scoping Stage Lesson Observations

An alternative form of the Practical Activities Analysis Inventory (PAAI) that can be used to summarise information on 10 practical activities

2 Learning objective(s) (or intended learning outcome(s))

Activity number →		1	2	3	4	5	6	7	8	9	10
1.1	**Objective (in general terms)** (*Enter '1' for the* ***main objective****; '2' if necessary for a* ***subsidiary objective****.*)										
A: By doing this activity, students should develop their knowledge and understanding of the natural world		Y	Y	Y	Y	Y		Y	Y	Y	Y
B: By doing this activity, students should learn how to use a piece of laboratory equipment or follow a standard practical procedure							Y				
C: By doing this activity, students should develop their understanding of the scientific approach to enquiry											
1.2	**Learning objective (more specifically)** (*Tick ✓ one box in each group for which you have entered a number above*)										
A1	Students can recall an observable feature of an object, or material, or event			Y	Y			Y	Y		Y
A2	Students can recall a 'pattern' in observations (e.g. a similarity, difference, trend, relationship)	Y	Y		Y	Y					
A3	Students have a better understanding of a scientific idea, or concept, or explanation, or model, or theory										
B1	Students can use a piece of equipment, or follow a practical procedure, that they have not previously met						Y			Y	
B2	Students are better at using a piece of equipment, or following a practical procedure, that they have previously met										
C1	Students have a better *general understanding* of scientific enquiry										
C2	Students have a better *understanding of some specific aspects* of scientific enquiry										

For C2, rather than simply ticking ✓ the box, enter letters to indicate the *specific aspects* being taught, as follows:

a	How to identify a good investigation question	e	How to analyse data to reveal or display patterns
b	How to plan a strategy for collecting data to address a question	f	How to draw and present conclusions based on evidence

2 Design

Activity number	1	2	3	4	5	6	7	8	9	10
2.1 Openness/closure (Tick ✓ one box)										
No question given, and detailed instructions on procedure		X	X		X		X	X	X	X
Question given, and outline guidance on procedure; some choices left to students				X						
Question given, but students choose how to proceed										
Students decide the question and how to proceed										
2.2 Logical structure of the activity (Tick ✓ one box)										
Collect data on a situation, then think about how it might be summarised or explained										
Use your current ideas to generate a question or prediction; collect data to explore or test										
Other. Please describe: Follow instructions	X	X	X	X	X	X	X	X	X	X
2.3Importance of an understanding of scientific ideas (to carry out the activity well) (Rate: 4= essential; 3=fairly; 2=not very; 1=unimportant)										
Importance of an understanding of scientific ideas	1	1	1	1	2	1	1	3	1	1
2.4 What students haveto do with objects and materials (Tick ✓ all that apply)										
Use an observing or measuring instrument	X	X	X	X	X					X
Follow a standard practical procedure	X	X	X	X	X	X	X	X	X	X
Present or display an object or material				X				X		
Make an object										
Make a sample of a material or substance			X	X	X				X	
Make an event happen (produce a phenomenon)	X	X	X		X	X	X		X	
Observe an aspect or property of an object, material, or event	X	X	X	X				X	X	X
Measure a quantity	X	X	X		X		X			X
2.5 What students have to 'do' with ideas (Tick ✓ all that apply)										
Report observations using scientific terminology				X				X		
Identify a similarity or difference (between objects, or materials, or events)			X							
Explore the effect on an outcome of a specific change (e.g. of using a different object, or material, or procedure)									X	
Explore how an outcome variable changes with time			X							
Explore how an outcome variable changes when the value of a continuous independent variable changes	X	X					X			
Explore how an outcome variable changes when each of two (or more) independent variables changes						X				X
Design a measurement or observation procedure										

Obtain a value of a derived quantity (i.e. one that cannot be directly measured)										
Make and/or test a prediction										
Decide if a given explanation applies to the particular situation observed										
Decide which of two (or more) given explanations best fits the data										X
Suggest a possible explanation for data										

3 Presentation

Activity number ⮰	1	2	3	4	5	6	7	8	9	10
3.1 How is the purpose, or rationale, communicated to students? (Tick ✓ one box)										
Activity is proposed by teacher; no explicit links made to previous work	X	X	X		X	X	X			X
Purpose of activity explained by teacher, and explicitly linked to preceding work				X				X	X	
Teacher uses class discussion to help students see how the activity can help answer a question of interest										
Purpose of activity readily apparent to the students; clearly follows from previous work										
Activity is proposed and specified by the students, following discussion										
3.2How is the activity explained to students? (Tick ✓ all that apply**)**										
Orally by the teacher	X	X	X	X	X	X	X	X	X	X
Written instructions on OHP or data projector	X	X	X		X	X	X	X	X	
Worksheet								X		
(All or part of) procedure demonstrated by teacher beforehand								X		
3.3 Whole class discussion before the practical activity begins? (Tick ✓ all that apply)										
None										
About equipment and procedures to be used		X	X	X	X	X	X	X	X	X
About ideas, concepts, theories, and models that are relevant to the activity									X	
About aspects of scientific enquiry that relate to the activity										
3.4 Whole class discussion following the practical activity? (Tick ✓ all that apply)										
None						n/a				X
About confirming 'what we have seen'	X	X	X	X	X	n/a	X	X	X	
Centred around a demonstration in which the teacher repeats the practical activity						n/a				
About how to explain observations, and to develop conceptual ideas that relate to the task						n/a				
About aspects of investigation design, quality of data, confidence in conclusions, etc.						n/a				
3.5 Students' record of the activity (Tick ✓ one box)										
None					X	X				X
Notes, as the student wishes										
A completed worksheet										

Written report with a given structure and format	X	X	X	X			X	X	X	
Written report in a format chosen by the student										

4 Learning demand

In the light of your entries above, how would you judge the **learning demand** of this activity? (Rate: 5=very high; 4=fairly high; 3=moderate; 2=fairly low; 1=very low)										
Learning demand	1	1	1	1	1	1	1	1	1	1

Appendix 4.1 Leaf Yeast Lesson Design

Appendix 4.1a – Worksheet for Leaf Yeast Investigation

Leaf Yeast Experiment: Aseptic technique

Which is more important when working with microorganisms?

a. Disinfect bench and cutting board with alcohol

b. Wash bench and cutting board with warm soapy water

Give a reason for your answer:

How many agar plates are you going to use? (Remember you want to make this as easy as possible) _________________

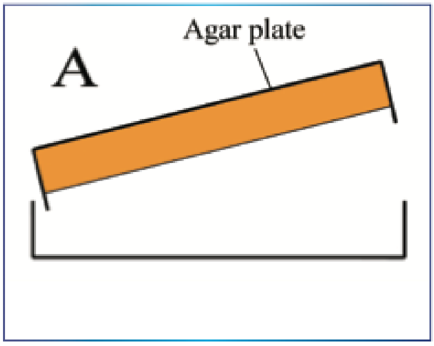
You are going to use leaves from an ash tree. They are not all the same size so how can you ensure that you make them the same size?

How can you ensure that you do the above aseptically?

You can't put the leaves directly onto the agar because other microorgansims from the leaf may contaminate the agar. Use the fact that S. roseus is a "mirror" yeast to decide where you will place the leaves if you can't put them directly onto the agar. Say how you will secure them in place (look at the materials in front of you)

How will you ensure that you secure the leaves in place aseptically?
____
_____

You will also have to work with the agar plates upside down. Why do you think this is so?



Which surface of the leaf will be facing the agar?

a. The topside of the leaf

b. The underside of the leaf

From the information you have read today – give a reason why this is so

---

Once you have the leaves secured on the plates you wrap parafilm around the plates. What is the purpose of the parafilm?____

How will you distinguish one plate from another?

____

Now decide how you will store the plates and give a reason for your answer:

Pick your temperature first

a. 10°C

b. 20°C

c. 30°C

d. 40°C

Give a reason for the temperature you have chosen.

Pick the position of your plates

a. Right side up for 4 days

b. Upside down for 4 days

c. Right side up for a day and then upside down for 3 days

d. Upside down for a day and then right side up for 3 days

Give a reason for your answer

What result are you expecting for this experiment?

Use the sheet you have just completed to write a question, a hypotheses and a method for this experiment

Question:

Hypothesis:

Method:

Read the extract about leaf yeast and underline 4 important points about it.
Then we discuss:
What do you understand by indicator species?

What does a "mirror" yeast species mean?

How does S. roseus act as an indicator species?

How is the population density of S. roseus measured?

Why were the leaves collected in September rather than in April?

Check powerpoint with Background information

Think about an experiment you could conduct to assess the quality of air in the area where you live using S. roseus
Things to think about
What question are you going to ask?
What is your hypothesis?

Appendix 4.1b – Reading Material for Leaf Yeast Investigation

Leaf Yeast – Background Information

Name: **Sporobolomyces roseus**.
This species is the most common of the leaf yeasts. It grows on both the upper and lower surfaces of plant leaves. Its presence is influenced by factors such as leaf exudates, light intensity and temperature. The age of the leaf and its position on the tree also play a part in determining the presence and abundance of the yeast. Furthermore, the type and amount of wax, the number and position of stomata on the leaf surface and the presence of epicuticular hair will also play a role.
This species grows as pink colonies and its abundance has been used to monitor air quality. It is known as a 'mirror' yeast because it can forcibly discharge its spores which then grow on the agar forming a mirror image. It is thought that the leaf yeasts overwinter on grasses, especially on ryegrass and meadow fescue. These then provide the source of the initial populations in the Spring/Summer.
S. roseus has evolved efficient air uptake mechanisms and as a result, where the air contains poisonous pollutants, particularly sulfur dioxide, the number of leaf yeast colonies per disc is greatly reduced. Since leaf yeast cells have a rapid life cycle, changes in the leaf populations can be used to monitor short-term changes in air quality. It is not possible to count yeast cells directly on the leaf surface but an indirect measure of population density can be obtained by measuring the number of colonies that can be isolated on agar plates from a given area of the leaf. This would be difficult to do with most leaf-surface fungi but the fact that S. roseus shoots basidiospores into the air where they can be intercepted, means that relatively simple techniques can be used.
The number of colonies will reflect the health of the yeast populations and also the quality of the air. Large-scale comparative studies, carried out by school children in several European countries, have established that the lowest numbers of leaf yeast colonies correlate well with higher levels of sulfur dioxide pollution. EannaNíLamhna of An ForasForbartha co-ordinated the Irish studies undertaken from 1982 to 1986. Secondary school students from the mid-west, the south coast, Cork city and the east coast used lichens, leaf yeasts (from the underside of ash tree leaves), and the acidity of the rainfall to monitor the air quality. While the lichens reflected the air quality in the few years prior to the study, the results for the leaf yeast study depended on the air quality in the weeks prior to the investigation.

Common ash – Fraxinus excelsior

The common ash is a large familiar tree with a long silvery stem.

- The 20 cm – 30 cm leaves are pinnate with 9 – 13 toothed oval leaflets arranged in pairs with a single one at the tip.
- In April, the flowers appear before the leaves – the flowers are green in colour, are small and inconspicuous having neither a calyx nor a corolla.
- In Autumn, the leaves turn a muddy brown or yellow colour and are shed in October.
- The ash tree is hardy enough to survive almost anywhere.
- In Winter, clusters of black velvety buds will help to identify the tree.

Tips for Teachers

Advance preparation
• Collect fresh leaves.
• Set the incubator and check the temperature with a thermometer.
• Prepare/purchase malt agar plates.

Helpful hints
• Leaves from common ash, lilac, sycamore, red alder or hawthorn are generally suitable for use in this investigation. Ash leaves are particularly good as they are widely available, easy to identify and have good yeast populations. Ash trees can be found in parks and roadsides and also in hedges used to mark field boundaries. Clover leaves and cherry laurel leaves release cyanide thus inhibiting the growth of S. roseus.
• The investigation is best conducted in September when the leaves have been growing for a few months and the yeasts have had time to colonise and grow.
• Take leaves from the base of long shoots as these are the older leaves and have been on the tree since Spring. New young leaves from the tips of the shoots have fewer yeasts on them. • After collecting the leaves keep them in a rigid container e.g. a plastic box, to prevent the leaves being crushed and the leaf yeasts from being rubbed off.
• After heavy rainfall or high wind, wait a few days to collect leaves as rain or wind may remove some of the leaf yeasts.
• Process the samples the same day that you collect them.
• Take care not to get petroleum jelly on the side of the leaf discs from which the spores are to be collected.
• Malt agar plates can be made up if they are not readily available.
• Variations on the investigation could be carried out as project work e.g. compare the leaf yeast populations from the upper and the lower leaf surfaces or from trees growing in different areas.

Appendix 4.1c Powerpoint: Making Agar and Aseptic Technique

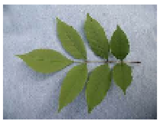
Leaf Yeast

Making agar

Aseptic Technique

Collect the leaves in september!

- Freeze them in a plastic container until you need them – you don't want them getting squashed, the yeast will rub off
- Use the leaves of the ash tree



Making Agar

- Make up solution as per instructions on the container
- Use a clean beaker
- Example 38g in 1L of deionised water.
- Stir to dissolve

- BRING TO THE BOIL (if you skip this bit the agar wont set)
- Put in the autoclave at 121 degrees for 15 mins to sterilise
- Cool to 50 degrees and pour the plates quickly

How to pour plates

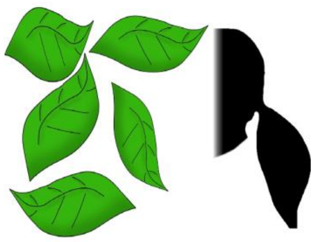
- Light bunsen
- Set up plates around bunsen burner
- Lift lid of plate slightly on side nearest bunsen and cover base of plate with agar – not too thick
- Leave to set with lid slightly askew
- When set put lid on and store in fridge till needed

The lit bunsen moves air up and reduces chances of contamination of plates from air

Leave to set with open side facing bunsen

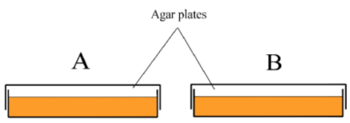
Appendix 4.1d – Visual on Desk for Leaf Yeast Experiment

Step 1



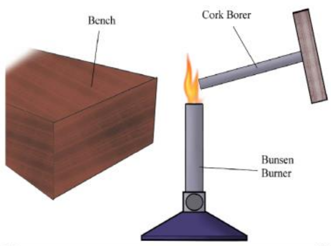
Collect leaves. Tie back hair and wash hands.

Step 2



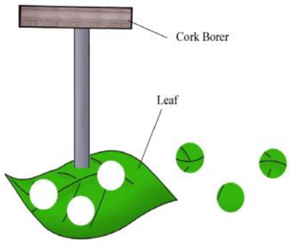
Place two agar plates on the bench. Label 'A' and 'B'.

Step 3



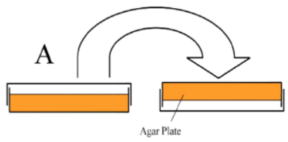
Wash and disinfect the chopping board. Flame the forceps to sterilise.

Step 4



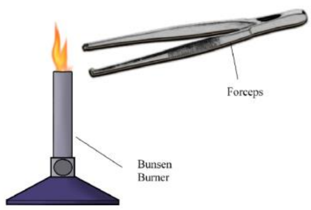
Cut as many discs as possible from the leaf using the **scalpel**.

Step 5



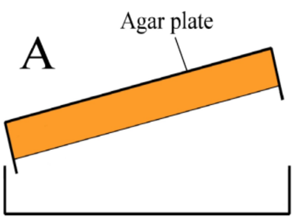
Place plate 'A' upside-down on the bench.

Step 6



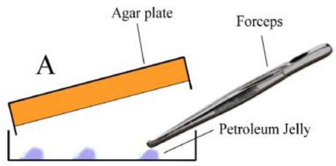
Flame the forceps and allow it to cool.

Step 7



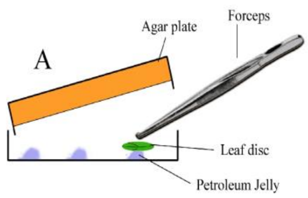
Carefully raise the base of the petri dish just enough to work with.

Step 8



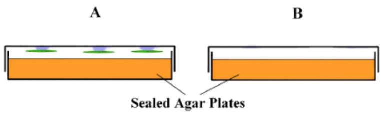
Using the forceps, smear dots of petroleum jelly onto the inside of the lid.

Step 9



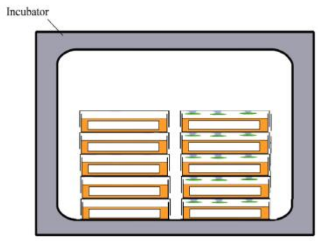
Use the forceps to attach a leaf disc to each blob of jelly with the underside of the leaf facing the agar. Re-flame the forceps.

Step 10



Seal the plate with parafilm. Seal plate 'B' with parafilm. Label and date both plates.

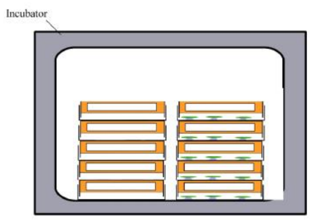
Step 11



Store all petri dishes right way up in an incubator at 20° C for 24 hours.

Why?

Step 12



Turn the petri dishes upside down and incubate at 20° C for 3 days.

Appendix 4.1e – Risk Assessment for Leaf Yeast Experiment

RISK ASSESSMENT SHEET

CLASS NAME: BI317 INQUIRY BASED BIOLOGY TEACHING & LEARNING
ACTIVITY: Lab Practical - Investigation of the growth of leaf yeast using agar plates and controls
NAME OF TEACHER(S): Natalie O'Neill

ASSESSMENT DATE: 19 September 2019 2 pages

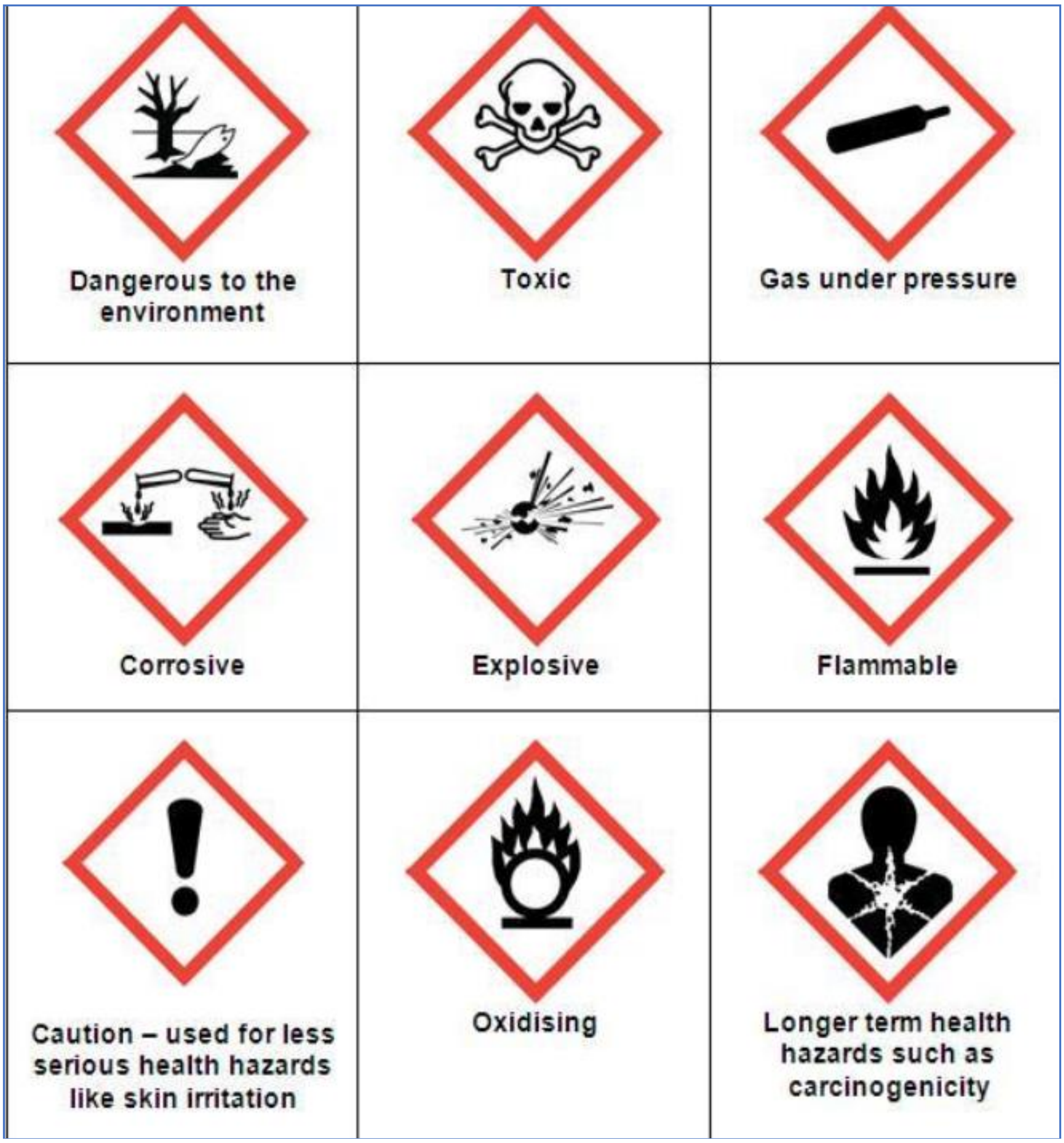
HAZARD	PERSONS AT RISK:	*EXISTING CONTROLS*	*RISK CLASS	RECOMMENDED CONTROLS
Flammable Ethanol	Students Demonstrators Technicians Academics Cleaners	Supervision Safety data sheet (SDS) available Pipette fillers Pre-lab talk Fire extinguishers Training Spill kit Flammable storage cabinet Lab coats & glasses	Medium	None
Harmful Bunsen flame	Students Demonstrators Technicians Academics Cleaners	• Supervision • Pre-lab talk • Training • Mains gas shut off switch • Lab coats, & safety glasses • Fire extinguishers / fire blankets	Medium	None
Harmful Knives Possible broken glassware	Students Demonstrators Technicians Academics Cleaners	• Supervision • Pre-lab talk • First aid kit • Glass disposal bin • Lab Coats & safety glasses	Low	None

HAZARD	PERSONS AT RISK:	*EXISTING CONTROLS*	*RISK CLASS	RECOMMENDED CONTROLS
Harmful Bags, coats, books on the floor.	Students Demonstrators Technicians Academics Cleaners	• Supervision • Pre-lab talk	Low	None
Human factor Inexperience	Students	• Supervision • Pre-lab talk	Low	None

Hazard	Who is at Risk?	Current Controls	Risk Factor	Additional Recommended Controls	Person responsible for implementing additional controls and time frame.

RISK RATING	BROAD CATEGORIES OF COMBINATIONS OF SEVERITY AND LIKELIHOOD. Considering existing controls
LOW RISK	1. Injury or material loss unlikely though conceivable. Exposure unlikely to cause health problems but if it did would be such as to be easily treated with no lasting effects e.g. minor first aid injuries
MEDIUM RISK	1. Unlikely possibility of fatality, serious injury or significant material loss. 2. Possibility of minor injury (first-aid) to a small number of people or '3 day illness/injury to one person. Exposure may have acute (immediate) effects which may have lasting effect
HIGH RISK	1. Possibility of fatality, serious injury or significant loss. 2. Possibility of minor injury to a larger number of people. Exposure may have chronic (long-term) effects or could result in death. 4. Direct breach of legislation, Approved Code of Practice or HSA/HSE(Irl)/HSE(UK) guidelines.

RISK RATING	ACTION REQUIRED
LOW RISK	No additional controls are required, Consideration may be given to a more cost-effective solution that will not increase the risk and will not impose any additional financial or organisational burden (Reasonably Practicable).
MEDIUM RISK	Efforts should be made to reduce the risks but the costs of prevention should be carefully measured and limited. Increased supervision, training may be required.
HIGH RISK	Stop the activity, evacuate the workplace. Work should not be restarted until the risk has been reduced by additional control measures.



The exploding chest (longer term hazards) is always paired with toxic or caution, it never appears on its own.

Chemical Hazards			Biological Hazards
Harmful (Caution)	Toxic	Harmful to the Environment	Biological Risk Group 2
Irritant (Caution)	Flammable	Gas under pressure	Biological Risk Group 3
Sensitiser (Caution)	Oxidiser		Biological Risk Group 4
Corrosive	Explosive		

Physical Hazards		Human Factor & Organisational Hazards
Fire & smoke	Pressurised vessels	Control of Contractors
Electricity	Compressed air	Working Time
Working at heights	Noise	Shift Work
Confined Spaces	Vibration	Lone Working
Falling objects	Dust	Stress
Moving parts of work equipment	Heat	Workstation design
Ejection of material	Cold	Workspace
Disintegrating parts	Humidity	Youth Factor
Slips, trips and falls	Lighting	Inexperience
Access and egress	Display Screen Equipment	Pregnant Staff
Poor housekeeping	Radiation (e.g. UV, microwave, radon, ionising)	Violence
Manual handling	Vehicles	

Appendix 4.1f – Aseptic Technique Powerpoint

Aseptic Technique

Aseptic

/eɪˈsɛptɪk/

adjective

free from contamination caused by harmful bacteria, viruses, or other microorganisms; surgically sterile or sterilized.

(of surgical practice) aiming at the complete exclusion of harmful micro-organisms.

What are you aiming for?

- With the aseptic technique you are trying to eliminate as many microorganisms as possible from the experiment
- In order to do this – all of your equipment has to be sterilised before you start
- The best solution to use as a steriliser is ALCOHOL

To begin

- Swab the area you will be working on with alcohol including the bench and chopping board
- Wash hands in hot soapy water
- From now on, use your equipment (scalpel, forceps) rather than your hands to manipulate the materials

Flaming to sterilize equipment

- Dip the forceps/scalpel in alcohol and run through the Bunsen flame. Let the alcohol burn off
- Make sure to hold it at an angle facing downwards!!!
- Each time you use a

piece of equipment

Flame it!

Appendix 4.2 DNA Lesson Design

Appendix 4.2a - Framework for Planning Practical Work

Title of Experiment: Isolate DNA from a Plant Tissue

<u>Context</u> **Procedural (hands-on)** **Informational (minds-on)**	Isolation of DNA from plant tissue • Using kiwi to isolate DNA Students need an understanding of • The structure of DNA • Chemical and physical properties of molecules and structures within the cell • Why the experiment is designed this way (i.e. the reason for each step in the procedure) After the experiment students are asked to develop a hypotheses and conduct an experiment based on what they learn in class
<u>Preparation for Experiment</u>	Powerpoint on the structure of DNA / isolation of DNA experiment https://www.youtube.com/watch?v=RtTZNTil4Tw https://www.youtube.com/watch?v=RIUzkViSB2A Students can watch youtube video on DNA isolation with kitchen materials Setting up equipment • ethanol has to be put in the freezer at least 24 hours before the experiment • set up water bath to 60°C (if there is no water bath, use a hot plate) • Set up the desks for each group so that students have as much equipment to hand as possible Laminate procedure and leave on desks - *Protocol*
<u>Laboratory skill attainment</u>	Teacher : Set up and run a lab in 1hr 20 mins Student: Making up 50cm^3 of 3% salt, 10% detergent solution - *worksheet*
<u>Risk assessment</u>	Risk assessment carried out by teacher beforehand and sheet filled in and signed – *risk assessment*
<u>List of equipment needed</u>	**Equipment/reagents (per pair):** ½ x Kiwi fruit 1x chopping board 1x knife 1x spatula 1x weigh boat 2x 200 mL glass beakers

	3x 10 mL syringes 1x bucket of ice 1x tape for labelling 1x sharpie for labelling 2x test tubes 1x test tube rack 2x 1.5. mL Eppendorf tubes 1x Eppendorf rack 2x sterile loops 1x 30 mL ice cold ethanol 1x dropper 1x thermometer Sodium chloride (salt) Washing-up liquid (not the concentrated type) Distilled water Protease enzyme e.g. trypsin (1%) **Equipment/reagents (per bench):** 1x water bath or oven set at 60°C 1x 1 L beaker 1x large funnel (to fit the 1L beaker) 1x food blender 4x layers of cheesecloth (to fit funnel) 2x weigh balances
Procedural teaching methodology **Hands-on** **Minds- on** **Minds-on** **Minds-on** **Hands-on**	Teacher: show teachers how to isolate DNA / explain background information students need to know Student: Isolate DNA from kiwi fruit including making up a solution Use the worksheets in conjunction with the procedure as an assessment for learning tool *(making up solution, experiment questions)* Ask students to come up with a question that they would like to investigate based on the discussion with the teacher afterwards Convert the question into a hypotheses Repeat the experiment so that the student can conduct their own investigation using DNA isolation as the method
Data collection	Students should be able to see DNA at the end of the experiment
Data analysis **Minds-on**	Depending on the questions asked by students - Second experiment: Students will record the presence/ absence of DNA

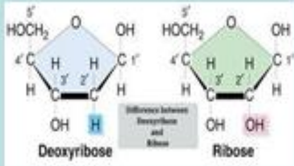
Minds-on	
<u>Data presentation</u> **Minds-on**	Students create a poster or a report under the following headings: Title Hypothesis Procedure Data Collected Data presentation Analysis of data Conclusion
<u>Real World Application</u>	After doing the experiment students should are asked what the next step would be in their experiment – they have isolated DNA, how could they go about identifying the DNA isolated (lead in to gel electrophoresis??)
<u>Evaluation</u>	Teacher evaluates the lesson under the following headings: What worked – what aspects of the lesson did students understand What needs improvement- where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge What will I do differently next time Teacher evaluates the learning by examining the student report or poster (give it a grade???)
LC exam questions relating to DNA isolation	2015 Q7b 2011 Q9 2005 Q8
Tips for Teachers	• Use kiwi as alternative to onions as it has its own protease • Pineapple juice is a source of fresh protease • Do not use bactericidal washing up liquid- it contains an enzymes that causes the breakdown of DNA • DNA should appear as thin threads – if it appears as a fluffy mass, it has been sheared by too much blending (3 seconds is enough to blend) • DNA is insoluble in ice cold ethanol but soluble in ethanol at room temperature – use the ethanol immediately from the freezer • If DNA remains at the interface – place the test tube back into the ice bath for a few minutes • Methylated spirits can be used as an alternative to ethanol which is expensive

Appendix 4.2b – PowerPoint Presentation for DNA Isolation Experiment

What does the acronym "DNA" stand for?

- Deoxy-ribo nucleic acid

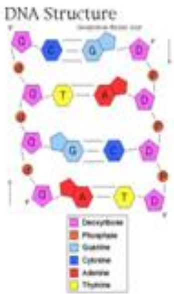
Because the sugar in DNA is a **deoxyribose sugar**



DNA is a double stranded polymer of repeating units called nucleotides.

A single nucleotide consists of a:
- phosphate
- sugar
- base

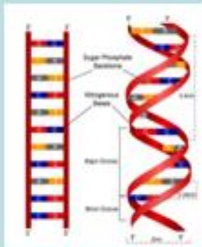
Complementary bases on opposite strands are held together by **hydrogen bonds.**



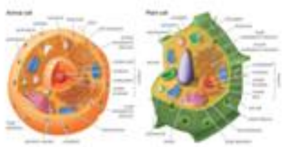
What structure does DNA have?

- A **double-helix**, which is essentially like a twisted ladder.

This structure gives **DNA** physical and chemical properties that make it very **stable**.



Where would you find DNA?



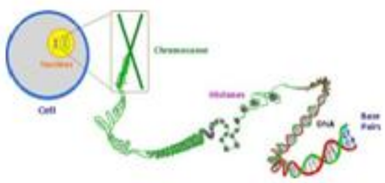
Animal cells: nucleus and mitochondria
Plant cells: nucleus, mitochondria and chloroplasts.

How much DNA do we have in the nucleus of our cells?

- 46 chromosomes: 3 billion nucleotides.
- If it were stretched out, it would reach up to 2 or 3 metres in length.
- If you put all the **DNA** molecules in your body end to end, the **DNA** would reach from the Earth to the Sun and back over 600 times.

How does 3 billion nucleotides fit into something that is only about 6 µm in diameter?

- DNA is very tightly packed inside the nucleus – wound around proteins called histones.
- These proteins also help to stabilise DNA.

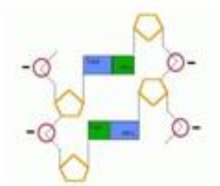


Here's an analogy:

Histone proteins help to pack DNA into a configuration small enough to fit into the nucleus.

What charge does DNA have?

Organic molecules such as DNA are charged. DNA is negatively charged because the phosphates (red circles) that form the sugar-phosphate backbone of a DNA molecule have a negative charge.

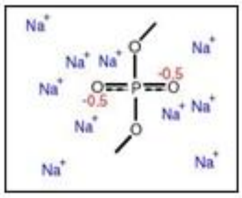


Salt can neutralize the charges on the sugar-phosphate backbone of a DNA molecule.

Positively charged sodium ions neutralize the negative charge on the PO_4 groups on the nucleic acid.

This makes the molecule less hydrophilic, and therefore less soluble in water.

This enables the DNA to be precipitated from solution when alcohol is added.



The salt binds to the DNA – this allows it to clump so that we can eventually see it.

Could you isolate DNA from this person?

Could you isolate DNA from this plastic chair?

Could you isolate DNA from these glasses?

Could you isolate DNA from this tree?

What do these have in common?

Could you isolate DNA from this leg of meat?

Could you isolate DNA from these hamburgers?

Could you isolate DNA from these apples?

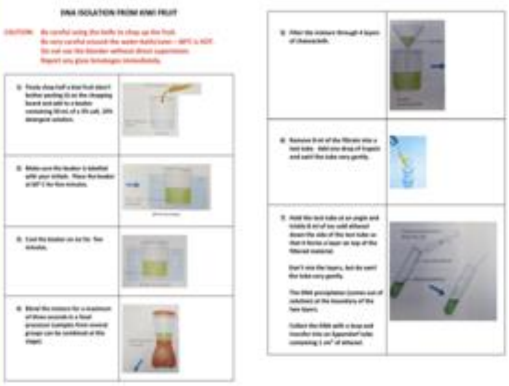
What is our hypothesis?

Practical: Isolate DNA from a plant tissue

DNA can be isolated from cells (animal, plant, fungal, bacteria etc.) even after the cells are in the process of dying or **senescing**.

Because: DNA is a **very stable** bio-molecule.

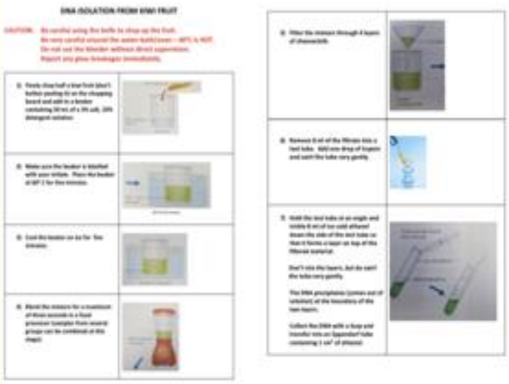
Protocol



Lab Skill

- Make a percentage solution

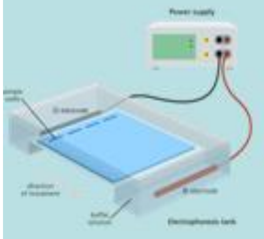
Protocol

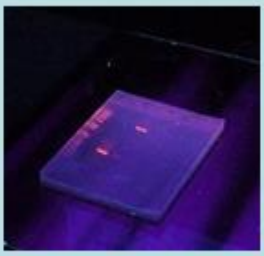


Visualizing DNA

Recap on learning

- How can you visualize DNA?





What do you need to do to get the DNA out of plant cells?

Plant cells

Recap on learning

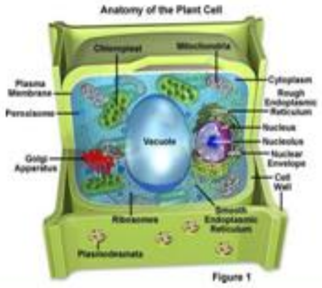


Figure 1

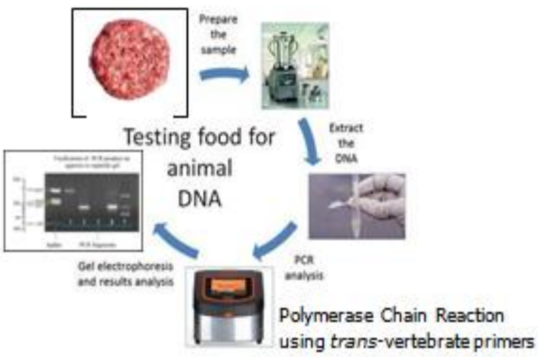
- **Washing up liquid:** disrupts both cell and nuclear membranes and releases the DNA into solution.
- **Salt:** neutralises the negative charges on the DNA. It helps to precipitate "clump" DNA. It also precipitates proteins and carbohydrates
- **Heat:** Enzyme denaturation (e.g. DNAses)
- **Cold:** Stop any residual enzymatic activity
- **Blender:** completes breakage of the plant cell walls
- **Filtering:** removes cell debris
- **Protease (pepsin):** breaks down (denatures) any proteins associated with the DNA (e.g. histones)
- **Ice-cold ethanol:** Precipitates/clumps DNA – brings the DNA out of solution and makes it visible.

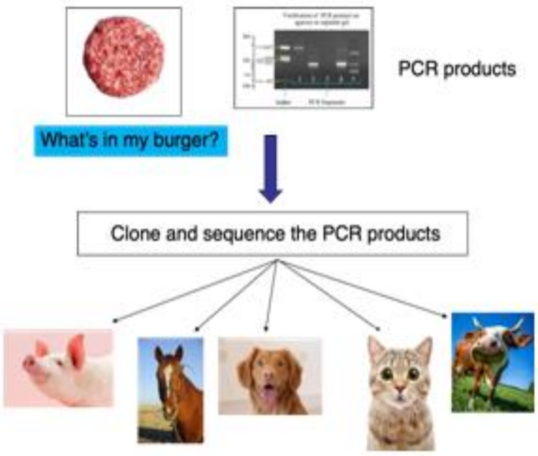

SUBSTITUTION
DILUTION
CONCEALMENT
FOOD FRAUD
COUNTERFEITING
MISLABELLING
UNAPPROVED ENHANCEMENTS
GREY MARKET PRODUCTION/ THEFT/ DIVERSION


This story broke in January 2003
Daily Mail
HORSE MEAT IN TESCO BURGERS
Mirror
HORSE MEAT IS FOUND IN TESCO BURGERS

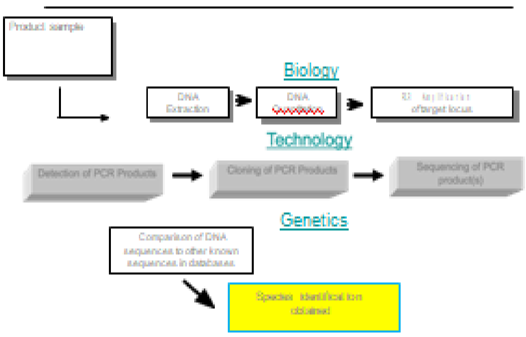

384 HORSEFLESH 384
FOR HUMAN CONSUMPTION
BOLT


Question: What's in my burger?


Prepare the sample
Testing food for animal DNA
Extract the DNA
PCR analysis
Gel electrophoresis and results analysis
Polymerase Chain Reaction using trans-vertebrate primers


PCR products
What's in my burger?
Clone and sequence the PCR products

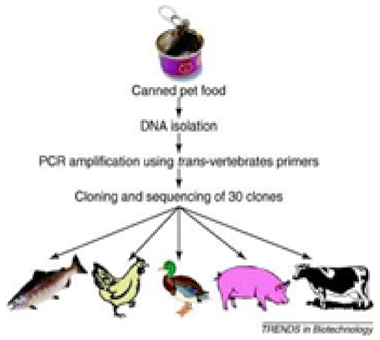
The Investigative Pipeline



Extension exercise:

What would you investigate using this pipeline?

I did this project with a student once



Appendix 4.2c – Calculating % w/v Worksheet

Calculating percentage weight per volume (%w/v)

The percentage weight per volume is used to make up solutions containing a **soluble solid**, e.g. salt
This means the number of grams of a substance you would add to 100ml of solution
It is written as %w/v
A 50%w/v solution of salt contains 50g of salt dissolved in 100ml of water
If you are required to make a 3%w/v solution of salt you will weigh_____ grams of salt and add it to _______ ml of water

Calculating percentage volume per volume (%v/v)
The percentage volume per volume is used to make up solutions where a **liquid** needs to be diluted
This means the number of _______ of a liquid you would add to 100ml of water
It is written as %v/v
A 50%v/v solution of washing up liquid contains _____ml of washing up liquid dissolved in _____ml of water
If you are required to make a 10%v/v solution of detergent you will measure _____ml of washing up liquid and add it to _____ml of water.

In this experiment, you are required to add chopped kiwi to a beaker containing 50ml of a 3%w/v salt, 10%v/v detergent solution:
Discuss with your partner what quantities of salt, washing up liquid and water you will use. Write the quantities you will measure in the table below:

Substance	Quantity
Salt (g)	
Washing up liquid (ml)	
Water (ml)	

Appendix 4.2d - Worksheet for use with DNA isolation experiment – Cloze Test

Step 1: Chopping the Fruit
Physical chopping breaks the _____________________ and allows the _____________ to leak out

Step 2: Adding detergent
Breaks down the lipids in the __________________ bilayer of the plasma membrane and causes the _____________ in the membranes to break apart. This releases ________ from the cell

Step 3: Adding salt
The proteins in the membranes which have been exposed by the detergent are now ________________ charged. These attract the ________________ charged phosphate groups in the DNA (which can cause a problem extracting the DNA). The salt is added to minimise the attractive forces between the __________ and the _____________ by shielding DNA molecules causing them to clump together

Step 4: 60°C for 5 mins
Causes ___________ to be broken down. After 5 minutes the DNA itself will be broken down

Step 5: Ice for 5 mins
Decreases the rate of chemical ______________, slowing down the actions of any remaining ______________ before they destroy the DNA

Step 6: Blend in 3 second bursts
Further destroys cell _____________ and plasma __________. Causes DNA to be released. Blending for more than 3 seconds ____________the fragile DNA strands

Step 7: Filter through cheesecloth
Allows the DNA to be collected in the _______________

Step 8: Pipette into test tube and add a drop of protease
Breaks down the ______________associated with DNA

Step 9: Add ice-cold ethanol
Ethanol forms a layer on top of the filtrate. Alcohol draws water out of the ______ making it less dense. The DNA moves to the _______________ of the 2 liquids. DNA is ______________ in ice cold ethanol but _____________ in ethanol at room temperature.

Choose you answers from these words:

Phospholipid Positively Protein Enzymes Shears DNA Soluble
Cytoplasm DNA Insoluble Reactions Membranes Proteins DNA
Cell walls Protein Negatively DNases Walls Filtrate
Interface

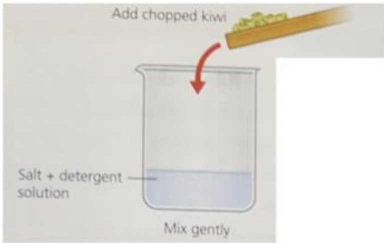
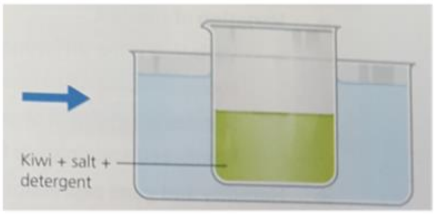
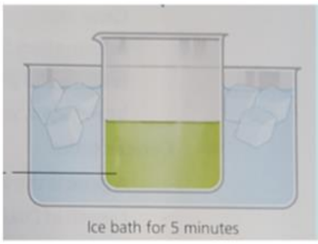
Answers in the correct order:

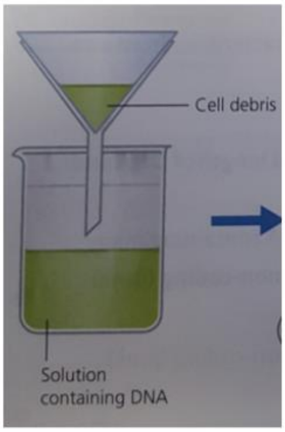
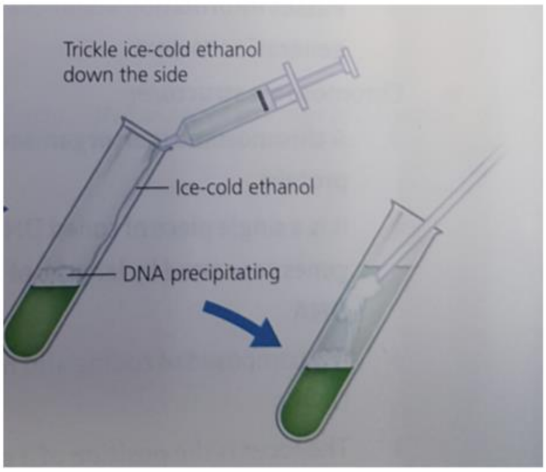
Cell walls
Cytoplasm
Phospholipid
Protein
DNA
Positively
Negatively
DNA
Protein
DNases
Reactions
Enzymes
Walls
Membranes
Shears
Filtrate
Proteins
DNA
Interface
Insoluble
Soluble

Appendix 4.2e – Visual on Desk During DNA Experiment

DNA ISOLATION FROM KIWI FRUIT

CAUTION: Be careful using the knife to chop up the fruit.
Be very careful around the water-bath/oven – 60°C is HOT.
Do not use the blender without direct supervision.
Report any glass breakages immediately.

1) Finely chop half a kiwi fruit (don't bother peeling it) on the chopping board and add to a beaker containing 50 mL of a 3% salt, 10% detergent solution.	
2) Make sure the beaker is labelled with your initials. Place the beaker at 60° C for five minutes.	 60°C for five minutes
3) Cool the beaker on ice for five minutes.	
4) Blend the mixture for a maximum of three seconds in a food processor (samples from several groups can be combined at this stage).	

5) **Filter the mixture through 4 layers of cheesecloth.**	
6) **Remove 8 ml of the filtrate into a test tube. Add one drop of trypsin and swirl the tube very gently.**	
7) **Hold the test tube at an angle and trickle 8 ml of ice-cold ethanol down the side of the test tube so that it forms a layer on top of the filtered material.** **Don't mix the layers, but do swirl the tube very gently.** **The DNA precipitates (comes out of solution) at the boundary of the two layers.** **Collect the DNA with a loop and transfer into an Eppendorf tube containing 1 cm^3 of ethanol.**	

Appendix 4.3 – Data Collated from PST Pre- and Post-Module Surveys

Question 1: What is your understanding of enquiry based practical work?
1. PW that focuses on why we are doing an experiment rather than how we do an experiment
2. PW based on students asking questions and their understanding of answer
3. To get the student to think about what they're doing and why
4. To get the students thinking for themselves and not being given a 'recipe'
5. Using higher levels of thinking to investigate the topic
6. Student must propose a hypothesis and carry out an experiment to collect data
7. Student led. Broad idea given to class, relevant information given, the students work out the rest with help when needed
8. The questioning of an aspect in science and conducting a experiment around a hypothesis
9. This is where the student formulates their own investigation
10. To allow students the opportunity to understand the experiment, the meaning of the experiment and to make them think
11. Asking questions in relation to the practical
12. You pose a question and discuss how to go about finding the answer
13. To get students to ask questions, more involved in their learning
14. To get students physically involved e.g. worksheets, group work. Get them to use their own thinking
15. Not just following a procedure. Being able to formulate your own hypothesis
16. The students asking questions. Student based learning
17. Practical that involves learning and not just following a procedure
18. Is asking outside the box questions to sark student interest in science
19. Is as much minds-on as hands-on. Gets students thinking about what they are doing and why they are doing it.
20. The students are able to form their own hypothesis based off the lab
21. Allows students to gain more of an understanding of what they're investigating and why, rather than to mindlessly follow steps
23. Understanding why we are doing the practical as well as knowing how to do it
24. That it would be a lot of cognitive thinking and discussion more than skill
25. Asking and answering your own questions

Question 2: The scientific method involves many aspects. How many of these aspects would you say were included in your own experience as a secondary student when you were doing practical work?
a. Asking a question – 6/25 = 24%
b. Forming a hypotheses- 4/25 = 16%
c. Conducting an experiment – 21/25 = 84%
d. Learning a laboratory skill – 12/25 = 48%
e. Collecting data – 22/25 = 88%
f. Analysing data – 12/25 = 48%
g. Comparing your data with the class data – 9/25 = 36%
h. Forming your own conclusion – 8/25 = 32%
i. Writing a report/ presenting your results – 22/25 = 88%

Question 3: Think back to the DNA Lab and the Leaf Yeast Lab. How many of aspects of the scientific method were addressed?
a. Asking a question – 21/25 = 84%
b. Forming a hypotheses- 24/25 = 96%
c. Conducting an experiment – 25/25 = 100%
d. Learning a laboratory skill – 25/25 = 100%
e. Collecting data – 23/25 = 92%
f. Analysing data – 14/25 = 56%
g. Comparing your data with the class data – 6/25 = 24%
h. Forming your own conclusion – 21/25 = 84%
i. Writing a report/ presenting your results – 21/25 = 84%

Quesiton 4: In terms of teaching a biology practical class – did the lab you attended last Friday provide you with the experience and knowledge that you need to teach those two experiments in school (Leaf yeast and DNA)
1. Yes, the steps in the practical provided me with the knowledge of how to conduct an experiment
2. Yes these labs taught me how to engage the students more in their own learning
3. Yes in terms of how the experiment should be carried out, but did not feel there was much focus on learning from the teachers perspective
4. Yes as it gave a good outline of the steps to follow
5. yes the practical class prepared me to teach a more enquiry based focused practical
6. Yes- how to get class more involved in experiment other than following a method with no understanding of the reasoning behind the method
7. Yes, gave useful tips on how to make sure the students are both hands on and minds on
8. Yes they did. They provided framework and guidance, from preparing agar plates to worksheets and reading comp.
9. I found the second experiment gave me lots of techniques to incorporate into teaching a practical
10. Yes taught me how to approach forming a hypothesis with a class, more students led
11. yes as we learned to make agar plates
12. Yes it taught me on how you as a teacher need to provide information as to why and how you're doing this experiment instead of rushing straight into the experiment when the students don't understand why they are doing something.
13. Yes, I feel like I understand the experiments better and the real world application made me see why teaching experiments is important
14. Yes, it was great to see the inquiry aspect brought into the lesson with the use of the comprehension and the real life applications
15. Yes I feel more confident for when I have to do the practicals in the suture in relation to carrying out the experiment and asking enquiry based questions
16. Yes I became more confident in the methods of the experiments. Higher order questions were also asked which I could use in my own teaching practice

17. yes it gave me some ideas as to how I can create a lab environment that is more student led. I believe it makes the labs more enjoyable when students get to question why they are doing things in a certain way and answer these questions through their own exploration of the topic at hand
18. Yes, I was a bit worried before about how I was going to have 'enquiry' based practicals. The leaf yeast experiment showed me how to engage the students and they ask their own questions.
19. Yes, having no experience of enquiry based practicals before this it was helpful to hear some questions that would get students genuinely engaged and thinking.
20. Yes, learning to make agar plates was very useful. Risk assessment for both experiments was good so I know what can go wrong and what to look out for. The layout of both experiments gave me a much better understanding of what it means to teach through enquiry based practicals.
21. Yes they informed me as to how an inquiry based lab would look and be like. For myself, I was not too certain as to how to approach an inquiry based lab
22. yes visualising the experiment helps with confidence conducting it
23. Yes it taught me how to prepare agar plates as a teacher.
24. Yes because I learned from both experiments the best way to present this information to students and also to include enquiry based learning throughout.

Question 5: Can you compare the way you conducted the two experiments last Friday to your experience of LC biology experiments (what was similar and what was different)
1. There was a deeper understanding of the experiments last Friday compared to my experience, as it was clear to see why we were conducting these experiments
2. Similar- protocol was given. Different – more student thinking esd involved, more inquiry based.
3. In LC biology we were given a method & followed it but didn't think of any real world applications or have any enquiry ourselves. However on Friday we had both
4. It was different as I felt I had a lot more knowledge of what was happening as I was conducting the experiment myself with no recipe method like leaving cert
5. LC biology was always casual – no questioning, no lab coats, just "doss class"
6. What was different to the experiment was the small ways in which we gained the skills before going on our own to do it ourselves independently
7. Much more relaxed in lab Friday, less rushed. More understanding of what I was meant to be doing
8. In LC we followed method and rarely went into any depth about why we were doing it (about background info). Whereas we did on Friday
9. I understood why I was conducting the experiment on Friday. In school I conducted an experiment because I was told to and gained no knowledge from it
10. Different- during LC, teacher did not ask many questions, we were asked to follow a procedure. Same – wrote a lab report where we had to form our own conclusion
11. Similar, except no questions in school were asked on anything other than what had come up on past papers
12. For most leaving cert experiments we never conducted them. We were just given a sheet of what to do and what results to see so I can't compare
13. I can't remember doing them at Leaving Cert level

14. In LC bio we didn't ask too many questions about why we were doing things, we just done as we were told
15. The similarities was how the experiment + report was conducted, however in school no background or information before the experiment was told + this I found was helpful. Made me feel more engaged + knowledgeable about what I was doing
16. Last Friday was more thought provoking that LC. At LC we were spoon fed answers + didn't need to think
17. Method was given in school and expected results were explained. We never formed hypothesis.
18. In leaving cert we didn't get asked questions, we were just given the method and told to do the experiment.
19. In the LC we just read a recipe format with no intro, no reasons as to why we wanted to (do) these experiments and didn't understand the results we gained
20. Did not do experiments in biology
21. A lot more independent thinking, forming own understanding of the purpose of the experiment and the reasoning behind each step
22. In the leaving cert my teachers just handed us the procedure without the class actually understanding the point of the experiment.
23. They were fairly similar
24. Did not do LC

Question 6: Will the lab you attended last week inform your own teaching when you have to design and present an experiment later in the term (please comment on how your teaching will / will not be informed)
1. The lab not so much. This lecture and material given yes.
2. Yes as it shows a good guide to follow
3. It informed me on how to conduct a lab in an efficient manner – preparation is key. It also informed me that a practical should be conducted to allow students gain a greater understanding of the topic rather than just completing the experiment because it has to be written up
4. Yes- aim to have a more enquiry based lesson to allow students to form their own hypothesis instead of spoon feeding the experiment. Guide students to come to the correct method themselves.
5. Yes. Will focus more on the information behind the experiment rather than the method of the experiment
6. Yes. It has provided me with some guidance and has helped my understanding on inquiry based teaching.
7. It has informed me a small bit on ow to present / design an experiment. I felt we could have focused more on how to teach the practical as teachers. *idea of what a teacher does
8. Yes I will try to make it more student led + enquiry based, however I do fell time is still a factor with the experiment and how little / much guidance you can give to your students
9. Yes as I think the intro we had at the beginning of each experiment was very interesting with just the appropriate amount of info so I will be more aware when I am teaching to do something similar. The different activities that we had in relation to the experiment was also good, between handouts and powerpoints. In school I only had board work

10. Yes, I will look back at this + hope my experiments will resemble how I was just taught
11. All experiment are different, what works for one may not work for them all. However it was good to see how enquiry based teaching can be introduced
12. I will base a brief powerpoint on background information / recap before getting students to form a question as to why we're actually carrying out the experiment. Risk assessment is also another key aspect of the lesson that I will be sure to focus on and not glaze over.
13. Yes, when presenting later in the term I will know to include everyday examples form hypotheses and make it more enquiry based
14. Yes, although a smaller introduction to the experiment would be made to not lose the focus of the students and allow them to "figure things out for themselves" idea of enquiry (with some guidance)
15. Yes I will make sure students are the ones somehow 'leading' the lab. They hypothesise and test their hypothesis. More enquiry based.
16. Yes it will. I will try give real world examples and ask the students to think how they would come up with their own experiment
17. Yes. I will be sure to put more emphasis on enquiry. From doing it myself on Friday I have learned a lot more and understand more than I did in LC
18. Yes I think it allowed me to grasp the concept more by seeing it myself. Before I was still a little unsure of enquiry based teaching.
19. It is informed in how to approach and conduct an inquiry based lab
20. Yes improved confidence
21. Yes it will as it will help me allow students to think for themselves rather than me giving them the method and them not knowing what is actually happening or the reason behind it
22. Yes, I will teach an experiment with an enquiry based strategy and also relate out experiments to real world applications so that students can see the connection from the lab to life
23. Yes I am now aware of how to include inquiry into a practical lesson
24. Yes I think that it is important to give the students information while also allowing them to form their own questions and actively investigate. I thought that the activity at the end of the leaf yest experiment was very beneficial as it showed how to use one experiment to link into an active learning activity whereby students become actively engaged in their own learning. This is important for the overall learning of students.

Appendix 4.4 -PST FTPAs

Appendix 4.4 a – PST FTPA for Experiment Investigating the Effect of pH on the Rate of Enzyme Activity

Risk assessment	Risk assessment carried out by teacher beforehand and sheets filled in and signed – *Appendix 1*
List of equipment needed	Equipment for each group: 1. a source of catalase 2. 50ml hydrogen peroxide (<20%) 3. 50mL of each of the 4 buffer solutions (pH 4, 7, 10, 13) 4. pH paper 5. 5-10mL washing up liquid 6. 1 500mL beaker to hold catalase solution 7. 4 200mL beakers to hold buffer solutions 8. 4 100cm^3 (or 200cm^3) graduated cylinders 9. 1 10mL graduated cylinder 10. 1 syringe 11. 4 test tubes 12. 1 test tube rack 13. 4 droppers 14. 1 Thermometer 15. Gloves 16. Labels / masking tape 17. Sharpie marker 18. 1 Timer Equipment for teachers: 1. 3 1L beakers for blended catalase solution 2. 1 Blender
Procedural teaching methodology	Teacher: • Ensuring all students understand the task at hand by clarifying misconceptions and guiding investigations where necessary • Gathering data from class group and developing a discussion based around the class' findings. Student:
Minds-on	Students come up with their own hypothesis for the experiment based on their background knowledge of enzymes.
Minds-on	Fill out method worksheet (*Appendix 2*) and conduct experiment so that the students can carry out their own investigation of how pH effects enzyme activity based on their hypothesis.
Hands-on	Practice their lab skill and conduct an experiment to investigate their hypothesis.

Hands-on/ Minds-on	Compare data with other groups and discuss results to formulate a conclusion based on the hypothesis tested.
Extension work	Extra work/ activity sheets will be given to groups that are ahead of others to ensure that they remain engaged with the experiment.
Data collection	Students should be able to measure the volume of foam produced in the graduated cylinders at the different pH level. Students fill out table of results given and predict graph shape based on their findings.
Data analysis	
Hands-on/Minds-on	Students graph their results and evaluate how enzyme activity is affected by pH.
Minds-on	Using their graph, students can conclude that the cylinder with the most foam produced, had the greatest enzyme activity and was therefore at the enzyme's optimum pH. They can discuss the trend in the graph and justify it with an appropriate explanation.
Minds-on	Students compare the rate of catalase activity in animals (liver) versus plants (radishes) and in pairs, come up with a reason why there is a significant difference between the two.
Data presentation **Minds-on**	Students write a report under the following headings: Title Hypothesis Procedure Data Collected Data presentation Analysis of data Conclusion
Real World Application/ Extension **Minds-on**	Students are presented with a real-world application of how pH affects the rate of enzyme activity Students are asked to consider the difference in pH between the mouth and the stomach and identify the principle digestive enzymes present in both. Students are encouraged to think about how the enzyme amylase (in saliva) is affected once it reaches the stomach. Would it still function normally? Why/ why not?

Minds-on	Also, students are asked to consider what other factors might affect the catalytic activity of an enzyme? For example, what would happen to the enzymes in our body if our body temperature increased or decreased dramatically? When might this happen? How might this look graphically?
Evaluation **Minds-on**	Teacher evaluates the lesson under the following headings: What worked – what aspects of the lesson did students understand What needs improvement- where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge What should be done differently next time Teacher assesses the learning by examining the student evaluation of experiment.
LC exam questions relating to experiment	2017 Section B Q8 (HL) 2017 Section A Q5 (OL) 2016 Section B Q8 (OL)

Appendices

1. RISK ASSESSMENT SHEET

CLASS NAME: BI317 INQUIRY BASED BIOLOGY TEACHING AND LEARNING
ACTIVITY: Lab Practical – To investigate the effect of pH on the rate of catalase activity.
NAME OF TEACHER(S): Lucy Bellotti, Caoimhe Page, Micheál Hughes, Katie Buchanan and Eimear Kelly

ASSESSMENT DATE: 15/11/2019 **NUMBER OF PAGES:** 3

HAZARD	PERSONS AT RISK:	*EXISTING CONTROLS*	*RISK CLASS	RECOMMENDED CONTROLS
Sharps Knives Blender blades Possible broken glassware	Students Demonstrators Technicians Academics Cleaners	• Supervision • Pre-lab talks • Lab coats & safety glasses • First aid kit • Glass disposal bin	Low	None
Biological Hydrogen Peroxide *(corrosive)* Buffer Solutions	Students Demonstrators Technicians Academics Cleaners	• Supervision • Pre-lab talks • Training • Lab coats & safety glasses • Protective gloves • Eye wash	Medium	None
Electricity Food processor	Students Demonstrators Technicians Academics	• Supervision • Pre-lab talks • Training • Mains shut off switch on the bench	Low	None
Human factor Inexperience	Students	• Supervision • Pre-lab talks	Low	None
Trip Hazard Bags, coats and other belongings on the floor	Students Demonstrators Technicians Academics Cleaners	• Pre-lab talks • Coat hooks • Bag shelves/ storage area	Low	None

RISK RATING	BROAD CATEGORIES OF COMBINATIONS OF SEVERITY AND LIKELIHOOD. Considering existing controls
LOW RISK	1. Injury or material loss unlikely though conceivable. 2. Exposure unlikely to cause health problems but if it did would be such as to be easily treated with no lasting effects e.g. minor first aid injuries
MEDIUM RISK	1. Unlikely possibility of fatality, serious injury or significant material loss. 2. Possibility of minor injury (first-aid) to a small number of people or 3-day illness/injury to one person. 3. Exposure may have acute (immediate) effects which may have lasting effect
HIGH RISK	1. Possibility of fatality, serious injury or significant loss. 2. Possibility of minor injury to a larger number of people. 3. Exposure may have chronic (long-term) effects or could result in death. 4. Direct breach of legislation, Approved Code of Practice or HSA/HSE(Irl)/HSE(UK) guidelines.

RISK RATING	ACTION REQUIRED
LOW RISK	No additional controls are required, Consideration may be given to a more cost-effective solution that will not increase the risk and will not impose any additional financial or organizational burden (Reasonably Practicable).
MEDIUM RISK	Efforts should be made to reduce the risks, but the costs of prevention should be carefully measured and limited. Increased supervision, training may be required.
HIGH RISK	Stop the activity, evacuate the workplace. Work should not be restarted until the risk has been reduced by additional control measures.

2. METHOD WORKSHEET

1. Add 20cm^3 of pH 4 ___________ to a 100cm^3 graduated cylinder.
2. Using a dropper, add 1 drop of___________.
3. Add the blended___________ solution to the cylinder.
4. Add 2cm^3 of ___________ to a 10cm^3 graduated cylinder.
5. Ensure everything is kept at___________.
6. Pour the hydrogen peroxide into the 100cm^3___________.
7. Record the ___________immediately.
8. Wait for 2 minutes and record the___________.
9. Find the amount of___________ produced.
10. Repeat the ___________ for pH 7,10 and 13.
11. Tabulate your results to show how pH effects the ___________ of enzyme activity.
12. Conclude what the ___________ pH for catalase is.

catalase	washing-up liquid	results	hydrogen peroxide
body temperature	foam		graduated cylinder
initial volume	pepsin	procedure	optimum
room temperature	flask	rate	sulfuric acid
buffer	minimum		final volume

Appendix 4.4b- PST FTPA for Experiment Investigating the Production of Alcohol From Yeast

Group 2 -

Framework for Planning Practical Work
Title of Experiment: To Prepare and Show the Production of Alcohol by Yeast

Context **Procedural (hands-on)**	Preparing and showing the production of alcohol by yeast • Using yeast in anaerobic conditions to produce alcohol by respiration
Informational (minds-on)	Students need to have an understanding of: • The chemical process of Respiration • The difference between aerobic and anaerobic respiration • The reasoning behind each step in the procedure
Preparation for Experiment	Students: Revise the chapter on respiration in textbook Teachers: PowerPoint presentation on the preparation of alcohol by yeast Setting up equipment • Fermentation of alcohol at least 48 hours prior to practical. • Preparation of a serial dilution to show the iodoform test with known concentrations • Set up of workstations for the pairs. Including as much equipment as possible Printing of worksheet for lab, including procedure on one side and results questions on the other - left on desk for each pair
Laboratory skill attainment	Teacher: set up and run a lab in 1hr 20minutes Student : 1) Using an electronic balance to measure mass of a solid. 2) How to flute filter paper correctly.
Risk assessment	Risk assessment carried out by group beforehand and signed sheets.
List of equipment needed	**Equipment/reagents (per pair of students):** • Worksheet with protocol • 3x 500cm3 concial flasks • 2x fermentation locks • 1x 2g of yeast solution • 2x 100cm3 of boiled sucrose solution • 6x labels • 2x 100cm3 beakers • 4x 5cm3 syringes • 2x test tubes • 1x test tube rack • 2x filter papers • 1x filter funnel • 1x alcohol strip Equipment/ reagents per class • 3x weigh balances (or as many are available) • Free yeast solution that was fermented (to be divided equally among class)
Procedural teaching methodology	Teacher: show students how to use lab scales correctly & how to flute filter paper correctly. Students: Learn how to use lab scales & correctly flute filter paper.
Hands-on **Hands-on**	• Set up the Fermentation of Yeast, preparing their yeast solution and their control & attaching fermentation locks to the conical flasks.
Minds- on	• Everyday examples of anaerobic respiration
Minds-on	• Ask students what's the next step? – How can we test for alcohol?
Hands-on	• Setting up for Iodoform test, preparing the potassium iodide and bleach solution. • Setting up alcohol strip test, placing dipstick in yeast and sucrose filtrate.
Minds-on	• Iodoform Test – Did this test work? Does it prove that alcohol was produced?
Minds-on	• Alcohol strip test – Does this now confirm the production of alcohol by yeast, despite the low percentage of alcohol?
Hands-on / Extension work	• Filling in the second page of worksheet, answering questions and filling in tables
Data collection	Students should be able to see the presence/absence of alcohol using the iodoform test & alcohol strip test.
Data presentation and analysis **Minds-on**	Students will record the presence/absence of alcohol Students are asked if their observed results match their predicted. Students are asked the limiting factor of the iodoform test.

Minds-on	Students asked about intensity of the colour changes.
Data presentation **Minds-on**	Students fill in table of results for Iodoform Test & Alcohol strip test under the following headings: Iodoform test headings: Flask Original colour of filtrate Final colour of filtrate Colour changes Alcohol strip test headings: Flask Original colour of dipstick Final colour of dipstick Presence of alcohol (Y/N) Students write a report under the following headings: Title Hypothesis Procedure Skill practiced Data collected and interpreted Conclusion Appreciation of possible errors (where can things go wrong) Real world application
Real World Application/ Extension **Minds-on**	While the sucrose solution is filtering, Students are presented with a real-world application that involves anaerobic respiration. Example; pickling of food, muscle cramps, beer brewing and bread making. • PET scans and their ability to identify and diagnose conditions such as cancer. • How it works
Evaluation **Minds-on**	The teacher evaluates the lesson using the KWL approach: Ask the students to write down; • What they already Knew • What they Want to know • What they have Learnt The teacher evaluates the learning by examining the student answers.

LC exam questions relating to Production of Alcohol by Yeast	2019 Q8 OL 2017 Q8

Tips for Teachers

- Boil and cool sucrose solution for test, anaerobic conditions.
- Fill fermentation locks before putting them onto flasks
- The level of the water bath should be high enough for the volume in test tube
- Filtering takes a very long time, immobilizing yeast combats the wait time
- Iodoform test is not that sensitive to less than 10% alcohol concentration, use alcohol saliva strips for low percentage of alcohol
- Use pure ethanol as a positive control for tests

Method for Production of Alcohol by Yeast

Preparing Yeast and Sucrose solution

- Add $100cm^3$ of boiled and cooled 10% w/v sucrose solution to two conical flasks.
- Accurately weigh out 2g of yeast and add to one of the conical flasks. Swirl the contents gently to mix. Label this conical flask 'sucrose and yeast'.
- Label the other test tube only containing sucrose solution as 'control'
- Half fill two fermentation locks with water and attach to each of the conical flasks.
- Place both conical flasks in an incubator at 25°C.

Iodoform test for alcohol

- Filter the pre-prepared sample of yeast and glucose using gravity filtration and fluted filter paper.
- To perform the iodoform test add $3cm^3$ of yeast and sucrose filtrate to a test tube and $3cm^3$ of control to another test tube.
- Add 3 cm3 of the potassium iodide solution and 5 cm3 of the bleach to each test tube.
- Warm both test tubes for 4-5 minutes in a water bath and 60°C.
- Allow to cool and observe any colour change.

Test for alcohol using alcohol strips

- To test for alcohol using test strips place the dipstick into the yeast and sucrose filtrate and wait two minutes.
- After two minutes record any changes you observe.

RISK ASSESSMENT SHEET

CLASS NAME: BI317 INQUIRY BASED BIOLOGY TEACHING AND LEARNING
ACTIVITY: Production of alcohol by yeast
NAME OF TEACHER(S): [redacted]

ASSESSMENT DATE: 15 November 2019 **NUMBER OF PAGES:** 3

HAZARD	PERSONS AT RISK:	EXISTING CONTROLS	*RISK CLASS	RECOMMENDED CONTROLS
Flammable Ethanol Glucose	Students Demonstrators Technician Academics Cleaners	• Supervision • Syringes • Pre lab talk • Fire extinguishers • Spill kit • Flammable storage cabinet • Lab coats, gloves and glasses	medium	
Heat 60°C water bath and 25°C incubator	Students Demonstrators Technician Academics Cleaners	• Surpervision • Pre-lab talk • Training • Heat resistant gloves • Lab coats and glasses	Low	None
Sharps Possible broken glassware	Students Demonstrators Technician Academics Cleaners	• Supervision • Pre-lab talk • First aid kit • Glass disposal bin • Lab coat, gloves and safety glasses	Low	none

Assessor's Name:

HAZARD	PERSONS AT RISK:	EXISTING CONTROLS	*RISK CLASS	RECOMMENDED CONTROLS
Fire				
Electricity Water bath and incubator	Students Demonstrators Technician Academics	• Supervision • Pre-lab talk • Mains shut off switch on bench	Low	None
Irritant Bleach Potassium Iodide	Students Demonstrators Technicians Academics Cleaners	• Supervision • Pre-lab talk • Lab coats, safety glasses and gloves • Hand and eye wash station	Low	None
Biological Yeast	Students Demonstrators Technician Academics Cleaners	• Supervision • Pre-lab talk • Lab coats, gloves and safety glasses	Low	None

…ssor's Name:

RISK RATING	BROAD CATEGORIES OF COMBINATIONS OF SEVERITY AND LIKELIHOOD. Considering existing controls
LOW RISK	1. Injury or material loss unlikely though conceivable. 2. Exposure unlikely to cause health problems but if it did would be such as to be easily treated with no lasting effects e.g. minor first aid injuries
MEDIUM RISK	1. Unlikely possibility of fatality, serious injury or significant material loss. 2. Possibility of minor injury (first-aid) to a small number of people or '3 day illness/injury to one person. 3. Exposure may have acute (immediate) effects which may have lasting effect
HIGH RISK	1. Possibility of fatality, serious injury or significant loss. 2. Possibility of minor injury to a larger number of people. 3. Exposure may have chronic (long-term) effects or could result in death. 4. Direct breach of legislation, Approved Code of Practice or HSA/HSE(Irl)/HSE(UK) guidelines.

RISK RATING	ACTION REQUIRED
LOW RISK	No additional controls are required, Consideration may be given to a more cost-effective solution that will not increase the risk and will not impose any additional financial or organisational burden (Reasonably Practicable).
MEDIUM RISK	Efforts should be made to reduce the risks but the costs of prevention should be carefully measured and limited. Increased supervision, training may be required.
HIGH RISK	Stop the activity, evacuate the workplace. Work should not be restarted until the risk has been reduced by additional control measures.

Assessor's Name:

Appendix 4.4c – PST FTPA for Experiment to investigate the growth of seeds using IAA

Group 3

Framework for Planning Practical Work

Title of Experiment: To investigate the effect of IAA growth regulator on plant tissue.

Context **Procedural (hands-on)** **Informational (minds-on)**	Investigate the effect of plant growth regulator, IAA, on the roots of a plant. • Making IAA solution (optional for students) • Carrying out a serial dilution of IAA Students need an understanding of: • Growth regulators such as auxin (IAA) and their functions. • The effect different concentrations of growth regulators have on plant tissue-roots and shoots. • To understand the difference between stimulation and inhibition. Students are asked to form their own hypothesis based on the information learned in class.
Preparation for Experiment	**Teacher** • Make up IAA solution. • Obtaining radish seeds • Having all teaching materials prepared for experiment including the PowerPoint presentation, activity sheets, equipment list, teaching plan and risk assessment. • Having a strong knowledge of the theory related to the experiment to ensure comprehensive answers to students' questions and the ability to clarify any misconceptions that students might have. • Set up the workstations for each group so that students have as much equipment to hand as possible. • Ensuring a laminated copy of the method is available for each station *Appendix 1* **Student** • Review topic in textbook and notes. • Familiarise themselves with the scientific method. • Remind themselves of the safety procedures in the lab. • Review safety precautions related to this experiment and how to handle them.
Laboratory skill attainment	**Teacher** • Making up the correct stock solution of IAA. • Ensuring a clear explanation and demonstration of a serial dilution is carried out.

	Student • Carrying out a serial dilution.
Risk assessment	Risk assessment carried out by teacher beforehand and sheet filled in and signed *Appendix 2*
List of equipment needed	6 packets of Radish Seeds IAA Solution (0.01% w/v) (2 litres) Distilled water 12 syringes (10cm3) 48 graduated droppers 48 small bottles 6 thermometers 6 beakers 48 petri dishes 48 circular acetate grids 96 filter papers 23 pairs of gloves adhesive tape incubator (25 degrees)
Procedural teaching methodology **Hands-on** **Minds- on** **Minds-on** **Minds-on** **Hands-on/Minds-on** **Minds-on**	**Teacher:** Ensure that students understand the experiment they are going to be carrying out by asking questions throughout related to the theory. **Student** Students come up with their own hypothesis for the experiment based on their background knowledge growth regulators. Practice their lab skill and conduct an experiment to investigate their hypothesis. Analyse pre-prepared data and formulate predictions of results. Complete a matching exercise comparing results of previous samples prepared. *Appendix 3.* Discuss pre-prepared results and formulate a prediction of their own expected results. Formulate a conclusion based on pre-prepared results.

	Students will observe their own results in the next lab when the seeds have been incubated overnight. Students will formulate a conclusion in line with their hypothesis based on these results.
Data collection	Analysing pre-pared results. Students fill examine table of results given and predict graph shape based on their findings.
Data presentation and analysis **Minds-on** **Minds-on**	Students graph their results based on the results provided. Students will be able to see from the graph that low concentrations of IAA stimulate root growth while high concentrations inhibit root growth.
Data presentation **Minds-on**	Students write a report under the following headings: Title Hypothesis Procedure Data Collected Data presentation Analysis of data Conclusion
Real World Application/ Extension **Minds-on** **Extension:**	Students will be introduced to the role of auxins in tissue culture and micropropagation. Ensuring that they have a clear understanding of the two techniques and how they relate to the experiment carried out. Students will be asked to think if there is any industry in which the production of plants on such a large scale is necessary. The importance of tissue culture with disease free plants and the mass production of plants by micropropagation in third world countries will be introduced to the students. Hand out relating to real world application *Appendix 4.*
Evaluation **Minds-on**	Teacher evaluates the lesson under the following headings: What worked – what aspects of the lesson did students understand What needs improvement- where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge What will I do differently next time?

	Students will evaluate their learning at the end of the lesson by the 'traffic light system' with the different colours corresponding to their level of understanding.
LC exam questions relating to experiment	HL 2015 Q8 (c) HL 2010 Q9 (b)

Appendix 1

Method, Part 1

1. Label the petri dishes and bottles as follows: 102 ppm, 10 ppm, 1ppm, 10-1 ppm, 10-2 ppm, 10-3 ppm, distilled water (control).
2. Using a syringe add 10cm3 of IAA solution to the bottle labelled 102 ppm.
3. With another syringe add 9cm3 of distilled water to each of the next seven bottles.

Method, Part 2: Serial dilution.

1. Using a dropper, remove 1cm3 of the IAA solution from the first bottle and add it to the second bottle.
2. Using a different dropper, remove 1cm3 of solution from the second bottle and add it to the third bottle.
3. Using a different dropper each time, repeat this serial dilution procedure for the fourth, fifth, sixth and seventh bottles.
4. Discard 1cm3 of solution from the 7th bottle. Each bottle now contains 9cm3 of solution.

Method, Part 3

1. Fit a circular acetate grid and a piece of filter paper inside the lid of each dish.
2. Cover each lid in their respective IAA solution, use the dropper bulb to press gently
3. Place 5 radish seeds along a gridline near the top of the acetate grid on each dish.
4. Add the remaining solution to the appropriate dish.
5. Put the base of each dish in place and secure with a small piece of adhesive tape on either side.
6. Stand the dishes vertically on their edge and place into the trough, to ensure the roots grow down. Leave in the incubator for 2 to 3 days.

RISK ASSESSMENT SHEET

Appendix 2

CLASS NAME: BI317

ACTIVITY: To investigate the effect of IAA growth regulator on plant tissue.

NAME OF TEACHER(S): [redacted]

ASSESSMENT DATE: 22/11/2019 **NUMBER OF PAGES:** 3

HAZARD	PERSONS AT RISK:	EXISTING CONTROLS	*RISK CLASS	RECOMMENDED CONTROLS
Heat Incubator	Students Demonstrators Technicians Academics Cleaners	· Supervision · Pre-lab talk · Training · Heat resistant gloves · Lab coats, & safety glasses	Low Risk	None
Sharps Glassware could break	Students Demonstrators Technicians Academics Cleaners	· Supervision · Pre-lab talk · First aid kit · Glass disposal bin · Lab Coats & safety glasses	Low Risk	None
Flammable Ethanol	Students Demonstrators Technicians Academics Cleaners .	· Supervision · Safety data sheet (SDS) available · Pipette fillers · Pre-lab talk · Fire extinguishers · Training · Spill kit · Flammable storage cabinet · Lab coats & glasses	Medium	None

Assessor's Name:

HAZARD	PERSONS AT RISK:	EXISTING CONTROLS	*RISK CLASS	RECOMMENDED CONTROLS
Trip hazard Bags, coats, books on the floor.	Students Demonstrators Technicians Academics Cleaners	· Coat hooks, bag storage area · Supervision · Pre-lab talk	Low risk	None
Human factor Inexperience	Students	· Supervision · Pre-lab talk	Low Risk	None
Irritant	Students Teachers	• Pre lab talk • Supervision • Gloves • Goggles [redacted]	Low Risk	None

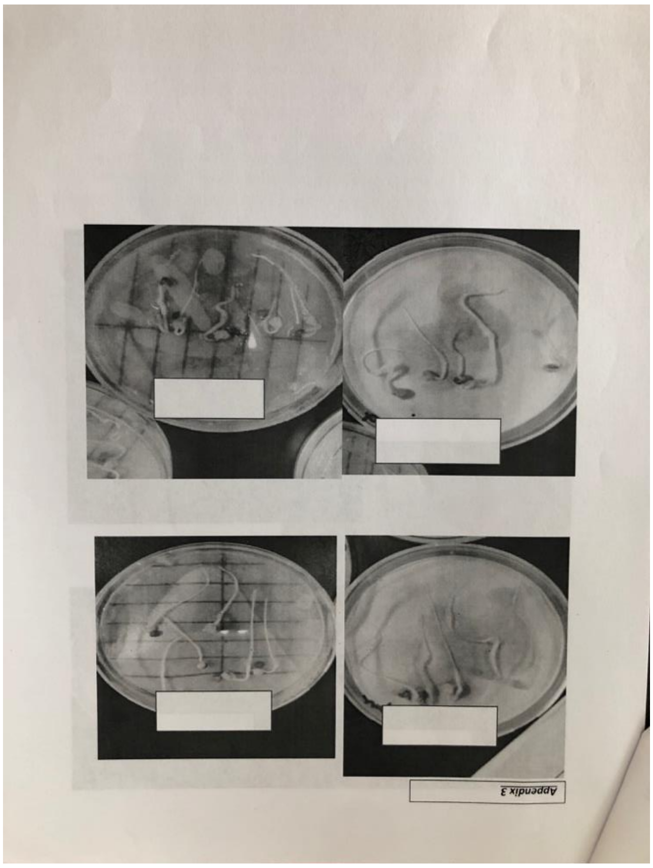
Assessor's Name:

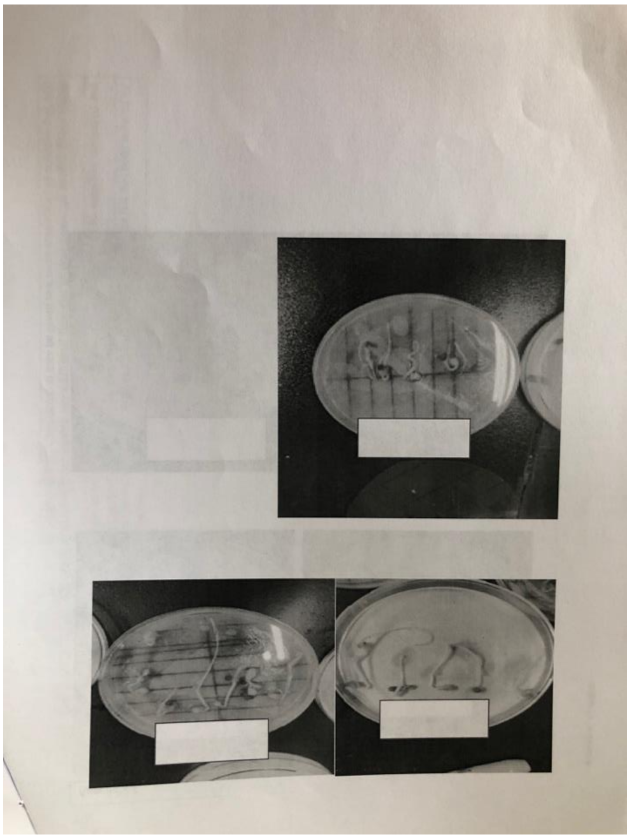
RISK RATING	BROAD CATEGORIES OF COMBINATIONS OF SEVERITY AND LIKELIHOOD. Considering existing controls
LOW RISK	1. Injury or material loss unlikely though conceivable. 2. Exposure unlikely to cause health problems but if it did would be such as to be easily treated with no lasting effects e.g. minor first aid injuries
MEDIUM RISK	1. Unlikely possibility of fatality, serious injury or significant material loss. 2. Possibility of minor injury (first-aid) to a small number of people or '3 day illness/injury to one person. 3. Exposure may have acute (immediate) effects which may have lasting effect
HIGH RISK	1. Possibility of fatality, serious injury or significant loss. 2. Possibility of minor injury to a larger number of people. 3. Exposure may have chronic (long-term) effects or could result in death. 4. Direct breach of legislation, Approved Code of Practice or HSA/HSE(Irl)/HSE(UK) guidelines.

RISK RATING	ACTION REQUIRED

Assessor's Name:

LOW RISK	No additional controls are required, Consideration may be given to a more cost-effective solution that will not increase the risk and will not impose any additional financial or organisational burden (Reasonably Practicable).
MEDIUM RISK	Efforts should be made to reduce the risks but the costs of prevention should be carefully measured and limited. Increased supervision, training may be required.
HIGH RISK	Stop the activity, evacuate the workplace. Work should not be restarted until the risk has been reduced by additional control measures.


Appendix 3



Appendix 4

Tissue Culture.

All cells except sperm and egg cells of a plant contain the full complement of genes, therefore it is often possible to grow individual cells and pieces of tissue into full healthy plants. This process is called tissue culture or micro propagation when whole plants are grown under artificial controlled conditions (*in vitro*) from sections of plant tissue. The plants that result are clones of the original.

Under tissue culture, a single original shoot tip is heat-treated to destroy diseases and then used through as many as ten cycles of regeneration to produce up to 1,500 daughter plants. Tissue culture is used to create large amounts of plants or growing material in a sterile environment with the required water and nutrients to suit the plant species and a gelling agent such as agar. During the process, plant hormones that regulate growth can also be added to increase multiplication or to enable the development of roots. Because the tissues are isolated and raised in contained and sterile environments, tissue culture is a highly effectively method for producing pest- and disease-free planting material.

Although most commonly used for high value horticultural crops, today tissue culture propagation has also been very successful in producing improved subsistence crops widely used in developing countries. One major breakthrough made possible by tissue culture is the development of disease-free bananas in East Africa. Bananas are a major source of consumption, nutrition and income in Africa; Ugandans for example eat on average 1kg per person per day. Other notable examples include higher-yielding varieties of rice and a frog-skin disease resistant cassava variety.

Demand for rice in West Africa is rising rapidly, failing to be met by local production. The region imports around 6 million tonnes of rice each year (half of the region's requirements) at the considerable cost of US$1 billion. In order to address this shortfall, Monty Jones, a Sierra Leone scientist working at the Africa Rice Centre (previously WARDA), began a programme utilising tissue culture technologies to develop crosses between the African species of rice (*Oryza glaberrima*) and the Asian species (*Oryza sativa*). The former is better adapted to local environments, but typically returns low yields of around 1 ton per hectare whereas the latter yields around 5 tons per hectare. Crossing the 2 species created numerous embryos but these could only be grown to maturity with the use of tissue culture. The resulting 'new rices for Africa,' or NERICAs are tolerant to a variety of harsh conditions and produce much higher yields.

Answer the following questions based on your knowledge of tissue culture and the reading comprehension:

1) What is tissue culture?

2) Name a plant hormone that you have used which regulates growth.

3) Why is tissue culture an effective method for producing disease free plants?

4) What was the major breakthrough made in Africa? How did tissue culture help this breakthrough?

Appendix 4.4d – PST FTPA for Experiment Investigating the Effect of Temperature on the Rate of Enzyme Reaction

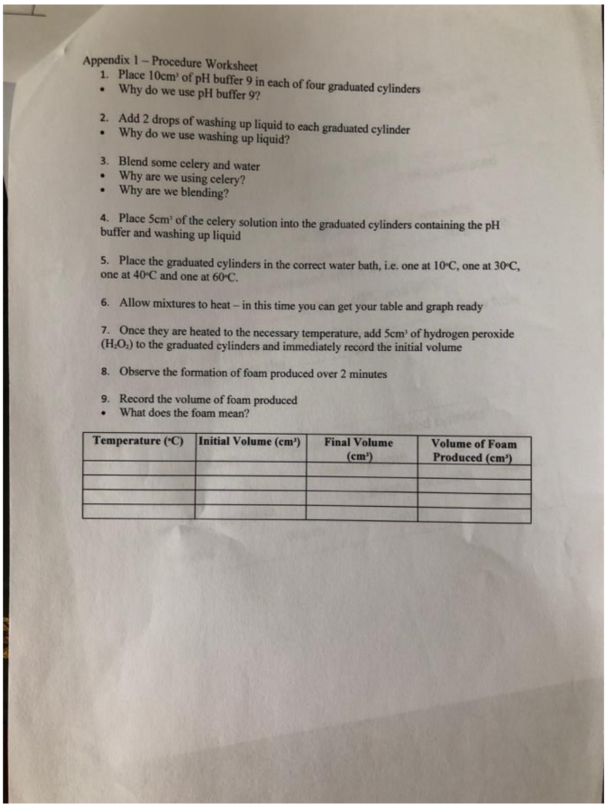
Group 4

Framework for Planning Practical Work

Title of Experiment: To Investigate the Effect of Temperature on Enzyme Activity

Context **Procedural (hands-on)**	To develop students' understanding of the effect of temperature range on the rate of catalase activity through the process of scientific investigation. Using water baths to alter the temperature of an enzyme source before measuring its rate of reaction with hydrogen peroxide
Informational (minds-on)	Students need an understanding of; • Enzymes and the reaction with their substrate • Denaturation • Optimum activity levels Students are asked to develop a hypothesis and conduct an experiment based on what they learn in class
Preparation for Experiment	Teacher: • Obtaining catalase source • Blending and diluting catalase solutions to appropriate concentrations • Gathering and preparing apparatus for experiment • Having all teaching materials prepared for experiment including the PowerPoint presentation, activity sheets, equipment list, teaching plan and risk assessment. • Procedure worksheet for students – *Appendix 1* Student: • Revising chapter content
Laboratory skill attainment	Student: Measuring liquids accurately using a graduated cylinder and syringe. Reading a thermometer correctly.
Risk assessment	Risk assessment carried out by teacher beforehand and sheet filled in and signed.
List of equipment needed	**For preparing catalase sample;** Chopping board; Celery Knife; Food blender **For the experiment;** Graduated cylinders; Boiling tubes Syringes; Dropper Timer; Labels Boiling tube holder; Boiling tube rack Thermometer; Water baths Enzyme source e.g. catalase from celery; Hydrogen peroxide Buffer solution pH 9; Washing up liquid Disposable gloves

Procedural teaching methodology	Teacher: recap students on theory surrounding enzymes
Hands-on	Students: create a hypothesis, fill in procedure worksheets and use the method to investigate the effect of temperature on enzyme activity
Minds- on	Students: collate their data to be analysed on excel Teacher: input data to excel and display a graph of class results
Data collection	Students will observe the volume of foam produced at each temperature and record this as the rate of activity
Data presentation and analysis **Minds-on**	Students will collate their data with the rest of the class to find an average. This average will then be used to create a graph on excel for analysis.
Data presentation **Minds-on**	Students will each create a graph of their own results Teacher will create a graph of the class average on excel
Real World Application/ Extension **Minds-on**	Siamese cats' colouring is temperature dependent. The optimum temperature for tyrosinase in human bodies is body temperature (37oC). A mutation in tyrosinase in Siamese cats causes it to work best at room temperature (25oC). Areas of a Siamese cat's body that are cooler allow the enzymes to function and they become darker in color.
Evaluation **Minds-on**	Teacher evaluates the lesson under the following headings: What worked – what aspects of the lesson did students understand What needs improvement- where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge What will I do differently next time By the end of this lesson students should be able to: • Describe, carry out and write up an experiment to investigate the effect of temperature range on the rate of catalase activity
LC exam questions relating to Production of Alcohol by Yeast	HL 2019 Q 12 (a) (b) 2018 Q 12 (c) 2017 Q 8 (a) (b) OL 2013 Q 5 2012 Q 8 (a) (b) 2011 Q 8 (b)



Appendix 1 – Procedure Worksheet

1. Place $10cm^3$ of pH buffer 9 in each of four graduated cylinders
- Why do we use pH buffer 9?

2. Add 2 drops of washing up liquid to each graduated cylinder
- Why do we use washing up liquid?

3. Blend some celery and water
- Why are we using celery?
- Why are we blending?

4. Place $5cm^3$ of the celery solution into the graduated cylinders containing the pH buffer and washing up liquid

5. Place the graduated cylinders in the correct water bath, i.e. one at 10°C, one at 30°C, one at 40°C and one at 60°C.

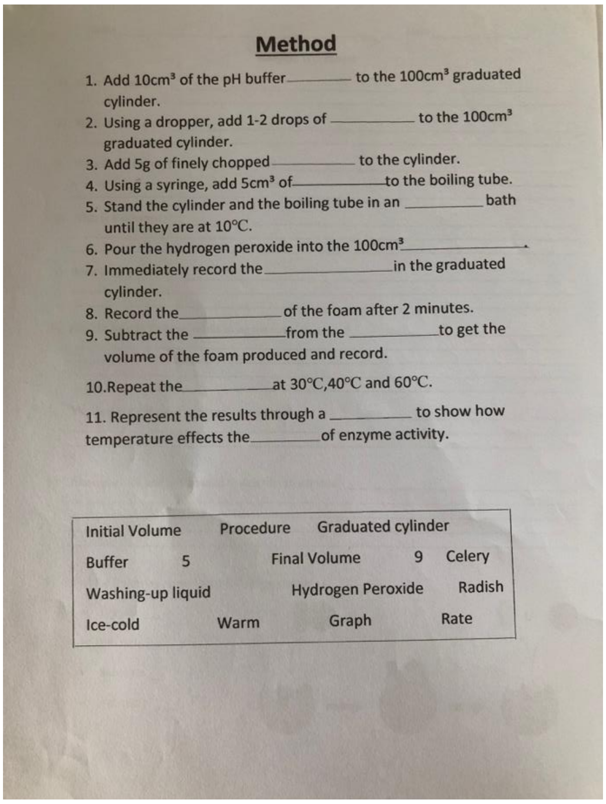
6. Allow mixtures to heat – in this time you can get your table and graph ready

7. Once they are heated to the necessary temperature, add $5cm^3$ of hydrogen peroxide (H_2O_2) to the graduated cylinders and immediately record the initial volume

8. Observe the formation of foam produced over 2 minutes

9. Record the volume of foam produced
- What does the foam mean?

Temperature (°C)	Initial Volume (cm^3)	Final Volume (cm^3)	Volume of Foam Produced (cm^3)



Method

1. Add $10cm^3$ of the pH buffer_______ to the $100cm^3$ graduated cylinder.
2. Using a dropper, add 1-2 drops of _______ to the $100cm^3$ graduated cylinder.
3. Add 5g of finely chopped_______ to the cylinder.
4. Using a syringe, add $5cm^3$ of_______to the boiling tube.
5. Stand the cylinder and the boiling tube in an _______ bath until they are at 10°C.
6. Pour the hydrogen peroxide into the $100cm^3$_______.
7. Immediately record the_______in the graduated cylinder.
8. Record the_______of the foam after 2 minutes.
9. Subtract the _______from the _______to get the volume of the foam produced and record.

10.Repeat the_______at 30°C,40°C and 60°C.

11. Represent the results through a _______ to show how temperature effects the_______of enzyme activity.

Initial Volume	Procedure	Graduated cylinder		
Buffer	5	Final Volume	9	Celery
Washing-up liquid		Hydrogen Peroxide		Radish
Ice-cold	Warm	Graph		Rate

Name ______________________________ Date ____________

Enzyme Worksheet

1) What is a **catalyst**? ______________________________

2) What is an **enzyme**? ______________________________

3) What is the **active site** and what is its job? ______________________________

4) What is a **substrate**? ______________________________

5) What is the **product**? ______________________________

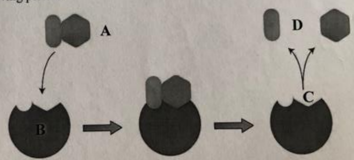
6) Explain how an Enzyme works using the terms from 1 – 5 ______________________________

7) What is denaturing and what can cause it to occur? ______________________________

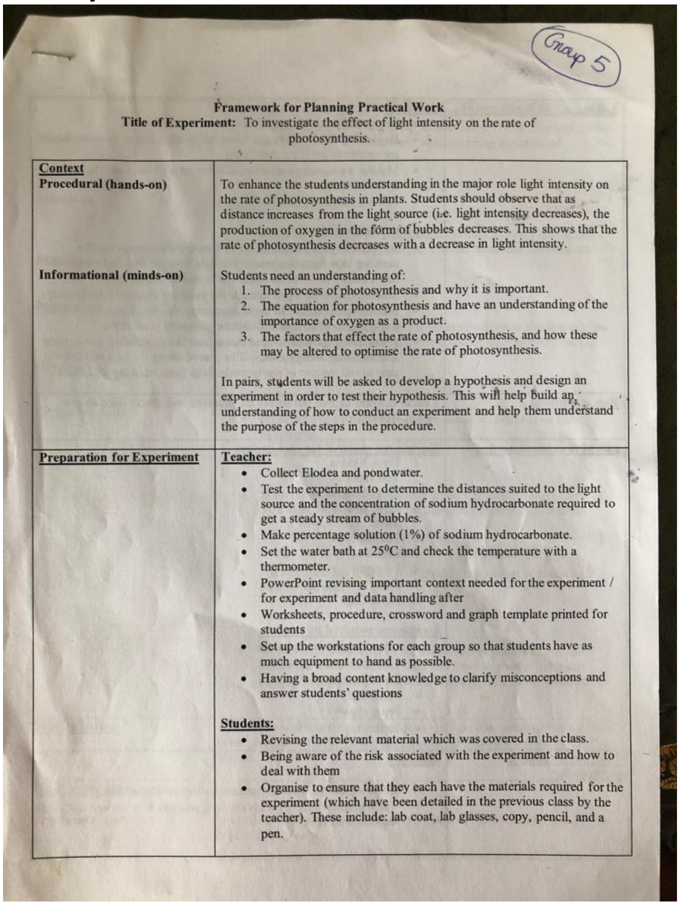
8) How can a lock and key be used to describe an enzyme? ______________________________

9) Label the following terms in the following picture

- Enzyme ___
- Products ___
- Substrate ___
- Active site ___



Appendix 4.4e – PST FTPA for Experiment Investigating the Factors that Affect the Rate of Photosynthesis



Group 5

Framework for Planning Practical Work

Title of Experiment: To investigate the effect of light intensity on the rate of photosynthesis.

Context **Procedural (hands-on)**	To enhance the students understanding in the major role light intensity on the rate of photosynthesis in plants. Students should observe that as distance increases from the light source (i.e. light intensity decreases), the production of oxygen in the form of bubbles decreases. This shows that the rate of photosynthesis decreases with a decrease in light intensity.
Informational (minds-on)	Students need an understanding of: 1. The process of photosynthesis and why it is important. 2. The equation for photosynthesis and have an understanding of the importance of oxygen as a product. 3. The factors that effect the rate of photosynthesis, and how these may be altered to optimise the rate of photosynthesis. In pairs, students will be asked to develop a hypothesis and design an experiment in order to test their hypothesis. This will help build an understanding of how to conduct an experiment and help them understand the purpose of the steps in the procedure.
Preparation for Experiment	**Teacher:** • Collect Elodea and pondwater. • Test the experiment to determine the distances suited to the light source and the concentration of sodium hydrocarbonate required to get a steady stream of bubbles. • Make percentage solution (1%) of sodium hydrocarbonate. • Set the water bath at 25^0C and check the temperature with a thermometer. • PowerPoint revising important context needed for the experiment / for experiment and data handling after • Worksheets, procedure, crossword and graph template printed for students • Set up the workstations for each group so that students have as much equipment to hand as possible. • Having a broad content knowledge to clarify misconceptions and answer students' questions **Students:** • Revising the relevant material which was covered in the class. • Being aware of the risk associated with the experiment and how to deal with them • Organise to ensure that they each have the materials required for the experiment (which have been detailed in the previous class by the teacher). These include: lab coat, lab glasses, copy, pencil, and a pen.

Laboratory skill attainment	**Teacher:** • Set up and run a lab in 1hr 20 mins • Having Elodea firing in test tubes before the class in case students are unable to get their own firing • Making a percentage solution; making up a 10 litres of 1% sodium hydrocarbonate • Making graphs on excel **Student:** Measurement of distance • Accurately use a ruler in order to measure distance along the masking tape from the base of the light source. This distance is to be measured in 10cm sections. Up to and including 50cm. • Students must use a pen to mark the masking tape at 10cm intervals. • Students must ensure to begin measuring the distance at the base of the light source to ensure that the experiment is accurate. • These markings will be used throughout the experiment as the plant species being investigated will be placed along the tape at different time to test the rate of photosynthesis as light intensity decreases.
Risk assessment	Risk assessment carried out before the practical and sheets filled in and signed-Appendix 1
List of equipment needed	**Equipment required for each group:** 1. Fresh Elodea 2. Test tubes x4 3. Large beakers x2 4. Light source 5. Timer 6. Thermometer 7. Scissors 8. Forceps 9. Tray 10. Paper Clips **Equipment required by teacher:** • 1% sodium hydrocarbonate • Test tubes x15 • Large beakers x4 • Pyrex dish • Paper clips x15 • Tape
Procedural teaching methodology	**Teacher:** • Ensuring that all students understanding the task a hand. • The method which the students designed will be discussed and explained in detail.

Minds- on	• Any misconceptions which students may have will be analysed and explained in depth in order to ensure that students fully understand the process of photosynthesis which is being investigated.
Minds- on	**Student:** • Students will fill in a work sheet (*appendix 2*) based on the key background knowledge needed to understand and carry out the experiment.
Minds-on	• Students will come up with a hypothesis to test in the experiment, in which they will investigate the effect of light intensity on the rate of photosynthesis.
Minds-on	• Students will develop a procedure to use in order to test their hypothesis • Students will then fill in the blanks on a procedure sheet (*appendix 3*), if they are having problems designing their own procedure
Hands-on	• Practice their lab skill and conduct an experiment to investigate their hypothesis.
Extension work	• Word search (*appendix 4*) for those students that are finished before the rest of the class, they will have to answer questions relating to the practical to get the word to put into the word search.
Data collection	The student will count the number of oxygen bubbles produced in a minute at each of the distances for the light source and record the result in a table of data.
Data presentation and analysis **Minds-on / Hands-on**	Students use thier own results to plot a graph of light intensity against rate of photosynthesis

Minds-on	Class data is collected and averaged, this data is then plotted by the teacher using excel (demonstrating how it is done as they make the graph). Then comparisons are made between the students' own graphs and the graph of class averages; including which is more reliable and why. They then use the data on the graphs to form a conclusion and determine whether their hypothesis is accepted or rejected.
Data presentation **Minds-on**	Students write a report under the following headings: Title Hypothesis Procedure Data collected Data presentation Analysis of data Conclusion Real world example
Real World Application/ Extension **Minds-on**	After doing the experiment, students are presented with a real-world application that requires monitoring light intensity as a factor in photosynthesis. Student's will be informed how mass production of plants is achieved in areas such as 'Tromsø' in Norway, an area that has very little day light during the winter. A solution to this issue is to construct greenhouses with artificial lighting to replicate the light intensity from the sun. Example: Tomato Yield in Norway.
Evaluation **Minds-on**	Teacher evaluates the lesson under the following headings: What worked – what aspects of the lesson did students understand What needs improvement- where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge What will I do differently next time. Teacher evaluates the learning by examining the student reports Throughout the lessons their learning can be assessed by their answers on the worksheets, answers to questions asked by the teacher and ability to partake in discussion within the lesson. Right hand, left hand, both hands and no hands questions at the end of the lesson will give the teacher a quick over all view of the understanding of the students.
LC exam questions relating to Leaf Yeast	2018, Q8 part (b) (HL) 2014, Q9 part (b) (HL) 2019, Q7 part (b) (OL)

Keywords Worksheet: Photosynthesis

Name :________________ Date:________________.

Using the Keywords below, fill in the blanks.

- Plants are ____________, they can make their own food.
- ____________ absorb ____________ from the soil.
- Water travels up the ____________ via ____________ tissue.
- The ____________ ____________ from the atmosphere enters through the ____________ of the leaf.
- ____________ (a green pigment) in the ____________ cells absorb light energy.
- ____________ energy is used to react carbon dioxide and ____________ to form ____________ and ____________. This process is known as ____________.
- Glucose is a sugar produced than can be used to provide ____________.

Photosynthesis	Chlorophyll	Heterotrophs	Xylem	Energy	Water	
Glucose	Light	Leaf	Autotrophs	Waste	Stomata	Roots
Water	Catalase	Stem	Oxygen	Carbon Dioxide	Hydrogen Peroxide	

Complete and balance the equations below

____________ + ____________ $\rightarrow Oxygen +$ ____________.

Light

$$6CO_2 + \_\_H_2O \rightarrow 6O_2 + C\ \ H_{12}O$$

To Investigate the influence of light intensity on the rate of photosynthesis

Method

Experiment preparation: Cut 40cm of masking tape and stick it to the desk. On the tape, using a ruler, place a mark every 5cm. At the zero-mark set up the light source. This will be used as a guide during the experiment.

1. Using a fresh Elodea plant, remove several leaves from around the stem.
2. Cut the bottom of stem at an angle then lightly crush it.
3. Add 1% w/v of Sodium Hydrogen Carbonate to a test tube.
4. Attach a paperclip to the top part of the Elodea.
5. Place the plant into the test tube, keeping the cut end pointing upwards and the end with the paper clip pointing downwards.
6. Place this test tube into a beaker of water with a thermometer, which was kept at a temperature of approximately 25°C in a water bath.
7. Place the beaker 5cm away from the Light Source. (Use the tape as a guide)
8. Switch on the lamp and allow the Elodea to adjust to its environment for a few minutes. When oxygen bubbles begin to form at the cut part of the stem, the experiment can begin.
9. Using a stopwatch to count the number of oxygen bubbles produced in two - minutes at 5cm.
10. Record the number of bubbles produced and repeat step 9 for distances 10cm, 15cm, 20cm, 25cm, 30cm and 35cm.
11. Calculate the light intensity for each distance. Light intensity Is equal to the inverse of the distance squared. $(\frac{1}{d^2})$
12. Draw a graph putting light intensity on the x-axis and the Rate of Reaction/Photosynthesis on the y-axis.

To Investigate the influence of light intensity on the rate of photosynthesis

What is your hypothesis?

Dependent Variable:

Independent Variable:

Controlled Variable:

Using the words below, fill in the blanks in the method

Experiment preparation: Cut 40cm of masking tape and stick it to the desk. On the tape, using a ruler, place a mark every 5cm. At the zero-mark set up the light source. This will be used as a guide during the experiment.

1. Using a fresh ____________ plant, remove several leaves from around the stem.
2. Cut the bottom of stem at an angle then ____________ it.
3. Add 1% w/v of ______________________ to a test tube.
4. Attach a ____________ to the top part of the Elodea.
5. Place the plant into the test tube, keeping the _____ end pointing __________, and the end with the paper clip pointing __________.
6. Place this test tube into a beaker of water with a ___________, which was kept at a temperature of approximately _______ in a water bath.
7. Place the beaker 5cm away from the ___________. (Use the tape as a guide)
8. Switch on the lamp and allow the Elodea to adjust to it's ___________ for a few minutes. When_________ _________ begin to form at the cut part of the stem, the experiment can begin.
9. Using a ___________ to count the number of oxygen bubbles produced in ___ - ___________ at 5cm.
10. Record the number of bubbles produced and repeat step 9 for distances 10cm, 15cm, 20cm, 25cm, 30cm and 35cm.
11. Calculate the ___________ for each distance. Light intensity Is equal to the inverse of the distance squared. $(\frac{1}{d^2})$
12. Draw a graph putting the ___________ on the _____ and ______________ on the ______.

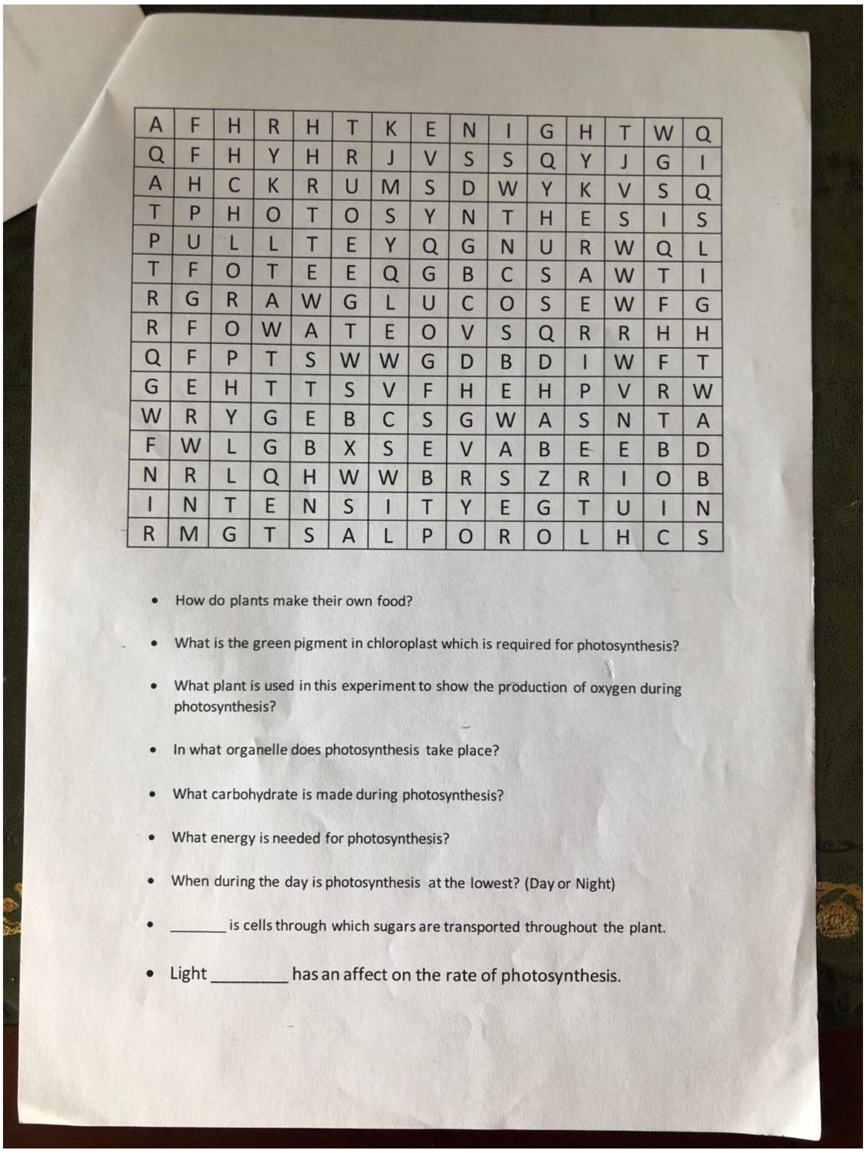
Elodea	X axis	Oxygen Bubbles	Rate of reaction/photosynthesis	25°C	Downwards	
Y axis	Two Minutes	paperclip	Lightly Crush	Upwards	Light Intensity	Cut
Light Source	Stopwatch	Thermometer	Light Intensity	Environment	Sodium Hydrogen Carbonate	

Results:

Distance from light source (cm)	Light Intensity = $^{10000}/_{distance^2}$	Trial 1 (No. of bubbles/ minute)	Trial 2 (No. of bubbles / minute)	Average (No. of bubbles / minute)

Plot a graph of Light Intensity (x axis) against Rate of Photosynthesis i.e. the number of bubbles produced per minute(y axis)

Conclusion:



A	F	H	R	H	T	K	E	N	I	G	H	T	W	Q
Q	F	H	Y	H	R	J	V	S	S	Q	Y	J	G	I
A	H	C	K	R	U	M	S	D	W	Y	K	V	S	Q
T	P	H	O	T	O	S	Y	N	T	H	E	S	I	S
P	U	L	L	T	E	Y	Q	G	N	U	R	W	Q	L
T	F	O	T	E	E	Q	G	B	C	S	A	W	T	I
R	G	R	A	W	G	L	U	C	O	S	E	W	F	G
R	F	O	W	A	T	E	O	V	S	Q	R	R	H	H
Q	F	P	T	S	W	W	G	D	B	D	I	W	F	T
G	E	H	T	T	S	V	F	H	E	H	P	V	R	W
W	R	Y	G	E	B	C	S	G	W	A	S	N	T	A
F	W	L	G	B	X	S	E	V	A	B	E	E	B	D
N	R	L	Q	H	W	W	B	R	S	Z	R	I	O	B
I	N	T	E	N	S	I	T	Y	E	G	T	U	I	N
R	M	G	T	S	A	L	P	O	R	O	L	H	C	S

- How do plants make their own food?
- What is the green pigment in chloroplast which is required for photosynthesis?
- What plant is used in this experiment to show the production of oxygen during photosynthesis?
- In what organelle does photosynthesis take place?
- What carbohydrate is made during photosynthesis?
- What energy is needed for photosynthesis?
- When during the day is photosynthesis at the lowest? (Day or Night)
- _______ is cells through which sugars are transported throughout the plant.
- Light ________ has an affect on the rate of photosynthesis.

Appendix 4.5 Niamh's (IST) Microscopy FTPA and Resources

Framework for Planning Practical Work

Title of Experiment: Prepare and examine one plant and one animal cell - unstained and stained using a light microscope (x100, x400).

Context **Procedural (hands-on)** **Informational (minds-on)**	Prepare and examine a plant and animal cell using the light microscope • Prepare a plant and animal cell • Use the light microscope Students need an understanding of • Structure of plant cell • Structure of an animal cell • Function of the light microscope Students are asked to develop a hypothesis and conduct an experiment based on what they learn in class to demonstrate understanding of the scientific method
Preparation for Experiment	Investigation of leaf stomata (http://www.pdstbiology.com/) Planning Stage Success Criteria Marking Rubric
Laboratory skill attainment	Teacher: Practical enquiry (allowing students design and conduct an experiment) Student: Manipulation of apparatus and interpretation of observation and results.
Risk assessment	Risk assessment carried out by students beforehand and signed by the teacher.
List of equipment needed	**Investigation of Leaf Stomata** Plant (house plant) Microscope Slide Clear nail polish Clear Sellotape **For the experiment** Basic: Microscope Slides Cover slips

	Additional: Vary depending on the student's own investigation
<u>**Procedural teaching methodology**</u> **Hands-on** **Minds- on** **Minds-on** **Minds-on** **Minds-on** **Hands-on**	*Teacher: demonstrated how to use the microscope and explained how to prepare a stomata sample.* Student: Prepare the stomata cell sample and view it under the microscope. Use the worksheet in conjunction with the procedure as an assessment for learning tool Students then design 3 additional questions they might ask about the stomata. *Teacher: Discussed the scientific method in theory and then its application if investigating.* Ask students to come up with a question that they would like to investigate relating to either a plant or animal cell – not restricted to the stomata. (Planning phase) Convert the question into a hypothesis and design a repeatable experiment and conduct a risk assessment. Repeat the experiment so that the student can conduct their own investigation into a plant or animal cell. (Investigating phase)
<u>**Data collection**</u>	This will vary depending on the student's investigation. If quantitative data a graph/table will be required. If qualitative data a diagram will be required.
<u>**Data presentation and analysis**</u> **Minds-on** **Minds-on**	<u>**Investigation of leaf stomata:**</u> Students will examine stomata cask and look at whether the stomata are open or closed and count the amount of each. Depending on the questions asked by students <u>**Student investigation:**</u> Students will draw observations and compare different samples/ Students will count the number of stomata (or another cell organelle) and present findings in a graph. (Analysis Phase)
<u>**Investigation presentation**</u> **Minds-on**	Students create an individual report under the following headings: Question Hypothesis Procedure Data Collected Analysis of data

	Conclusion (Reporting Phase) Students will then design a single exam question to accompany their investigation. (Creating phase)
Assessment	Students will be given a group grade using the marking rubric. Students will self-assess their own groups performance based on the rubric and then the teacher will examine this and give feedback and a grade. (Reflecting phase)
Real World Application	After doing the experiment and conducting their own investigations it is intended that students are provided with an opportunity to work like a biologist and appreciate the value of the scientific method to answering questions in the world around us.
Evaluation	What worked – what aspects of the lesson did students understand What needs improvement- where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge What will I do differently next time?
LC exam questions relating to the microscope	See attached Appendix 6 for copies of these questions HL 2019 Q7 (b) (i) 2018 Q7 (b) (iii) 2016 Q7 (b) (iii) 2014 Q8 2006 Q8 OL 2019 Q6 2016 Q7 2011 Q9

Investigation of Leaf Stomata

Materials:

1. Plant leaves e.g. Ivy
2. Clear fingernail polish,
3. Clear cellophane tape (clear package sealing tape),
4. Microscope
5. Microscope slides
6. Coverslips

Procedure:

1. Obtain a leaf from a plant, generally any plant will work for this procedure.
2. Paint a thick patch of clear nail polish on the leaf surface being studied. Make a patch at least one square centimeter.
3. Allow the nail polish to dry completely.
4. Tape a piece of clear cellophane tape to the dried nail polish patch. (The tape must be clear. Do not use Scotch tape or any other opaque tape. Clear carton-sealing tape works well.)
5. Gently peel the nail polish patch from the leaf by pulling on a corner of the tape and peeling the fingernail polish off the leaf. This is the leaf impression you will examine.
(Only make one leaf impression on each side of the leaf, especially if the leaf is going to be left on a live plant.)
6. Tape your peeled impression to a very clean microscope slide. Use scissors to trim away any excess tape.

Introduction:

Scan the slide until you find a good area where you can see the stomata. Each stoma is bordered by two sausage-shaped cells that are usually smaller than surrounding epidermal cells. These small cells are called guard cells and, unlike other cells in the epidermis, contain chloroplasts.

1. Sketch. Label the Stoma, Guard Cells, Epidermal Cells, and Chloroplasts

2. Estimate the number of stomata on your sample.

You will need to obtain a plant kept in the dark for the next part of the lab.

Experiment:

Guard cells are responsible for opening and closing the stoma. When water concentration is high, the guard cells will bulge, and cause the stoma to open. When the water concentration is low, the stoma will close. Stoma are generally open when plants are photosynthesizing.

Question: Will plants have more stoma open during the day than during the night?

3. Develop a hypothesis about the number of open stomata found in a plant kept in the dark compared to a plant in the light. Write your hypothesis below, and make sure that it is a complete sentence.

Repeat the procedure above for preparing your slide. You will make two impressions, one from a "Dark Plant" and one from a "Light Plant" You will compare the two impressions.

4. Data Table

Plant	Number of Stomata
Light	
Dark	

5. Conclusions: Write a short paragraph that answers the question, use your data to support your conclusions.

Link: http://www.biologycorner.com/worksheets/stomata.html

Success Criteria	**Yes/No**	**Standard (low, medium, high)**	**Reflection (if you were to do it again what would you do differently??**	**Teacher Feedback**
Apply the scientific method correctly.				
Ask questions and think like a biologist.				
Carefully record data and interpret it.				
Use the microscope correctly.				
Work as part of a team.				
Design an exam question to accompany my investigation.				
Complete a written report.				
Overall				

Appendix 4.6 DNA SEOS

SEOS for DNA isolation IST

Skills as outlined in the syllabus document		**DNA**
Following instructions	Follow instructions step by step Listen carefully to the teachers instructions	4 4
Correct manipulation of apparatus	Labelling solutions and equipment Using given apparatus in the correct manner Correct preparation of solutions and mixtures Using and/or measuring time as a variable Correct use of a measuring instrument Take an accurate reading	0 5 5 5 5 -
Observation	Accurate observation (using equipment) Appropriate observation of the phenomenon under study – (was the correct aspect of the phenomenon observed) Complete observation of the phenomenon under study (producing the correct phenomenon)	5 5 5
Recording	Careful recording of data Write up the procedure Perform calculations as required Tabulate results Draw diagrams or graphs to represent data collection	0 0 - - -
Interpretation	Draw reasonable conclusions from your observations and results Conclusions should ensue from hypothesis being tested Coherent final interpretation that explains how results are reached	0 0 0
Application	Awareness of any other application of what was learned Consider the results in a wider context Identify an activity that serves as a model for further investigation	2 2 2
Practical enquiry	Consideration of ambiguous results Repetition of activity if necessary Design of a new activity	- - 0
Use of the scientific method as outlined in the syllabus documents	Making initial observations Forming an hypothesis Designing a controlled experiment Reporting and publishing results Appreciation of errors Use of controls to reduce errors Collecting data- *see observation / recording above* Interpreting data & reaching conclusions - *see interpretation above* Placing conclusions in the context of existing knowledge & development of theory and principal – *see application above*	0 2 1 0 0 0 - - -
Notes on experiment		

Appendix 4.7 Practical Activity Analysis Inventory for DNA Isolation Lesson during PBTM

Title:	Isolation of DNA from a Plant Tissue

1 Learning objective(s) (or intended learning outcome(s))

Objective (in general terms)	*Tick ✓ one box to indicate the main objective*	Learning objective (more specifically)	*Tick ✓ one box*
A: By doing this activity, students should develop their knowledge and understanding of the natural world	X	Students can recall an observable feature of an object, or material, or event	X
		Students can recall a 'pattern' in observations (e.g. a similarity, difference, trend, relationship)	
		Students have a better understanding of a scientific idea, or concept, or explanation, or model, or theory	
B: By doing this activity, students should learn how to use a piece of laboratory equipment or follow a standard practical procedure		Students can use a piece of equipment, or follow a practical procedure, that they have not previously met	
		Students are better at using a piece of equipment, or following a practical procedure, that they have previously met	
C: By doing this activity, students should develop their understanding of the scientific approach to enquiry		Students have a better *general understanding* of scientific enquiry	
		Students have a better *understanding of some specific aspects* of scientific enquiry	

If you have ticked this box, please complete the table below

Specific aspects of scientific enquiry	*Tick ✓ all that apply*
How to identify a good investigation question	
How to plan a strategy for collecting data to address a question	
How to choose equipment for an investigation	
How to present data clearly	
How to analyse data to reveal or display patterns	
How to draw and present conclusions based on evidence	
How to assess how confident you can be that a conclusion is correct	

2 Design

2.1 Openness/closure (Tick ✓ one box)	
Question given, and detailed instructions on procedure	X
Question given, and outline guidance on procedure; some choices left to students	
Question given, but students choose how to proceed	
Students decide the question and how to proceed	
2.2 Logical structure of the activity (Tick ✓ one box)	
Collect data on a situation, then think about how it might be summarised or explained	
Use your current ideas to generate a question or prediction; collect data to explore or test	
Other. Follow instructions / produce a phenomenon	
2.3 Importance of scientific ideas (to carry out the activity well) (Rate: 4= essential; 3=fairly; 2=not very; 1=unimportant)	
Importance of an understanding of scientific ideas	X
2.4 What students have to do with objects and materials (Tick ✓ all that apply)	
Use an observing or measuring instrument	x
Follow a standard practical procedure	x
Present or display an object or material	
Make an object	
Make a sample of a material or substance	x
Make an event happen (produce a phenomenon)	x
Observe an aspect or property of an object, material, or event	x
Measure a quantity	
2.5 What students have to 'do' with ideas (Tick ✓ all that apply)	
Report observations using scientific terminology	
Identify a similarity or difference (between objects, or materials, or events)	
Explore the effect on an outcome of a specific change (e.g. of using a different object, or material, or procedure)	
Explore how an outcome variable changes with time	
Explore how an outcome variable changes when the value of a continuous independent variable changes	
Explore how an outcome variable changes when each of two (or more) independent variables changes	
Design a measurement or observation procedure	
Obtain a value of a derived quantity (i.e. one that cannot be directly measured)	
Make and/or test a prediction	
Decide if a given explanation applies to the particular situation observed	
Decide which of two (or more) given explanations best fits the data	
Suggest a possible explanation for data	

3 Presentation

3.1 How is the purpose, or rationale, communicated to students? (Tick ✓ one box)	
Activity is proposed by teacher, no explicit links made to previous work	
Purpose of activity explained by teacher, and explicitly linked to preceding work	X
Teacher uses class discussion to help students see how the activity can help answer a question of interest	
Purpose of activity readily apparent to the students, clearly follows from previous work	
Activity is proposed and specified by the students, following discussion	
3.2 How is the activity explained to students? (Tick ✓ all that apply)	
Orally by the teacher	
Written instructions on OHP or data projector	x
Worksheet	x
(All or part of) procedure demonstrated by teacher beforehand	
3.3 Whole class discussion before the practical activity begins? (Tick ✓ all that apply)	
None	
About equipment and procedures to be used	
About ideas, concepts, theories, and models that are relevant to the activity	
About aspects of scientific enquiry that relate to the activity	
3.4 Whole class discussion following the practical activity? (Tick ✓ all that apply)	
None	X
About confirming 'what we have seen'	
Centred around a demonstration in which the teacher repeats the practical activity	
About how to explain observations, and to develop conceptual ideas that relate to the task	
About aspects of investigation design, quality of data, confidence in conclusions, etc.	
3.5 Students' record of the activity (Tick ✓ one box)	
None	
Notes, as the student wishes	
A completed worksheet	X
Written report with a given structure and format	
Written report in a format chosen by the student	

4 Learning demand

In the light of your entries above, how would you judge the learning demand of this activity? (Rate: 5=very high; 4=fairly high; 3=moderate; 2=fairly low; 1=very low)	
Learning demand	1

5 Assessment of effectiveness when used

A Effectiveness at level (1)

Key question: ***Did students do what they were intended to do, and see what they were intended to see?***

		Mainly yes	Mainly no	Not applicable
1	Did students know how to use the equipment involved?	X		
2	Were students able to set up the apparatus, and handle the materials involved, correctly and safely?	X		
3	Were students able to use the apparatus with sufficient precision to make the necessary observations or measurements?	X		
4	Were students able to carry out any routine procedures involved?	X		
5	Were students able to follow any oral or written instructions given?	X		
6	Did students observe the outcome(s) or effect(s) you wanted them to see?	X		
7	Could students explain the purpose of the activity if asked? (what they were doing it for)	X		
8	Did students talk about the activity using the scientific terms and ideas you would have wished them to use?		X	

B Effectiveness at level (2)

Key question: ***Did students learn what they were intended to learn?***

		Most	Some	Only a few
1	How many students could recall what they did, and the main features of what they observed?			

Summarise the evidence for your answer above:

This was not assessed

		Most	Some	Only a few
2	How many students have a better understanding of the ideas the activity was intended to help them understand?			X

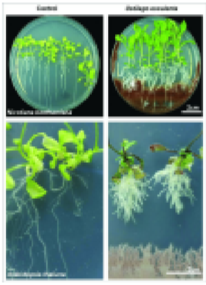
Summarise the evidence for your answer above:

In the audio transcript, students can be heard doing the worksheet – they struggle to fill in the blanks. The worksheet was designed as an accompaniment to the protocol so that the students would understand the reason for each step. One student repeatedly says she doesn't understand. Another group can be seen on the video struggling with the worksheet. Students did not connect the steps in the protocol to the task of releasing DNA from plant cells

Appendix 6.1 Walkthrough Workshop FTEAs

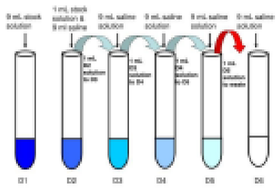
Appendix 6.1.1a Serial Dilution PowerPoint

Investigation of the effect of IAA on Plant tissue



Plant growth regulators

- Chemicals that at very low concentrations affect the development of plants
- Auxin is a growth promoter
- IAA is a naturally occurring auxin which affects the elongation of cells
- It is commonly made in the meristems of plants
- We are going to examine the effect of IAA on the growth of shoots of plants at different concentration of IAA
- Predict what will happen to shoots at
  - a) low concentrations of IAA
  - b) at high concentrations of IAA



Making a serial dilution

What is the purpose of a serial dilution

Auxins work at very low concentrations and it is impossible to weigh out small amounts

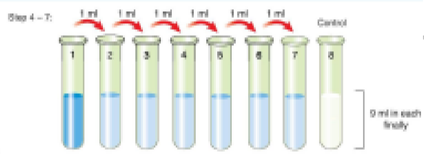
You can achieve very small amounts by doing a serial dilution

Make up a stock solution of 100ppm. (That's 100 parts IAA to 1,000,000 parts water)

With a serial dilution, each concentration is one tenth the concentration of the previous one.

Step 2 & 3:
At the start add these to the test tubes

IAA	10 ml	–	–	–	–	–	–	–
Water	–	9 ml	9 ml	9 ml	9 ml	9 ml	9 ml	9 ml



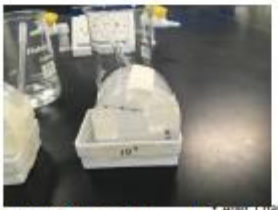
Step 2 & 3:
At the start add these to the test tubes

IAA	10 ml	–	–	–	–	–	–	–
Water	–	9 ml	9 ml	9 ml	9 ml	9 ml	9 ml	9 ml
IAA conc (ppm)	10^2	10^1	10^0	10^{-1}	10^{-2}	10^{-3}	10^{-4}	0
=	100	10	1	0·1	0·01	0·001	0·0001	0

Fig. 1 Serial dilution – preparing IAA solutions of different concentrations

Growing seeds in different concentrations of IAA

- In front of each bottle of IAA, lay out 1 petri dish.
- Draw a line 2/3 of the way down the underside of each plate
- Place 3 pieces of filter paper in each dish and soak with 2 droppers full of the IAA solution – the line should be visible through the paper
- Place 5 radish seeds along the line
- Repeat for the other dilutions
- Allow 1 day for the seeds to lie flat so that they adhere properly to the filter paper



Growing seeds in different concentrations of IAA

- After 1 day, collect all of the 10⁻ dishes and tape them together sideways so and place in a dish as show in the picture
- Make sure the seeds are horizontal – this ensures shoots grow up and roots grow down
- Fill the dish with 10^2 IAA solution so that the seeds are kept moist

- Collect class set of seeds and place at 20 degrees for 4 days

Data Collection

- Using a ruler measure the length of the shoots of each seedling and record the data in the table shown
- Calculate the average length of the shoots for each dish
- Work out the % stimulation (or inhibition) of shot growth for each

$$\% \text{ stimulation} = \frac{\text{(Average length – Average length of control)}}{\text{Average length of control}} \times 100$$

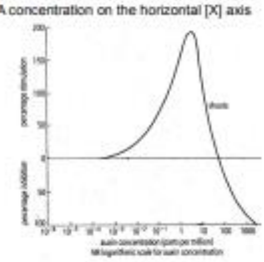
Positive answer => Stimulation Negative answer => Inhibition

Dish	Concentration of IAA		Length of Shoots (mm)								Total Length	Average Length	% increase or decrease
	(mg/dm³)	(ppm)	Seed 1	Seed 2	Seed 3	Seed 4	Seed 5	Seed 6	Seed 7	Seed 8	(mm)	(mm)	
A	[illegible]	[illegible]									0		
B	[illegible]	[illegible]									0		
C	[illegible]	[illegible]									0		
D	[illegible]	[illegible]									0		
E	[illegible]	[illegible]									0		
F	[illegible]	[illegible]									0		
G	[illegible]	[illegible]									0		
H	[illegible]	[illegible]									0		
I	[illegible]	[illegible]									0		
J (Control)	0	0									0		

Table of results for Shoots

Draw a graph of the % stimulation and inhibition of root and shoot growth against IAA concentration.

Put IAA concentration on the horizontal [X] axis



What about the roots? – application of Experiment

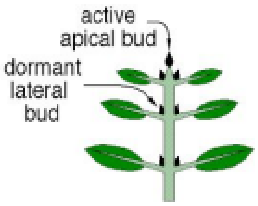
- Look at your seeds and make a generalization about the effect of IAA on roots
- Conduct an investigation to validate or invalidate your generalization
- Present your results in graph form

Dish	Concentration of IAA		Length of Roots (mm)								Total Length	Average Length	% increase or decrease
	(mg/litre)	(ppm)	Seed 1	Seed 2	Seed 3	Seed 4	Seed 5	Seed 6	Seed 7	Seed 8	(mm)	(mm)	
A	100.000000	10^{2}									0		
B	10.000000	10^{1}									0		
C	1.000000	10^{0}									0		
D	0.100000	10^{-1}									0		
E	0.010000	10^{-2}									0		
F	0.001000	10^{-3}									0		
G	0.000100	10^{-4}									0		
H	0.000010	10^{-5}									0		
I	0.000001	10^{-6}									0		
J (Control)	0	0									0		

Table of results for Roots…

Effects of Auxins

- Growth promoters
- Apical dominance – shape of trees
- Growing plants from cuttings – rooting powders



Appendix 6.1.1b FTEA, Lesson Plan and Resources for IAA experiment

Observation / Data / Research

Students set up a serial dilution using food dye/ introduction to auxins

↓

Diagnostic experiment

- Grow radish seeds in different concentrations of IAA
- Skill: prepare a serial dilution

↓

Observation

Students observe and measure the length of shoots at each concnetration

↓

Principle

Iaa stimulates shoot growth at medium concentrations and inhibits it at high concentrations

↓

Inference: What can we use this information for?

Students read a piece on auxins and apical dominance. Students also observe onin roots at different concentrations of IAA

↓

Working hypothesis

- IAA has a differnet effect on roots than shoots
- Reasoning: Students ask a question based on observation of onion roots and radish shoots

↓

Applied experiment

Students investigate the effect of IAA on roots using the same seeds

↓

Observation

- Collect data to answer the question asked, compare root growth to shoot growth.
- Choose how to present data

↓

Conclusion / next steps

- Confirm /refute hypothesis
- Share data with class
- Prepare a report
- Segue into connecting lesson

Framework for Planning Practical Work
Title of Experiment: Investigate the effect of growth regulator on plant tissue

Context **Procedural** **Informational**	Investigating the growth of radish seedlings under different concentrations of IAA (an auxin) • Serial dilution • Placing seeds in different concentrations of IAA in petri dishes so that they germinate Students need an understanding of • Auxins as growth regulators • IAA as an auxin • The purpose of a serial dilution • Students are asked to develop a hypotheses and conduct an experiment based on what they learn in class
Preparation for Experiment	• Reading comprehension for students • Setting up equipment • Planting broad bean seeds so they have grown into young plants • Onion roots in different concentrations of IAA
Laboratory skill attainment	Preparing a serial dilution – worksheet – *Appendix 1* Measuring roots and shoots Graph construction
Risk assessment	Risk assessment carried out by teacher beforehand and sheet filled in and signed
List of equipment needed	**For serial dilution** Ribena Small bottles Pipettes and pipette fillers (10ml) Droppers IAA solution (0.01%) – *Appendix 2* Distilled water **For the experiment** Petri dishes Filter paper Containers for petri dishes to stand upright in Radish or cress seeds soaked overnight Tape Forceps Rulers
Procedural teaching methodology **Induction:** **Diagnostic** **Experiment**	Teacher: show students how to make up serial dilutions (use Ribena) Student: Make up serial dilution of IAA – *Appendix 1* Carry out experiment

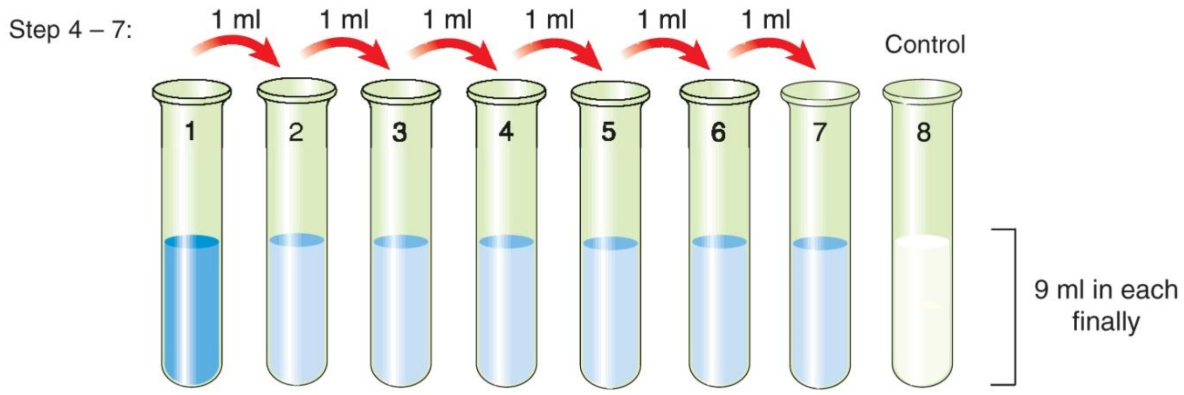
Deduction: **Applied Experiment**	Once roots have been measured, ask if IAA has the same effect on shoots. Students have to present data showing the effect of IAA on root growth Hand out reading comprehension – apical dominance and auxin – *Appendix 3* Ask students to come up with a question that they would like to investigate based on the reading. (Have onions and potted peas/beans prepared) Propose a hypotheses that can be investigated Conduct own experiment to investigate the effect of IAA on plant growth.(Will IAA have an effect on onion roots? Apical dominance?)
<u>**Data collection**</u> **Induction/Deduction**	Students will measure the lengths of roots and shoots and plot stimulation or inhibition of root growth compared to the water control on a graph. – *Appendix 4* The class set of data will be used to reach conclusions about the effects of IAA on root and shoot growth For the applied experiment, students collect new data informed by the previous experiment relating to either root growth or apical dominance
<u>**Data presentation and analysis**</u> **Induction** **Deduction**	Depending on the questions asked by students First experiment: Students will examine root growth and record the effect of different concentrations of IAA on root growth, compared to a water control. They will draw a graph of their findings First experiment: Students will then re-examine the seedlings to see the effect of IAA on shoot growth and graph their results Own experiment: Students will connect the results of their own experiment to what they have already learned about IAA and will present the conclusion of this second experiment
<u>**Data presentation**</u> **Induction/Deduction**	Students create a write upusing the following headings: Title Hypothesis Procedure Data Collected Data presentation Analysis of data Conclusion
<u>**Real World**</u>	Students repeat the data analysis to generate their own

<u>Application/ Extension</u> **Deduction**	data for shoot growth. After doing the experiment and reading the extra material, students should understand the importance of auxins and could investigate further by experimenting with rooting powders Horticulture – growing beech hedges / shape of Christmas trees
<u>Evaluation</u>	Teacher and students evaluate the lesson under the following headings: <u>What worked</u> – what aspects of the lesson did students understand <u>What needs improvement-</u> where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge <u>What will I do differently next time</u> Teacher evaluates the learning by examining the student report or poster and grading the report as appropriate.
LC exam questions relating to Leaf Yeast	See attached Appendix 6 for copies of these questions 2018 Q5 2016 Q13 2015 Q8 © 2013Part of long question 2010 Q9 2008 Q9. 2005 long question 2004 long question

Lab Skill – Making a Serial Dilution

1. You start with a stock solution – this contains 100 parts of IAA per million parts water
This solution is labelled 10^2 ($10^2 = 100$)

2. You take 1 ml of this and place it into 9ml of distilled water (Test tube 1). It is diluted to 1/10th of the original stock solution.
How many parts of IAA are in this solution?
How will you label it?



3. Now take 1 ml of the diluted solution and place into 9 ml of water
a. How many parts of IAA are in this solution?
b. How will you label it?
4. Try to fill in the table to help you label your serial dilution bottles

	Stock solution	1st dilution bottle	2nd dilution	3rd dilution	4th dilution	5th dilution	6th dilution	Control
IAA	10ml							
Water	none	9ml						
IAA concentration (parts per million water)	100	10						
Label on plate	10^2							

5. It is important that the diluted solutions are made up accurately. While you can use a pipette to measure the water into each bottle, you cannot use the same

pipette as you used for water to measure the IAA, nor can you use the same pipette every time you use IAA. What is your solution to this problem (look at the materials on your desk to help you)

Appendix 2
Making up IAA solution (0.01% w/v = 100ppm)

Note.
Relationship between ppm and %w/v:

- *0.01% w/v means 0.01 grams in 100ml*
- *If you are making a litre then you need to add 0.1g to 1000ml.*
- *To work out ppm – multiply the no. of grams per litre you have by 1000*
- *0.1 grams = 100ppm*
- *Hence the stock solution contains 100 or 10^2 parts per million IAA*

1. Weigh out 0.1g IAA powder and dilute with 0.5 ml alcohol in a small vial or weigh

boat

2. Shake to dissolve

3. Add approx. 500ml distilled water to a 1L volumetric flask

4. Add the IAA to the water

5. Make up to 1L with distilled water

6. Label 10^2.

IAA should be kept in the freezer at -20^{o}C
It is best to make up the IAA solution in the fume cupboard as you don't want to inhale the powder.
IAA is insoluble in water so it is necessary to dissolve it in alcohol first to make up a solution.

Reading Material:

A plant growth regulator is a chemical that at very low concentrations affects the growth and development of plants

Some growth regulators promote growth e.g. auxins, gibberellins, cytokinins

Others are growth inhibitors: Abscisic acid, ethene

Auxins are chemicals produced in the meristematic cells in the shoot tip and diffuse downward to promote cell elongation in the stem causing the shoot to grow.

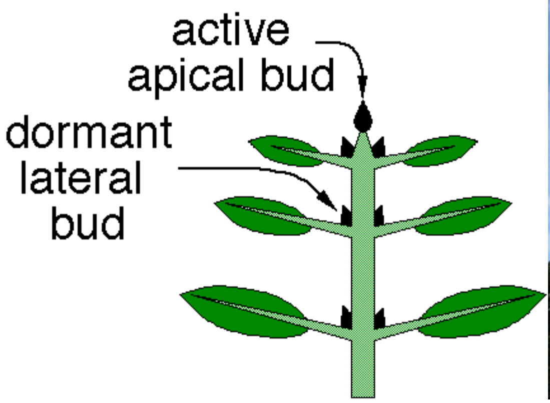
IAA (indoleacetic acid) is a naturally occurring auxin – it affects elongation of cells and is commonly produced in the top of growing shoots (meristem).

IAA has opposite effects on roots and shoots – i.e. the same concentration of IAA can inhibit the growth of roots but stimulate the growth of shoots

At different concentrations IAA can have the opposite effects on root growth – i.e. at low concentrations it stimulates growth while at high concentrations it inhibits it.

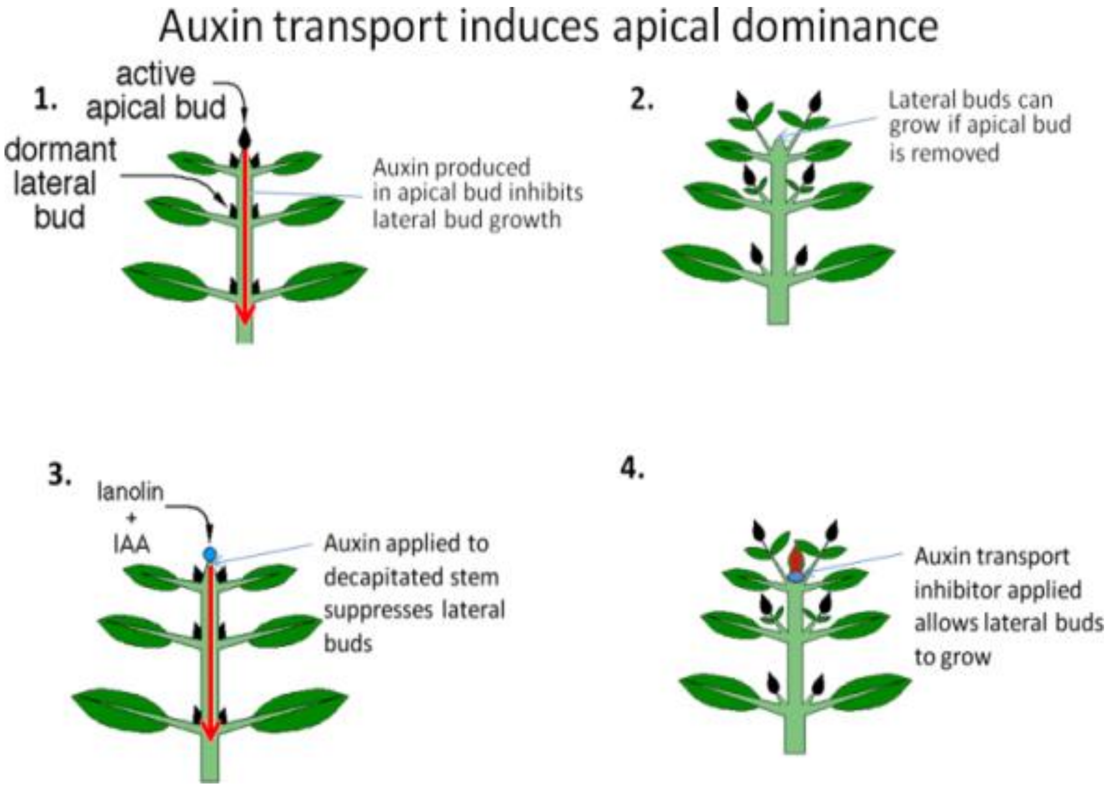
<u>Apical Dominance</u>

Apical dominance is seen in many plants where high auxin concentration in the apical bud inhibits the growth of side shoots (branches) from meristems in the axils of leaves. The apical shoot is producing auxin that is inhibiting the growth of lateral (side) shoots. This gives some trees their characteristic shape.

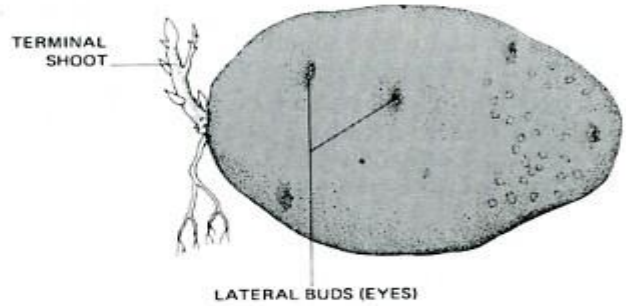


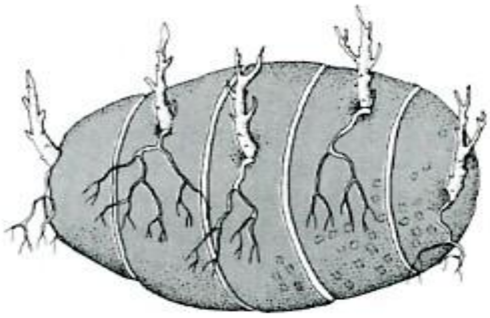
If the apical meristem of a shoot is removed, apical dominance is lifted, and lateral shoots begin to grow out from the meristems in the axils of the leaves. Gardeners exploit this principle by pruning the apical shoot of ornamental shrubs, etc. The removal of apical dominance enables lateral branches to develop and the plant becomes bushier. The process usually must be repeated because one or two laterals will eventually outstrip the others and reimpose apical dominance. An example of this is the growth of a beech hedge. The hedge is clipped annually to remove the apical buds and encourage the lateral buds to grow sideways.

Apical dominance is the result of downward transport of auxin produced in the apical meristem. In fact, if the apical meristem is removed and IAA applied to the stump, inhibition of the lateral buds can be maintained.



The common white potato is really a portion of the underground stem of the potato plant. It has a terminal bud or "eye" and several lateral buds. After a long period of storage, the terminal bud usually sprouts but the other buds do not. However, if the potato is sliced into sections, one bud to a section, the lateral buds develop just as quickly as the terminal bud.





Making up IAA solution (0.01% w/v = 100ppm)

Note.
Relationship between ppm and %w/v:

- *0.01% w/v means 0.01 grams in 100ml*
- *If you are making a litre then you need to add 0.1g to 1000ml.*
- *To work out ppm – multiply the no. of grams per litre you have by 1000*
- *0.1 grams = 100ppm*
- *Hence the stock solution contains 100 or 10^2 parts per million IAA*

7. Weigh out 0.1g IAA powder and dilute with 0.5 ml alcohol in a small vial or weigh

boat

8. Shake to dissolve

9. Add approx. 500ml distilled water to a 1L volumetric flask

10. Add the IAA to the water

11. Make up to 1L with distilled water

12. Label 10^2.

IAA should be kept in the freezer at -20^{o}C
It is best to make up the IAA solution in the fume cupboard as you don't want to inhale the powder.
IAA is insoluble in water so it is necessary to dissolve it in alcohol first to make up a solution.

Appendix 6.1.1c – Template for Recording Root and Shoot Length accompanied by a Data Set for the Experiment

Dish	Concentration of IAA		Length of Shoots (mm)								Total Length	Average Length	% increase or
	(mg/litre)	(ppm)	Seed 1	Seed 2	Seed 3	Seed 4	Seed 5	Seed 6	Seed 7	Seed 8	(mm)	(mm)	decrease
A	100.000000	10^{2}									0		
B	10.000000	10^{1}									0		
C	1.000000	10^{0}									0		
D	0.100000	10^{-1}									0		
E	0.010000	10^{-2}									0		
F	0.001000	10^{-3}									0		
G	0.000100	10^{-4}									0		
H	0.000010	10^{-5}									0		
I	0.000001	10^{-6}									0		
J (Control)	0	0									0		

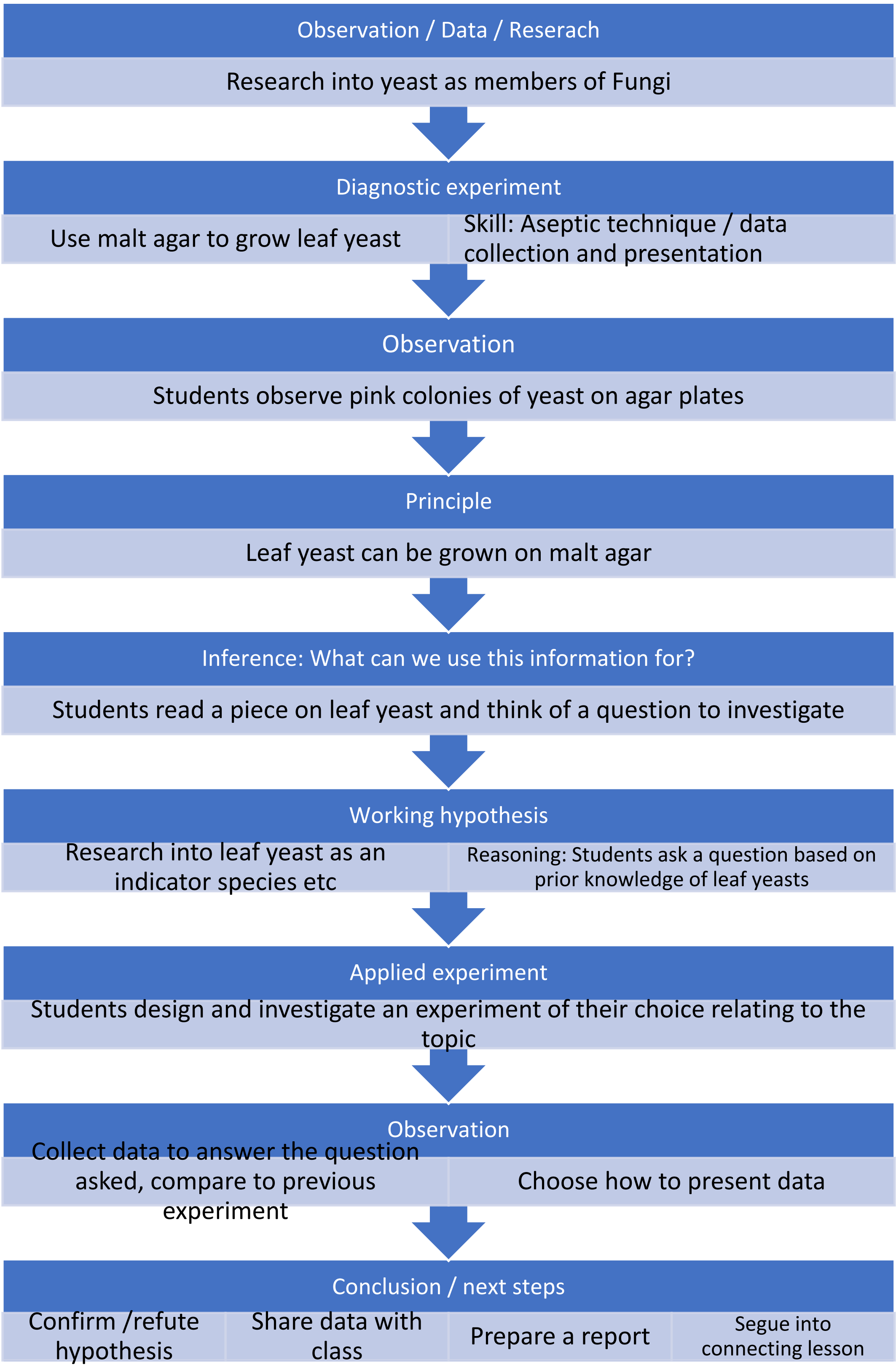
Dish	Concentration of IAA		Length of Roots (mm)								Total Length	Average Length	% increase or
	(mg/litre)	(ppm)	Seed	Seed	Seed	Seed	Seed	Seed	Seed	Seed 8	(mm)	(mm)	decrease
			1	2	3	4	5	6	7				
A	100.000000	10^{2}									0		
B	10.000000	10^{1}									0		
C	1.000000	10^{0}									0		
D	0.100000	10^{-1}									0		
E	0.010000	10^{-2}									0		
F	0.001000	10^{-3}									0		
G	0.000100	10^{-4}									0		
H	0.000010	10^{-5}									0		
I	0.000001	10^{-6}									0		
J (Control)	0	0									0		

Dish	Concentration of IAA		Length of Shoots (mm)								Total Length	Average Length	% increase or
	(mg/litre)	(ppm)	Seed 1	Seed 2	Seed 3	Seed 4	Seed 5	Seed 6	Seed 7	Seed 8	(mm)	(mm)	decrease
A	100.000000	10^{2}	3	4	2	0	1				0		
B	10.000000	10^{1}	26	47	33	40	44				0		

C	1.000000	10^{0}	43	45	50	55	39				0		
D	0.100000	10^{-1}	23	24	30	25	27				0		
E	0.010000	10^{-2}	20	22	26	20	26				0		
F	0.001000	10^{-3}	14	15	15	17	19				0		
G	0.000100	10^{-4}	1	2	1	3	3				0		
H	0.000010	10^{-5}	0	0	0	0	0				0		
I	0.000001	10^{-6}	0	0	0	0	0				0		
J (Control)	0	0	15	14	16	15	16				0		

Dish	Concentration of IAA		Length of Roots (mm)								Total Length	Average Length	% increase or
	(mg/litre)	(ppm)	Seed 1	Seed 2	Seed 3	Seed 4	Seed 5	Seed 6	Seed 7	Seed 8	(mm)	(mm)	decrease
A	100.000000	10^{2}	1	2	1	0	2				0		
B	10.000000	10^{1}	5	6	7	3	5				0		
C	1.000000	10^{0}	6	7	8	9	4				0		
D	0.100000	10^{-1}	10	12	15	14	15				0		
E	0.010000	10^{-2}	14	15	17	12	13				0		
F	0.001000	10^{-3}	29	23	24	20	21				0		
G	0.000100	10^{-4}	30	29	25	33	35				0		
H	0.000010	10^{-5}	14	18	20	19	21				0		
I	0.000001	10^{-6}	5	6	8	7	12				0		
J (Control)	0	0	15	14	16	15	16				0		

Appendix 6.1.2 – Leaf Yeast FTEA



Framework for Planning Practical Work

Title of Experiment: Investigate the growth of leaf yeast using agar plates and controls.

Context **Procedural**	Investigation of the growth of leaf yeast using agar plates • Making malt agar plates (optional for students) • Using agar to grow leaf yeast
Informational	Students need an understanding of • leaf yeast and the conditions under which it grows • leaf yeast as an indicator species • leaf yeast basidiospores Students are asked to develop a hypotheses and conduct an experiment based on what they learn in class
Preparation for Experiment	• Reading comprehension for students (inc. tips for teachers) – *Appendix 1* • Making malt agar plates- *Appendix 2* • Setting up equipment – *Appendix 3*
Laboratory skill attainment	Teacher :Making up malt agar plates – *Appendix 2* Student: Aseptic technique- *Appendix 2*
Risk assessment	Risk assessment carried out by teacher beforehand and sheet filled in and signed – *Appendix 4*
List of equipment needed	**To make agar** Malt agar powder. Bunsen burner Sterile agar plates. Large beaker Stirrer. Deionised water **For the experiment** Ash Leaves – from a variety of areas (wood, country, town) and a variety of months (June, July, August, September) Other leaves – sycamore, alder, oak, holly etc Sterile malt agar plates Vaseline Disinfectant / Alcohol Cork borer / scalpel Chopping board Bunsen burner Lighter Forceps Parafilm / tape Marker Paper towels
Procedural teaching methodology **Induction**	Teacher: show teachers how to make up agar plates Student: Learn aseptic technique using the method to investigate the growth of leaf yeast –*Appendix 2* and Visual Sheet on desk

Deduction	*(Appendix 5).* Use the worksheet in conjunction with the procedure as an assessment for learning tool (*forked road situation)* Hand out reading comprehension – *Appendix 1* Ask students to come up with a question that they would like to investigate based on the reading. Convert the question into a hypotheses Repeat the experiment so that the student can conduct their own investigation into leaf yeast growth.
<u>Data collection</u> **Induction and Deduction**	Students will investigate their agar plates after a week to look for and count pink colonies of yeast
<u>Data presentation and analysis</u> **Induction** **Deduction**	Depending on the questions asked by students First experiment: Students will examine plates and record the presence or absence of leaf yeast Second experiment: Students will count colonies and record the results in a graph/ bar chart and report on whether the result is in agreement with their original hypothesis.
<u>Data presentation</u> **Deduction**	Students create a write up under the following headings: Title Hypothesis Procedure Data Collected Data presentation Analysis of data Conclusion
<u>Real World Application/ Extension</u> **Deduction**	Students repeated the experiment to generate their own data around leaf yeast After doing the experiment and reading the extra material, students should understand the value of leaf yeasts as indicator species and that scientists use leaf yeasts and other indicator species to determine the health of the environment.
<u>Evaluation</u>	Teacher evaluates the lesson under the following headings: <u>What worked</u> – what aspects of the lesson did students understand <u>What needs improvement-</u> where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge <u>What will I do differently next time</u> Teacher evaluates the learning by examining the student report or

	poster (give it a grade???)
LC exam questions relating to Leaf Yeast	See attached Appendix 6 for copies of these questions 2018 Q9 2015 Q8 b 2012 Q8 2007 Q8 2005 Q9

Appendix 6.1.3 – Digestive Activity FTEA with Resources

Observation / Data / Reserach

Introduction to digestive enzymes in seeds during germination / check broad bean seeds for starch

↓

Diagnostic experiment

- Grow broad bean seeds on starch agar
- Skill: aseptic technique

↓

Observation

Students observe that starch has been digested by the germinating seed

↓

Principle

Seeds contain amylase that digests starch into sugar which they use for energy to grow during germination

↓

Inference: What can we use this information for?

Students asked to think about what starch is converted into by amylase / students asked to thinkabout any other enzymes that might be present in a growing seed

↓

Working hypothesis

- Seeds contain protein digesting enzymes / starch is converted to sugar
- Reasoning: Students ask a question based on whether seeds contain protein of whether there is sugar on the agar plate

↓

Applied experiment

Students investigate aseptically whether seeds can digest protein / whether the colourless areas on the starch plate contain sugar

↓

Observation

- Collect data to answer the question asked.
- Choose how to present data

↓

Conclusion / next steps

- Confirm /refute hypothesis
- Share data with class
- Prepare a report
- Segue into connecting lesson

Framework for Planning Practical Work

Title of Experiment: To investigate the digestive activity in seeds during germination using agar plates

Context **Procedural** **Informational**	Investigation of the digestive activity in seeds during germination • Making starch and skimmed milk agar plates (optional for students) • Investigating the activity of digestive enzymes in seeds – amylases, proteases Students need an understanding of • Conditions required for germination • The events that occur during germination in the seed • Food tests • Digestive enzymes – amylase/ protease / lipase Following the diagnostic experiment students are asked to develop a hypotheses and conduct an experiment based on what they learn in class
Preparation for Experiment	• Making starch agar plates and skimmed milk agar plates – *Appendix 1* • Set up equipment – have food test materials prepared • Soak broad bean seeds / popcorn seeds
Laboratory skill attainment	Making up starch and skimmed milk agar plates – *Appendix 1* Aseptic technique- *Appendix 1*
Risk assessment	Risk assessment carried out by teacher beforehand and sheet filled in and signed
List of equipment needed	**To make agar** Agar powder. Bunsen burner. Sterile agar plates. Large beaker Stirrer. Deionised water Skimmed milk powder. Soluble starch powder **For the experiment** Broad beans seeds Popcorn seeds Sterile starch agar plates and sterile skimmed milk agar plates Beakers Disinfectant 10% domestos / 70% Alcohol Petri dish Bunsen burner

	Lighter Forceps Marker Paper towels Iodine solution / Benedicts solution / Biuret solution/ Sudan III
<u>Procedural teaching methodology</u> **Induction:** **Diagnostic Experiment** **Deduction:** **Applied Experiment**	Teacher: Presentation on germination (Powerpoint – *appendix 4*) Show students how to make up and/or pour agar plates (optional) Scrape the surface of split beanseeds and add iodine to show there is starch in the seed – this leads into discussion on amylase and its function Student: Learn aseptic technique using the method to place seeds onto agar–and Visual Sheet on desk Powerpoint to accompany visual sheet – *Appendix 5* Use the worksheet in conjunction with the procedure as an assessment for learning tool – allow students to make decisions about experiment during the experiment (the *forked-road)- Appendix 2* After experiment – Reading material: *Appendix 4* converted from ppt into sheet Ask students how they mightshow if the starch has been converted to sugar – Benedict's test Ask students to think about any other food store and related enzymes that might be in seeds – scrape seed again and add biuret reagent to test for protein. Discuss the role of protease. Examine monocot seed structure with a hand lens – add iodine and observe Think about how the mass of seeds changes as germination progresses Develop a hypotheses that can be investigated based on the diagnostic experiment Repeat the experiment so that the student can conduct their own investigation into the digestive activity of seeds
<u>Data collection</u> **Induction/Deduction**	Students will use food tests to analyse the digestive activity of enzymes in seeds – Test for starch – iodine Test for sugar – benedicts solution Test for protein – biuret reagent Test for fat – sudan III
<u>Data presentation and analysis</u>	Depending on the questions asked by students

Induction **Deduction**	First experiment: Students will examine plates and record the presence or absence of starch First experiment: Students will deduce that starch has been converted to sugar and will conduct a sugar test Second experiment: Students may investigate the activity of another enzyme using the technique they have learned and the appropriate agar plate Students may investigate how the mass of seeds changes as the food store in cotyledons are digested and the products of digestion are used by the embryo to grow into a new plant Students may investigate the digestive activity in monocot seeds
<u>Data presentation</u> **Induction/Deduction**	Students create a write up under the following headings: Title Hypothesis Procedure Data Collected Data presentation Analysis of data Conclusion
<u>Real World Application/ Extension</u> **Deduction**	After doing the experiment and connecting germination to digestion, students repeat the experiment to investigate a different digestive enzyme. (protease)
<u>Evaluation</u>	Teacher and students evaluate the lesson under the following headings: <u>What worked</u> – what aspects of the lesson did students understand <u>What needs improvement-</u> where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge <u>What will I do differently next time</u> Teacher evaluates the learning by examining the student report or poster and grading the report as appropriate.
LC exam questions relating to Leaf Yeast	See attached Appendix 3 for copies of these questions 2016 Q8 2014 Q7 2009 Q8

Making Agar Solutions

Malt agar: (makes 40 plates)

1. Use a clean sterilised 500ml beaker
2. Add 19g malt agar to 500ml of deioninsed water
3. Swirl to mix
4. BRING TO THE BOIL – if you skip this bit the agar won't set properly
5. Put the beaker in an autoclave and sterilise at 121^{o}C for 15 minutes
6. Allow to cool to 50^{o}C before pouring the plates

Starch Agar: (makes 40-50 plates)

1. Boil 500 ml of distilled water in a large beaker
2. In a separate smaller beaker mix 10g of starch with a small amount of cold distilled water
3. Add the starch solution to the boiling water and stir
4. In another small beaker mix 10g of agar with a small amount of cold distilled water
5. Add this solution to the boiling water and stir continuously – LET THE SOLUTION BOIL!
6. Sterilise at 121^{o}C for 15 minutes (if you have no autoclave, make sure you boil the solution well)
7. Allow to cool to 50^{o}C before pouring the plates

Skimmed Milk Agar (makes 40-50 plates)

1. Add 10g agar with 400ml water to a 1L beaker. Bring to the boil for approx. 10 mins (if agar starts to bubble, stir it)
2. Mix 10g skimmed milk powder with 100ml water in a clean, sterile beaker. Stir to dissolve
3. Allow the agar to cool to just under 80^{o}C and add the skimmed milk powder, stirring to dissolve with a sterile stirrer
4. Pour the agar plates aseptically

Making up 70% Ethanol

1. Add 70ml ethanol to a clean beaker
2. Make up to 100ml with water

Making 10% Sodium Hypochlorite solution (bleach e.gDomestos)

10% means 10 ml in every 100 ml

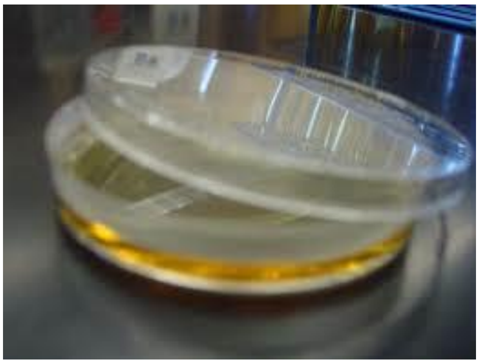
Pouring Agar Plates

1. Swab the bench with 70% ethanol to sterilise it.
2. Light the Bunsen (you may need to light more than one Bunsen if you have a large batch of plates)

3. Set up the plates in a ring around the Bunsen

4. Lift lid of plate slightly on side nearest bunsen and cover base of plate with agar – not too thick


5. Leave to set with lid slightly askew facing the Bunsen – the Bunsen moves air upwards and reduced the chances of contamination



6. When set put lid on and store in fridge till needed

Aseptic technique

Definition of Aseptic

Free from contamination caused by harmful bacteria, viruses, or other microorganisms; surgically sterile or sterilized.

(of surgical practice) aiming at the complete exclusion of harmful micro-organisms.

<u>What are you aiming for?</u>

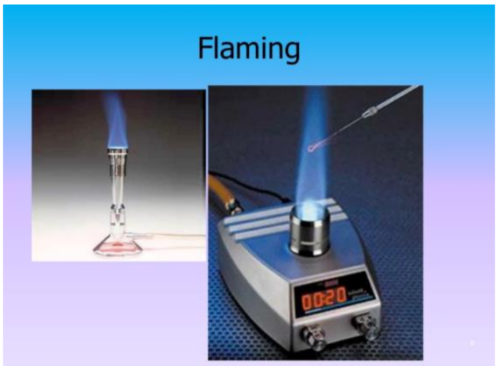
- With the aseptic technique you are trying to eliminate as many microorganisms as possible from the experiment
- In order to do this – all of your equipment has to be sterilised before you start
- The best solution to use as a steriliser is ALCOHOL

To begin:

- Swab the area you will be working on with alcohol including the bench and chopping board**or** use a sterile petri dish to do any cutting that you need to do
- Wash hands in hot soapy water
- From now on, use your equipment (scalpel, forceps) rather than your hands to manipulate the materials and flame forceps, scalpel EACH time you use it

How to flame equipment:

- Dip the forceps/scalpel/cork borer in alcohol and run through the Bunsen flame POINTING DOWNWARDS. Let the alcohol burn off
- **Make sure to hold it at an angle facing downwards!!!**
- Each time you use a piece of equipment dip in alcohol and FLAME IT!



Caution:
Keep the alcohol well away from the Bunsen

Don’t dip hot utensils into the alcohol – the alcohol can go on fire

If the alcohol does go on fire – cover the container with a damp cloth

Worksheet to accompany digestive enzyme experiment – do this while your seeds are soaking in disinfectant

1. You are using broad bean seeds to investigate the activity of digestive enzymes. How can you denature the enzymes in the seeds?

1. Using the information above, what will you use as your control?

2. How many a) seeds and b) agar plates do you need and how are you going to label them? (Draw a diagram here is it is easier for you)

3. Why do you think you have to put the seeds into disinfectant before you use them?

4. Before you actually use the seeds, you have to remove them from the disinfectant and rinse them in water. Why are you doing this?

5. Why does using a sterile petri dish to cut the seeds make more sense than using a chopping board?

6. You cannot touch the seeds with your hands – how are you going to remove the testa (outer layer of the seed)?

7. You are going to separate the seed into two halves- which way will you place them on the agar so that the digestive enzymes can begin to digest the agar? (Draw a diagram here if it is easier for you)

8. How are you going to place the seeds on the agar if you cannot touch them with your hands?

9. Explain the following:
a. Why do you put the seeds in an incubator at $20^{o}C$?
b. Why do you leave them for 2-3 days?

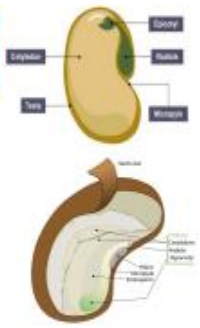
10. How are you going to test for enzyme activity? How will you know if your experiment has worked?

Germination

The re-growth of the embryo plant, following a period of dormancy

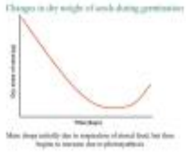
Process of Germination

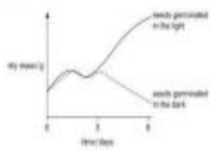
- Seeds absorb water through the micropyle and swell
- The testa splits
- The food store (cotyledons and/or endosperm) is digested to a soluble form.
- What chemicals carry out digestion?



Digestive enzymes

- Enzymes in the cotyledon become active and begin to breakdown the food stored there





- The products of digestion diffuse to the embryo plant and are used to produce ATP and new cells
- The radicle grows down into the soil
- The plumule emerges and grows upwards out of the soil

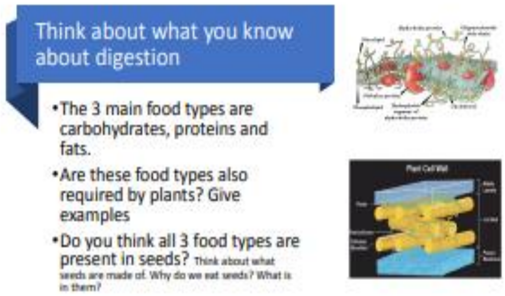
How do plants make carbohydrates?

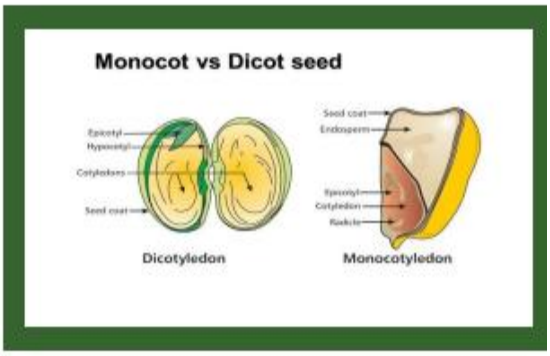
IN WHAT FORM DO PLANTS STORE CARBOHYDRATES?

HOW CAN WE TEST FOR THE PRESENCE OF THESE CARBOHYDRATES?

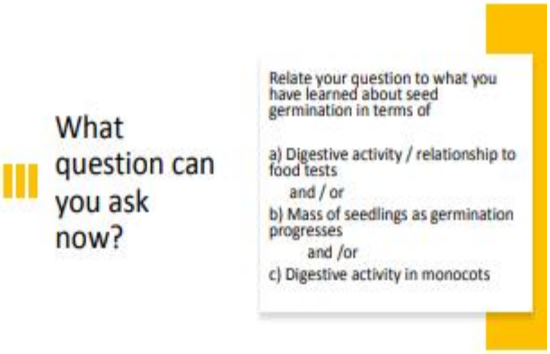
What enzyme might be present in seeds that would digest starch

- It's the same enzyme that is used in human digestion to digest starch
- What is the product of this digestion?
- What effect does iodine have on the substrate and product of starch digestion?


Think about what you know about digestion
•The 3 main food types are carbohydrates, proteins and fats.
•Are these food types also required by plants? Give examples
•Do you think all 3 food types are present in seeds? Think about what seeds are made of. Why do we eat seeds? What is in them?


Monocot vs Dicot seed
Epicotyl
Hypocotyl
Cotyledons
Seed coat
Dicotyledon
Seed coat
Endosperm
Epicotyl
Cotyledon
Radicle
Monocotyledon


Moving forward
• Plants have more than just amylases to digest starch.
• Think of another group of enzymes that seeds may have and what the substrate and product might be.
• How could you perform a similar experiment that would investigate the digestive activity of this other group of enzymes?
• Is there any other experiment you can think of that could investigate digestive activity?
• This experiment related to dicotyledons. What about monocotyledons?
• Think about how the digestive activity that goes on in seeds is related to the mass of the seedling


What question can you ask now?
Relate your question to what you have learned about seed germination in terms of
a) Digestive activity / relationship to food tests
and / or
b) Mass of seedlings as germination progresses
and /or
c) Digestive activity in monocots

Appendix 6.2 – Micro-evaluation FTEAs with Accompanying Resources

Appendix 6.2.1: Heart Dissection FTEA with Resources

Framework for Heart Dissection

Observation / data / research

Observe the position of the heart in relation to the lungs

↓

Diagnostic experiment

Dissection of heart and lungs (Teacher demonstration followed by student dissection) | Skill: Dissecting

↓

Observation

Students observe the structure of the heart

↓

Principle

Students relate the structure of the heart to its function

↓

Inference - what can we use this information for?

students relate the structure and function of the heart to the equation for respiration

↓

Working hypothesis

Research: Equation for respiration | Reasoning: Students investigate the relationship between the circulatory system and the respiratory system

↓

Applied experiment

Design an experiment to investigate the relationship between the breathing rate and the heart rate.

↓

Observation

Collect data on the relationship between the two systems and present it in a meaningful way

↓

Conclusion - next steps

Confirm or refute the working hypothesis | Use as a springboard for respiration experiment

Framework for Planning Practical Work

Title of Experiment:

1. **Dissection and display of a sheep's heart.**
2. **Investigation of the effect of exercise on breathing/pulse rate**

<table>
<tr><td><u>Context</u>
Procedural

Informational</td><td>
Dissection of a sheep's heart to display the main features
Measurement of heart rate and breathing rate

Students need some understanding of
The structure of the heart
The double closed circuit of the circulatory system
Some background knowledge of the digestive and respiratory systems
The relationship between the pulse and the heartbeat
respiration
Students are asked to develop a hypotheses and conduct an experiment based on what they learn in class</td></tr>
<tr><td><u>Preparation for Experiment</u></td><td>Worksheets and diagrams photocopied and laminated(Appendix1)
Set up equipment
Whiteboards – class set</td></tr>
<tr><td><u>Laboratory skill attainment</u></td><td>Teacher: Learning how to dissect the heart
Student: learning how to dissect the heart</td></tr>
<tr><td><u>Risk assessment</u></td><td>Risk assessment carried out by teacher beforehand and sheet filled in and signed – Appendix 4</td></tr>
<tr><td><u>List of equipment needed</u></td><td><u>For the dissection (per student)</u>
Scalpel
4 Probes / straws / pencils – labelled with names of 4 main bloodvessels
Dissecting tray
Diagrams - one of the heart structure; one of the double circuit
Worksheet
Whiteboards
Phone for pictures

<u>For the heart / breathing rate</u>
Stopwatch
Graph paper/ whiteboard</td></tr>
<tr><td><u>Procedural teaching methodology</u>
Induction</td><td>

Teacher:
Hand out questions prior to the lab for students to think about
Show students how to do the heart dissection by doing a demonstration
Student:</td></tr>
</table>

"The leap" **Deduction**	1. Conduct own heart dissection using the diagrams and the dissection equipment. 2. Take photos of the different stages Teacher: Return to initial questions and answer them as a class. Discussion about bloodflow in the heart/ double circuit / lub-dub sound etc. Students make the connection between the function of the heart and respiration – *(use the worksheet)* Students design an experiment to investigate the relationship between heart rate and breathing rate
Data collection **Induction and Deduction**	Photographic story of heart dissection – items on checklist to be documented Worksheet completed including drawing of dissected heart Pulse rate and breathing rate data collected
Data presentation and analysis **Induction** **Deduction**	First experiment: Photostory of heart dissection. Paragraph/ poster on how blood circulates around the body Second experiment: Students will record the results in a graph/ bar chart and report on whether the result is in agreement with their original hypothesis.
Data presentation **Deduction**	Students create a write up under the following headings: Title Hypothesis Procedure Data Collected Data presentation Analysis of data Conclusion
Real World Application/ Extension **Deduction**	Students observe heart dissection and then conducted their own dissection to learn the skill. Students are asked to relate the structure of the heart to the circulatory / respiratory systems using diagrams After doing the dissection, students design their own experiment to understand the relationship between respiration (demand for oxygen) heart rate and breathing rate
Evaluation	Teacher evaluates the lesson under the following headings: What worked – what aspects of the lesson did students understand What needs improvement- where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge What will I do differently next time Teacher evaluates the learning by examining the student report or poster (give it a grade???)
LC exam	See attached Appendix 2 for copies of these questions

questions relating to Heart Dissection	

Heart Dissection Worksheet

Before the heart dissection – think about these while looking at your diagrams:

1. How is the blood kept flowing one direction in the heart?
2. Why are there 2 sides to the heart?
3. Why is one side of the heart thicker than the other?
4. What makes the characteristic lub-dub sound of the heart beat?
5. The heart is a muscle and needs its own supply of oxygenated blood – how does it get that?
6. How do you think a heart attack occurs?

After the heart dissection – revisit and discuss the answers to the questions above

What differences did you see between the diagrams of the heart and the real heart?

Describe how blood flows around the heart – where does it enter/exit; what structures does it flow through

Describe how to find the coronary artery

Draw a diagram of the heart and include 4 chambers/ 4 main blood vessels / valves / 2 other labels

AEROBIC CELLULAR RESPIRATION

$C_6H_{12}O + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP$

Glucose Oxygen → Carbon Dioxide Water Energy

1. Can you relate what you learned about the function of the heart today to respiration? What is the relationship?

2. Where does respiration occur?

3. How many systems of the body are involved in respiration?

4. What is the role of each system you mentioned in respiration?

5. Identify a situation where you may need extra energy, and therefore extra oxygen.

6. What happens to your heart rate during a situation where you need extra energy/oxygen? What happens to your breathing rate?

7. How can you measure a) heart rate b) breathing rate?

8. Design an experiment / activity that shows the relationship between heart rate and breathing rate:

   Make sure to think about the following –

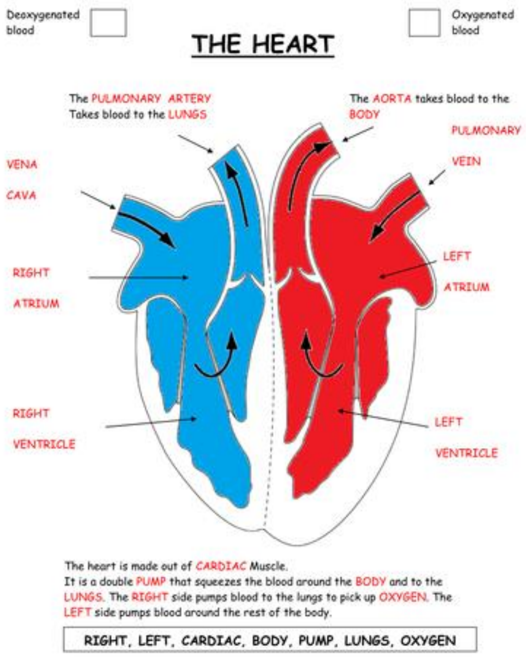
a. What is your hypothesis

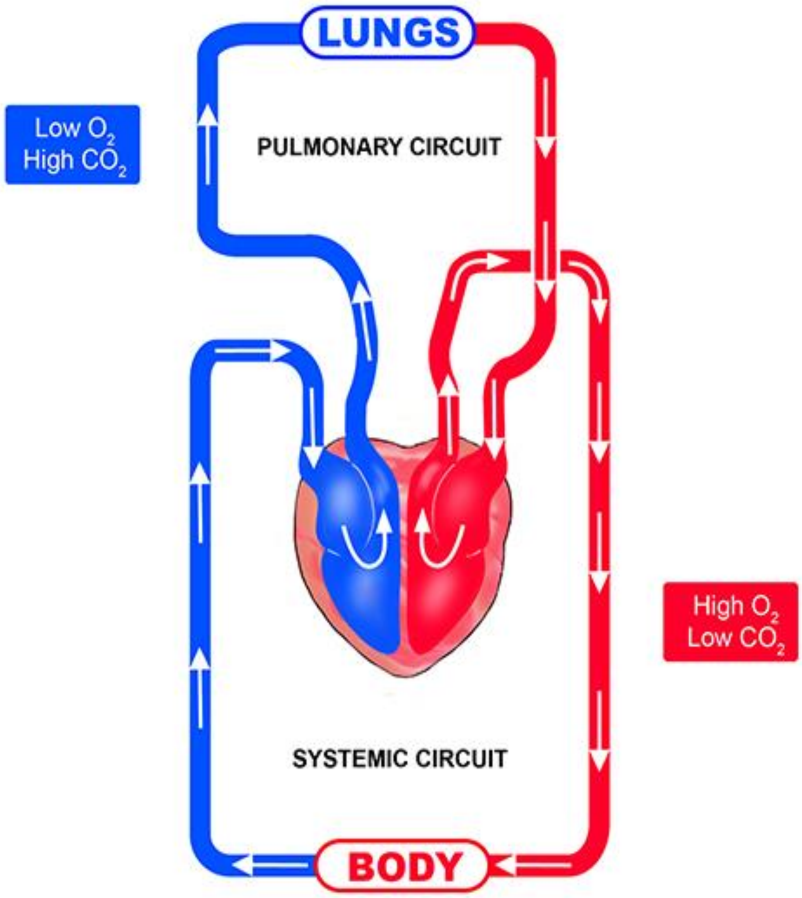
b. What will your control be?

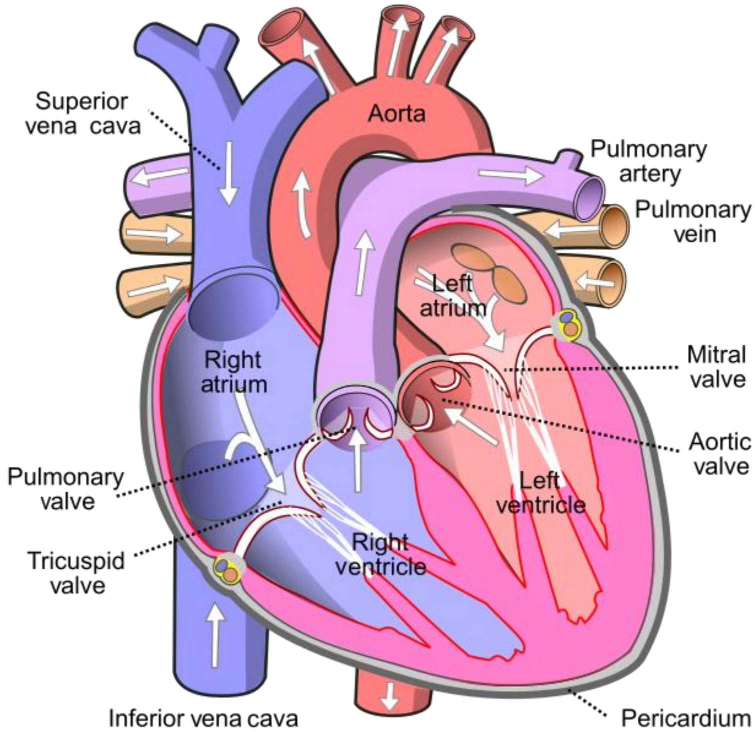
c. How will you measure the RATE of the heart / breathing?

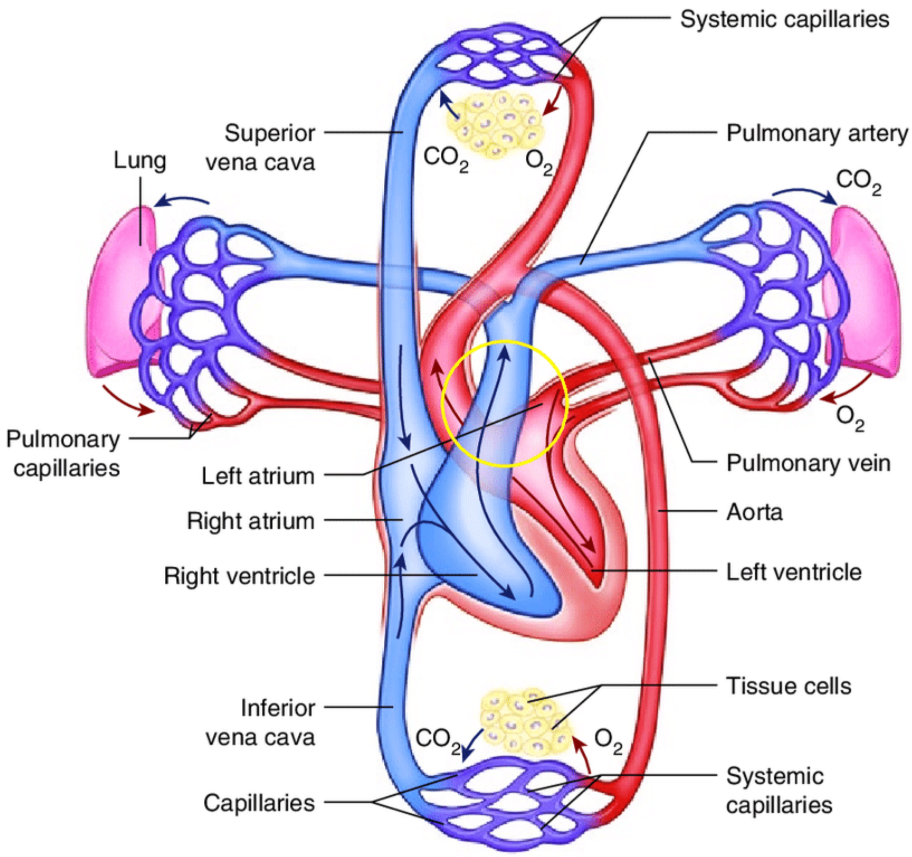
d. How will you collect data?

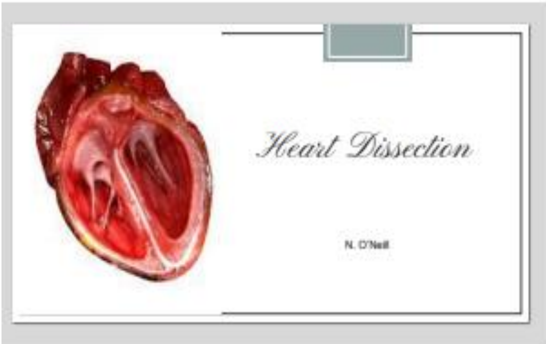
e. How will you present your data?

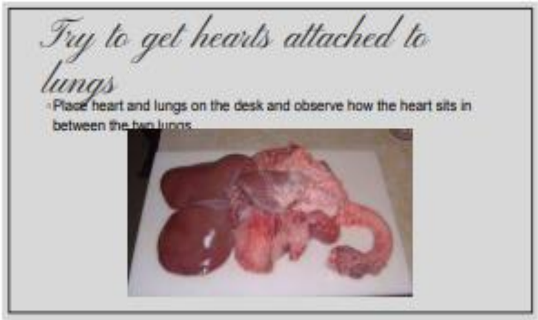

Deoxygenated blood
Oxygenated blood
THE HEART
The PULMONARY ARTERY Takes blood to the LUNGS
The AORTA takes blood to the BODY
PULMONARY VEIN
VENA CAVA
RIGHT ATRIUM
LEFT ATRIUM
RIGHT VENTRICLE
LEFT VENTRICLE
The heart is made out of CARDIAC Muscle.
It is a double PUMP that squeezes the blood around the BODY and to the LUNGS. The RIGHT side pumps blood to the lungs to pick up OXYGEN. The LEFT side pumps blood around the rest of the body.
RIGHT, LEFT, CARDIAC, BODY, PUMP, LUNGS, OXYGEN

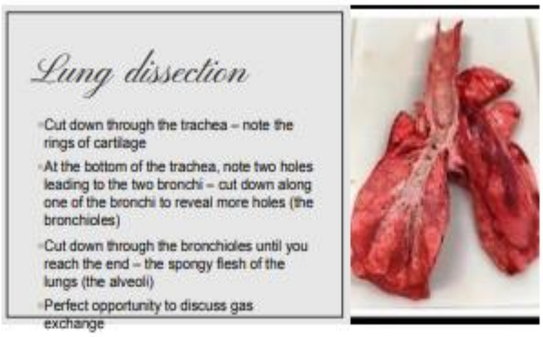

LUNGS
Low O_2 High CO_2
PULMONARY CIRCUIT
High O_2 Low CO_2
SYSTEMIC CIRCUIT
BODY

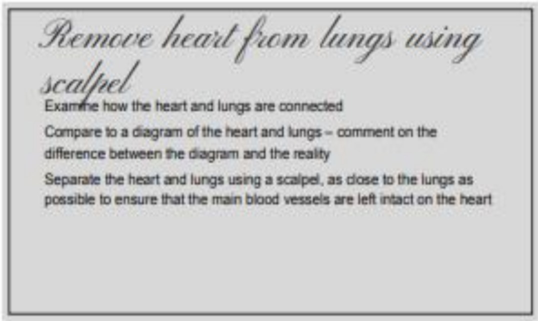

Superior vena cava
Aorta
Pulmonary artery
Pulmonary vein
Left atrium
Right atrium
Mitral valve
Aortic valve
Pulmonary valve
Left ventricle
Right ventricle
Tricuspid valve
Inferior vena cava
Pericardium


Systemic capillaries
Superior vena cava
Lung
CO_2
O_2
Pulmonary artery
CO_2
O_2
Pulmonary capillaries
Left atrium
Pulmonary vein
Right atrium
Aorta
Right ventricle
Left ventricle
Tissue cells
Inferior vena cava
CO_2
O_2
Systemic capillaries
Capillaries


Heart Dissection
N. O'Neill

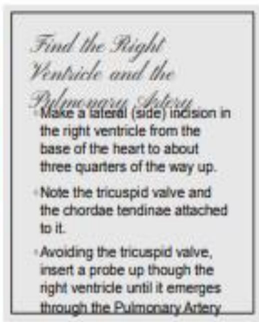

Try to get hearts attached to lungs
Place heart and lungs on the desk and observe how the heart sits in between the two lungs

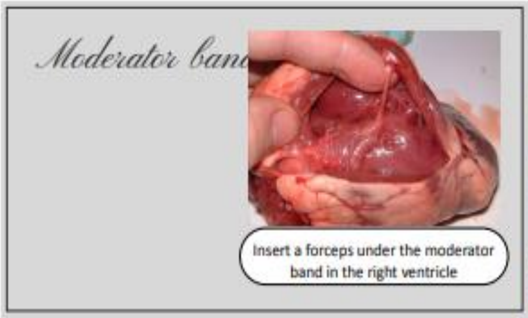

Lung dissection
Cut down through the trachea – note the rings of cartilage
At the bottom of the trachea, note two holes leading to the two bronchi – cut down along one of the bronchi to reveal more holes (the bronchioles)
Cut down through the bronchioles until you reach the end – the spongy flesh of the lungs (the alveoli)
Perfect opportunity to discuss gas exchange


Remove heart from lungs using scalpel
Examine how the heart and lungs are connected
Compare to a diagram of the heart and lungs – comment on the difference between the diagram and the reality
Separate the heart and lungs using a scalpel, as close to the lungs as possible to ensure that the main blood vessels are left intact on the heart

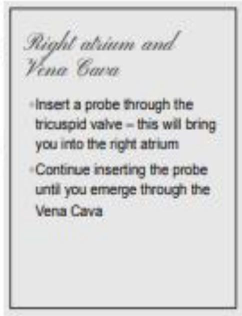

Coronary Vessel


Place heart on dissecting board face up
Once the heart has been removed place it face up (coronary artery visible)
If unsure – pinch both sides of the heart – right side is thinner than left

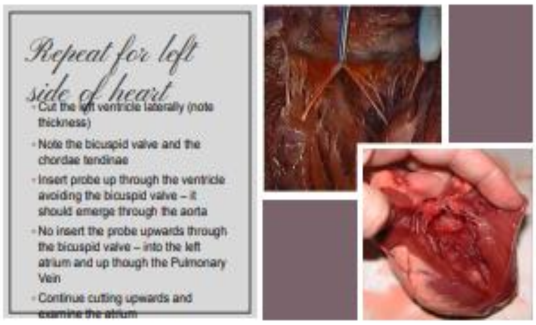

Find the Right Ventricle and the Pulmonary Artery
Make a lateral (side) incision in the right ventricle from the base of the heart to about three quarters of the way up.
Note the tricuspid valve and the chordae tendinae attached to it.
Avoiding the tricuspid valve, insert a probe up though the right ventricle until it emerges through the Pulmonary Artery

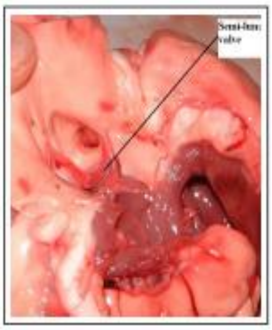

Moderator band
Insert a forceps under the moderator band in the right ventricle

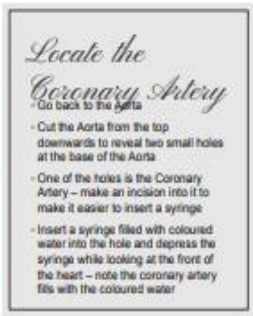

pulmonary trunk
vena cava


Right atrium and Vena Cava
Insert a probe through the tricuspid valve – this will bring you into the right atrium
Continue inserting the probe until you emerge through the Vena Cava


Checklist – right side of heart
Right ventricle
Pulmonary artery
Tricuspid valve
Chordae tendinae
Moderator band
Right Atrium
Vena Cava
Septum
Pericardium
Note – thickness of heart


Repeat for left side of heart
Cut the left ventricle laterally (note thickness)
Note the bicuspid valve and the chordae tendinae
Insert probe up through the ventricle avoiding the bicuspid valve – it should emerge through the aorta
No insert the probe upwards through the bicuspid valve – into the left atrium and up though the Pulmonary Vein
Continue cutting upwards and examine the atrium




Locate the Coronary Artery
Go back to the Aorta
Cut the Aorta from the top downwards to reveal two small holes at the base of the Aorta
One of the holes is the Coronary Artery – make an incision into it to make it easier to insert a syringe
Insert a syringe filled with coloured water into the hole and depress the syringe while looking at the front of the heart – note the coronary artery fills with the coloured water


FINALLY -
Open up the heart completely by cutting up along the septum to reveal the two sides of the heart

Appendix 6.2.2 – Microscopy FTEA by Pete and Rose

Observation / Data / Reserach

Microscopy as an important instrument for examining what cannot be seen with the naked eye

↓

Diagnostic experiment

Prepare and examine onion cells under the microscope	Skill: Using the microscope

↓

Observation

The structure of onion cells (cell membrane, cell wall, nucleus, cytoplasm)

↓

Principle

Connect to osmosis: Examine effect of salt on onion cells

↓

Inference: What can we use this information for?

Onion cell structure can be seen with the microscope

↓

Working hypothesis

Research - students learn about how osmosis occurs	Reasoning: Students ask a question based on lesson on osmosis

↓

Applied experiment

Students design an experiment to investigate osmosis in onion cells

↓

Observation

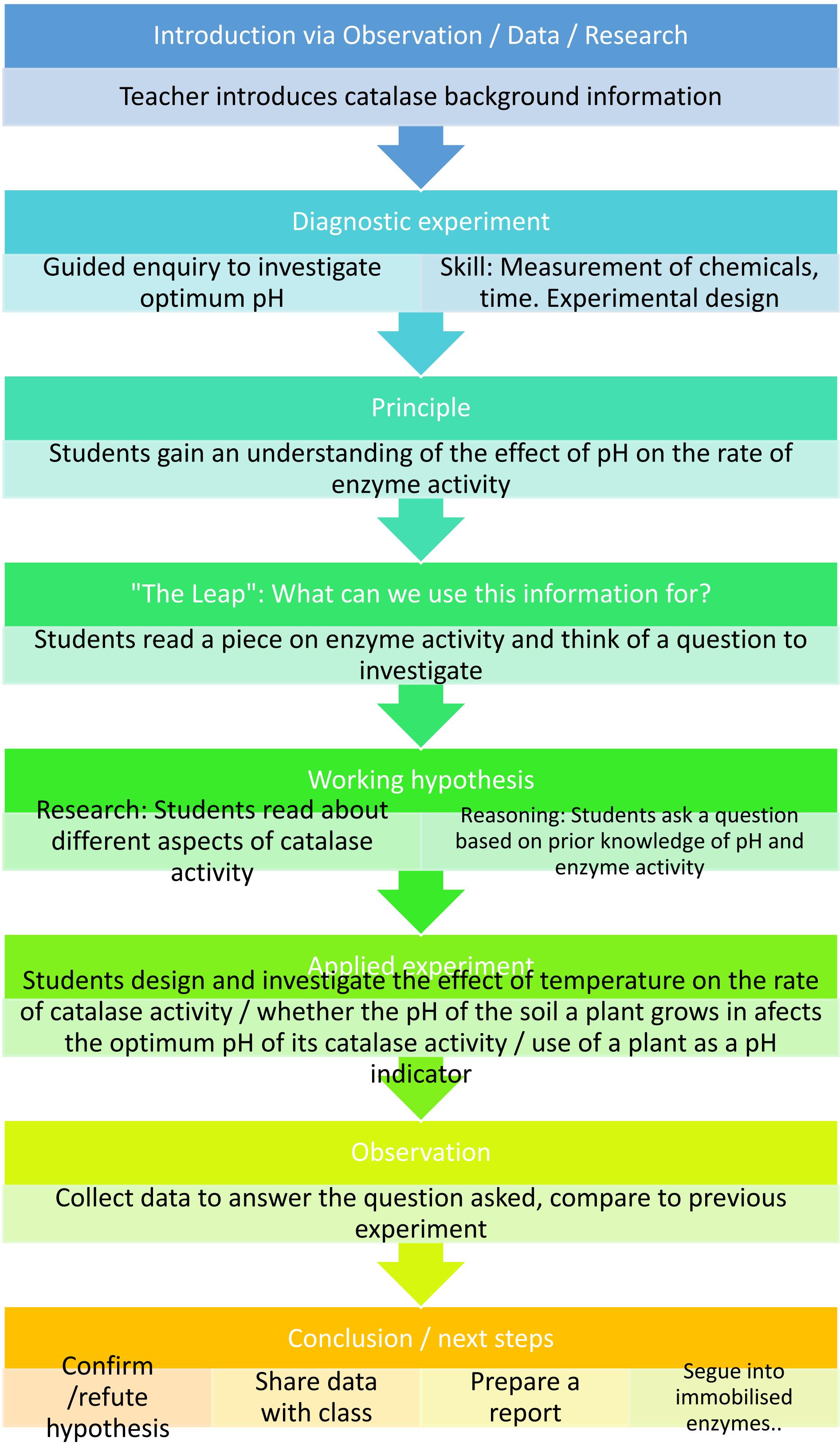
Students see the effect salt has on onion cells

↓

Conclusion / next steps

Confirm /refute hypothesis	Share findings with the class

Appendix 6.2.3 – Enzyme FTEA with Accompanying Resources



Framework for Planning Practical Work

Title of Experiment: To investigate the effect of pH on the rate of enzyme activity

Context **Procedural** **Informational**	 Design and conduct an guided enquiry experiment to investigate the effect of pH on enzyme activity Students need some understanding of • The nature of enzymes • How enzymes interact with substrates • The importance of the shape of an enzyme
Preparation for Experiment	• Gather equipment and prepare extracts of vegetables / liver • Photocopy worksheet
Laboratory skill attainment	Teacher: Preparation of extracts of different vegetables Student: Preparation of extracts of vegetables Measurement skills, • Using a measuring cylinder to measure liquids • Measuring time • Use of syringe • Graphing data collected
Risk assessment	Risk assessment carried out by teacher beforehand and sheet filled in and signed – *Appendix 4*
List of equipment needed	Measuring cylinders 100ml, 200ml, 500ml Beakers containing buffer of varying pHs Beakers containing hydrogen peroxide Washing up liquid Droppers Labels Extract of celery and other vegetables required Liver (if using) Access to timer Marker Sieve Beakers
Procedural teaching methodology **Induction**	Teacher: 1. Guide students through the initial experiment using the powerpoint (Appendix1) Student: 1. Set up and conduct experiment with guidance from teacher. Make note of any observations

"The leap" **Deduction**	Reading material about catalase (Appendix 2). Students read the piece and ask a question based on what they have read. Students design and conduct an experiment to answer the question they are asking – not all students need to ask the same question
<u>Data collection</u> **Induction and Deduction**	Induction: Students investigate optimum pH for enzyme activity and collect data accordingly Deduction: Students collect data from their own question
<u>Data presentation and analysis</u> **Induction** **Deduction**	First experiment: Students fill in worksheet. Class comparison and discussion Second experiment: Students present the results of their own experiment in a manner that they choose in an oral format
<u>Data reporting</u> **Deduction**	Students create a comparative write up of the entire investigation
<u>Real World Application/ Extension</u> **Deduction**	Students use the knowledge they gain from the first experiment to investigate a second aspect of enzyme activity
<u>Evaluation</u>	Teacher evaluates the lesson under the following headings: <u>What worked</u> – what aspects of the lesson did students understand <u>What needs improvement-</u> where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge <u>What will I do differently next time</u> Teacher evaluates the learning by examining the student report or poster (give it a grade???)
LC exam questions relating to practical ecology	See attached Appendix 3 for copies of these questions

INVESTIGATING THE EFFECT OF pH ON THE RATE OF CATALASE ACTIVITY

$$2H_2O_2 \xrightarrow{\text{Catalase}} 2H_2O + O_2$$

Hydrogen peroxide → Water + Oxygen

Principle behind the experiment:

- Catalase is an enzyme that is found in all living cells.
- Catalase catalyses the breakdown of hydrogen peroxide into water and oxygen (hydrogen peroxide is toxic to cells).
- Catalase is one of the fastest reacting enzymes known.
- If a detergent (e.g. washing up liquid) is included in this reaction, the oxygen produced in the reaction will cause the detergent to foam.
- The amount of foam produced can be used as an indicator of enzyme activity (amount of foam produced is proportional to the amount of oxygen produced it the reaction) and can be measured.
- The rate of enzyme activity can be recorded by measuring the amount of foam produced PER MINUTE under particular conditions.
- Several conditions can affect the rate of reaction of an enzyme such as temperature, enzyme concentration, concentration of reactant(s) and pH.
- The pH of a reaction can be varied by using different pH buffering solutions in the reactions.

In this experiment you will investigate how changing the pH of a reaction affects the rate of enzyme (catalase) activity. You will use celery as an enzyme source.

To change the pH of a reaction you change the BUFFER SOLUTION used in the reaction. A buffer solution is made to a specific pH and when it is added to an enzyme reaction it keeps the pH stable. For example using a buffer with a pH of 3 will maintain the enzyme reaction at pH 3.

Things to think about before you start the experiment:

- What are you investigating in this experiment?
- What is the independent variable in this experiment?
- What is the dependent variable in this experiment?
- What factors should be kept constant in this experiment?

How are you going to set up this experiment?

- How many different pHs will be tested?
- How many measuring cylinders will be needed?
- What FOUR things need to go into each measuring cylinder for the enzyme reaction to proceed and to be measurable?
- Will you include a control in this experiment?
- What could you use for a control?
- What TWO measurements should you take for EACH reaction you perform?
- How can you make sure that each measurement you take is a fair measurement?
- Draw a diagram to represent your experimental plan.
- Draw a table in which to record your experimental results.
- How are you going to measure the RATE of enzyme activity?

How will you present the results of this experiment?

- Present the results of your experiment on a graph.
- What is an appropriate title for this graph?
- How will you label the X-axis?
- How will you label the Y-axis?
- How will you add the data on this graph?

How will you interpret the results of this experiment?

- At what pH is the rate of reaction of catalase at its maximum in this experiment?

- The pH where the rate if reaction of an enzyme is at its highest is called the________________________ pH for the enzyme.

Applications of principle:

1) Vegetable crop soil pH tolerances

Vegetables and other plants grow best when the soil pH is optimal for the plants being grown. It is important to match a plant to the soil pH or to adjust the soil pH to a plant's needs.

Most plants grow between the pH range of 4.5 to 8.0; a soil pH of 5.0 has a high acid content; a soil pH of 7.5 has a high alkaline content; a soil pH of 7.0 is neutral. A soil pH test will determine a soil's pH.

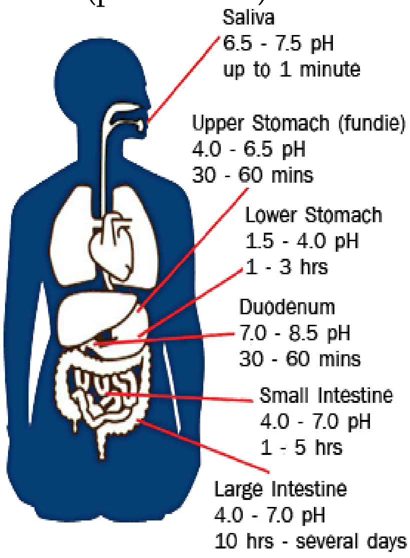
Soil pH is important because a soil's acidity or alkalinity determines what plant nutrients are available to plant roots. Nutrients in the soil—elements such as nitrogen, phosphorus, and potassium—become available to plants when they dissolve in water or soil moisture. Most plant nutrients will not dissolve when the soil is either too acidic or too alkaline. However, does soil pH affect optimum pH for enzyme activity WITHIN the plants?

The table below presents some well known crop plants that can tolerate acid soils (pH 4-5.5), moderately alkaline soils (pH 6-7 or greater) or are tolerant of a wide range of soil acidity or alkalinity, from about 5.0 to 7.0.

Acid Soil Crops	Moderately Alkaline Soil Crops	pH Tolerant Plants
Blueberry	Chinese cabbage	Strawberries
Potato	Celery	Tomatoes
Blackberry	Asparagus	Turnip

2) Human digestion

The pH in the human digestive tract varies greatly (see diagram to the right). The pH of saliva is usually between 6.5 – 7.5. After we chew and swallow food it then enters the fundic or upper portion of the stomach which has a pH between 4.0 – 6.5. This is where "predigestion" occurs while the lower portion of the stomach secretes hydrochloric acid (HCI) until it reaches a pH between 1.5 – 4.0. After the food mixes leaves the stomach it then enters the duodenum (small intestine) where the pH changes to 7.0 – 8.5. This is where 90% of the absorption of nutrients is taken in by the body while the waste products are passed out through the colon (pH 4.0 – 7.0).



This diagram illustrates the average time food spends in each part of the digestive system along with the average pH.

In the table below indicate the main digestive enzyme that's found in the mouth, the lower stomach and the small intestine. Also indicate the substrates and the products for these enzymes. What would you predict the optimal pH to be for these three digestive enzymes to be?

Human digestive enzymes:				
	Main enzyme	Substrate	Product	Optimum pH
Mouth				
Lower stomach				
Small intestine				

3) Plants as pH indicators

The natural world has given us numerous plants, from beets to grapes to onions, that can be used to test the pH levels of a solution. These plants have a natural pH indicator – the pigment anthocyanin. Anthocyanins are one of the largest and most important group of water-soluble pigments in most species in the plant kingdom. They are accumulated in cell vacuoles and are largely responsible for diverse pigmentation from orange to red, purple and blue in flowers, fruits, such as: blackberry, red and black raspberries, blueberries, and cherries.Some of the colours of autumn leaves are derived from anthocyanins.Anthocyanins may be used as pH indicators because their colour changes with pH (see table below for plants with high levels of anthocyanins). Anthocyanins are NOT enzymes, but anthocyanins can be used in enzymatic reactions as pH indicators.

Plant species with high levels of anthocyanins:

Blackberries	Blackberries, black currants, and black raspberries change from red in an acidic environment to blue or violet in a basic environment.
Blueberries	Blueberries are blue around pH 2.8-3.2, but turn red as the solution becomes even more acidic.
Grapes	Red and purple grapes contain multiple anthocyanins. Blue grapes contain a monoglucoside of malvidin, which changes from deep red in an acidic solution to violet in a basic solution.
Onions	Red onion also changes from pale red in an acidic solution to green in a basic solution.
Cherries	Cherries and their juice are red in an acidic solution, but they turn blue to purple in a basic solution.
Red cabbage	The pigment turns **red** in acidic environments with a **pH** less than 7 and the pigment turns bluish-green in alkaline (basic)

	environments with a **pH** greater than 7

Next step:

After reading the sections above and from the materials your teacher has supplied, what is the question you would like to investigate?

How are you going to investigate this question? Draw a diagram if you wish.

What is your hypothesis before you start your investigation?

Tips for teachers

<u>To extract the enzyme:</u>
100ml water
100g enzyme source
Blend into liquid form and sieve.
Use the filtrate.

Use **10ml of enzyme**

Use 20%v/v hydrogen peroxide – you may need to order this in for this experiment. One of the reasons why the experiment may not work is because the peroxide is not concentrated enough.
Start with **4mlof peroxide**– if it overflows in the measuring cylinder use half this amount

You can buy buffer tablets and just dissolve them in water as per the instructions – use **20ml of buffer.**

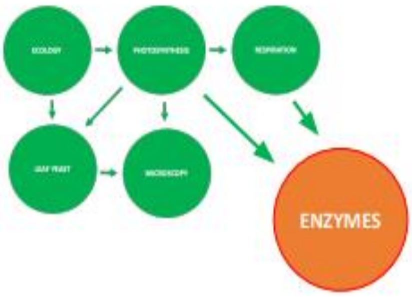
Use **2 drops of washing up liquid**.

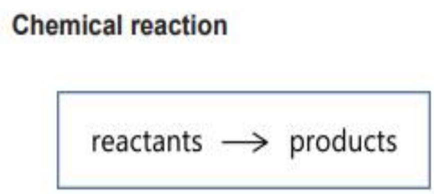
<u>Effect of pH on the rate of enzyme activity</u>
Using a vegetable that acts as a natural indicator can enhance the visual difference between different pHs.
Suitable vegetables; radish, red cabbage

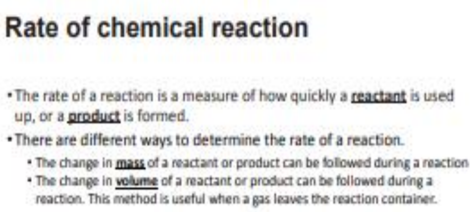
<u>Effect of temperature on enzyme activity</u>
It is very important to have all of the chemicals at the correct temperature in order to examine the effect of temperature on the rate of enzyme activity
E.g if you choose zero degrees then the enzyme, buffer, peroxide and washing up liquid should all be brought to this temperature before they are mixed.

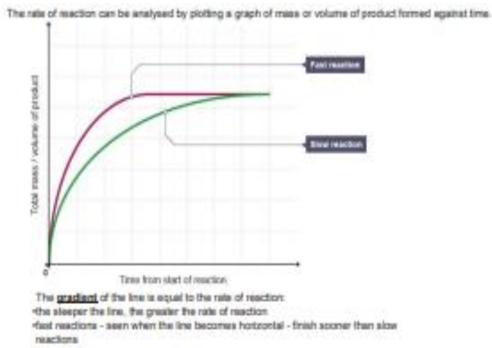
<u>Use of liver</u>
Lamb's liver contains much more catalase than celery and can have quite a dramatic production of bubbles of oxygen – great for the elephant's toothpaste experiment.

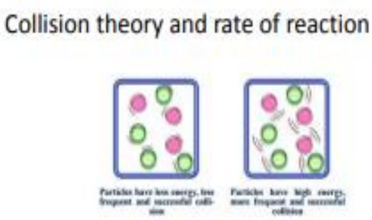
Powerpoint Presentation

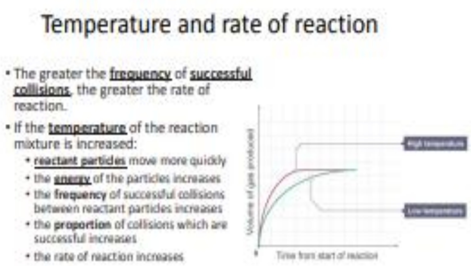












Chemical reactions that take place inside living things are called **biochemical reactions.** The sum of all the biochemical reactions in an organism is referred to as **metabolism**

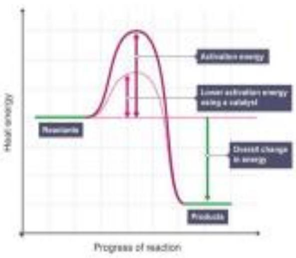
Most biochemical reactions in organisms need help in order to take place

- Temperatures are usually too low inside living things for biochemical reactions to occur quickly enough to maintain life
- The concentrations of reactants may also be too low for them to come together and react.
- Biochemical reaction times: several days – several centuries
- Biochemical reactions need help to proceed at a life sustaining rate
- The help comes from enzymes.

Enzymes

- Are specific organic molecules found in biological systems that allow cellular life to exist and function on earth –e.g. earth temperatures.
- Most life-supporting chemical reactions could only occur above 90°C or 200°F in the absence of enzymes.
- Enzymes are referred to as macromolecular biological catalysts.
- They allow chemical reactions to occur that would otherwise not occur because of conditions such as temperature and pH within cells.
- Metabolic processes within cells require enzyme catalysts in order to occur at rates fast enough to support life.

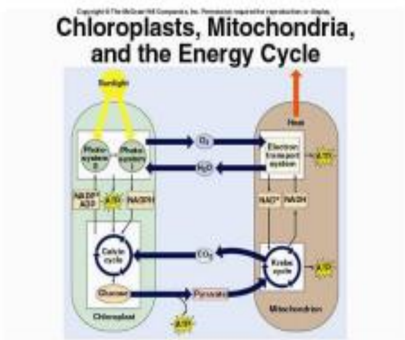
Enzymes are biological catalysts

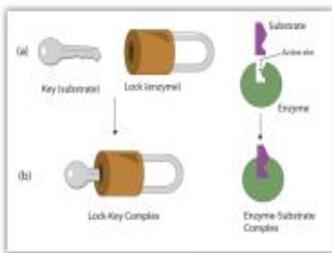


A catalyst provides an alternative **reaction pathway** that has a lower **activation energy** than the un-catalysed reaction.

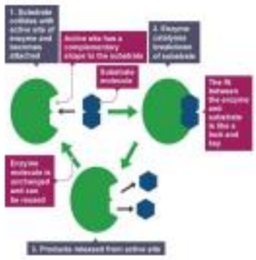
This does not change the frequency of collisions.

However, it does increase the frequency of successful collisions because more particles have energy greater than the activation energy, therefore there are more successful collisions.





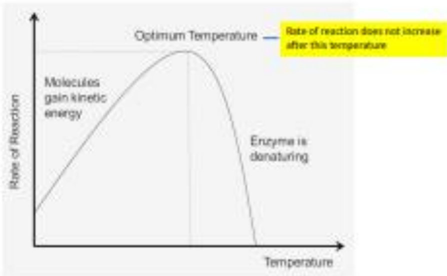
The breakdown of a substrate molecule by an enzyme.

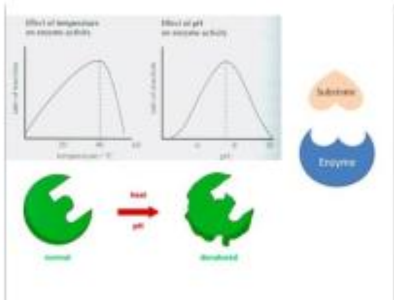


Other enzymes join smaller substrate molecules together into larger ones

Factors that can affect the rate of reactions catalyzed by enzymes:

- Temperature
- pH
- Concentration of reactants





Rate of an enzyme reaction

- The rate of a reaction is a measure of how quickly a **reactant** is used up, or a **product** is formed.
- There are different ways to determine the rate of a reaction.
  - The change in **mass** of a reactant or product can be followed during a reaction
  - The change in **volume** of a reactant or product can be followed during a reaction. This method is useful when a gas leaves the reaction container.

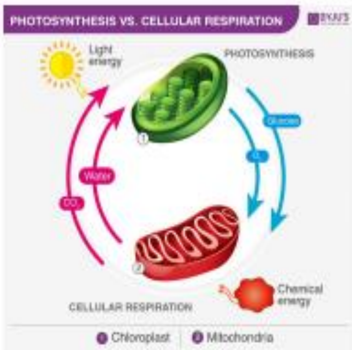
Rate of catalase activity

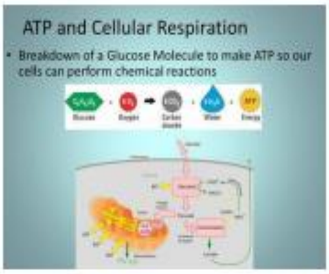
$$2H_2O_2 \xrightarrow{\text{Catalase}} 2H_2O + O_2$$

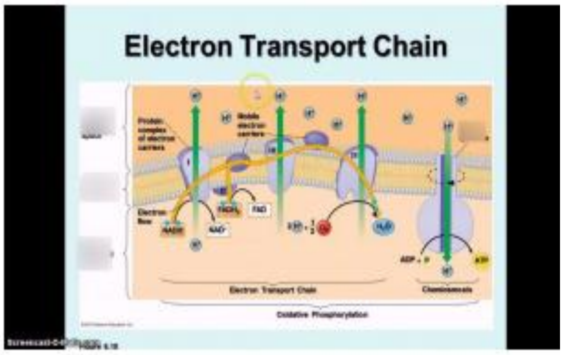
Hydrogen peroxide → Water + Oxygen

Catalase

- It's found in all aerobic organisms –> many potential sources of this enzyme
- It's involved in preventing the accumulation of free radicals in cells.
- A **free radical** is any molecular species capable of independent existence that contains an unpaired electron in an atomic orbital.
- Many free radicals are unstable and highly reactive.

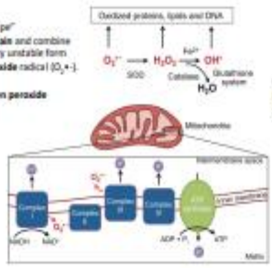






Some **electrons** can "escape" the **electron transport chain** and combine with oxygen to form a very unstable form of oxygen called a **superoxide** radical (O_2•-).

The formation of **hydrogen peroxide** in **cells** is an attempt to protect itself from superoxide.



Catalase decomposes **hydrogen peroxide** before it can form hydroxyl radicals.

Good/easy sources of catalase:

- Liver
- Yeast
- Many vegetables – celery, cabbage, onions, asparagus, potatoes, sweet potatoes
- Many unripe fruits – green tomatoes

Appendix 7.1 Reading list for PBTM

Book: Experience and Education by John Dewey
2 hard copies in the library or it can be found online at the address below
http://www.schoolofeducators.com/wp-content/uploads/2011/12/EXPERIENCE-EDUCATION-JOHN-DEWEY.pdf

Does **practical work** really **work**? A study of the effectiveness of **practical work** as a teaching and learning method in school science

This is a journal article and can be found with google scholar. When you click the pdf icon to the right of the title of the article, you should be able to download the whole article.
The reference is below
Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International journal of science education*, *30*(14), 1945-1969.

Does **practical work** really motivate? A study of the affective value of **practical work** in secondary school science

You should be able to find this through the Maynooth library online
Abrahams, I. (2009). Does practical work really motivate? A study of the affective value of practical work in secondary school science. *International journal of science education*, *31*(17), 2335-2353.

The **professional knowledge base** and practice of Irish post-primary teachers: what is the research evidence telling us?

Gleeson, J. (2012). The professional knowledge base and practice of Irish post-primary teachers: what is the research evidence telling us?. *Irish Educational Studies*, *31*(1), 1-17.

The BSCS **5E** instructional model: Personal reflections and contemporary implications

This is an article about enquiry based teaching by Roger Bybee
https://newscenter.sdsu.edu/education/projectcore/files/05329-5E_instructional_Model_R_Bybee.pdf
Bybee, R. W. (2014). The BSCS 5E instructional model: Personal reflections and contemporary implications. *Science and Children*, *51*(8), 10-13.

Phases of **inquiry-based learning**: Definitions and the **inquiry** cycle
https://www.sciencedirect.com/science/article/pii/S1747938X15000068
Pedaste, M., Mäeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A., Kamp, E. T., ... &Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational research review*, *14*, 47-61.

The many levels of inquiry

Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science and children*, *46*(2), 26.

Biology by **inquiry** an invervention **programme** in **Irish post** primay **schools**

Read chapter 2
Ryan, E. (2011). Biology by inquiry an intervention programme in Irish post primary schools.

Appendix 7.2 – PST PBTM Surveys
Appendix 7.2.1 PST Pre- Module Surveys

ID	1	2	3	4	5
Start time	9/25/20 11:58:13	9/25/20 12:12:52	9/25/20 12:02:48	9/25/20 12:08:56	9/25/20 13:09:52
Completion time	9/25/20 12:08:05	9/25/20 12:16:12	9/25/20 12:23:03	9/25/20 12:23:07	9/25/20 13:21:37
During LC practical work students learned to follow instructions step by step	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher
During LC practical work students learned new laboratory skills e.g. aseptic technique, preparation of solutions, measurement skills	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher
During LC practical work the students learned to make accurate observations e.g. when using measuring equipment	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher
During LC practical work students observed experimental phenomena i.e saw what was meant to happen	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	My teacher mostly completed this part with some input from students	Students completed this part with a little assistance form the teacher	
During LC practical work students were encouraged to ask a question and to formulate a hypothesis	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	My teacher usually did this part without input from students	Students completed this part with a little assistance form the teacher	My teacher mostly completed this part with some input from students

regarding the answer to this question.					
During LC practical work students collected data	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher
During LC practical work students recorded data appropriately e.g. in table form, diagrams, photos etc.	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher
During LC practical work students analysed collected data in order to draw conclusions	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher
During LC practical work students presented the findings of experiments in graph form or otherwise	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher
During LC practical work students applied experimental findings to new experiments	Never	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher
During LC practical work students wrote an experimental report	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher
During LC practical work students got to design their own experiment	Never	My teacher mostly completed this part with some input from students	Never	Never	My teacher mostly completed this part with some input from students

Please sum up your experience of LC practical work in secondary school here:	My experience was pleasant. The class was always encouraged to carry out the experiment and follow the instructions by them selves and use problem solving skills. If there was any trouble it was mostly because maybe the results weren't what you expected and the teacher assisted a lot of students when it came to analysing and concluding a lab report	Good, but it was not hands on or emphasised enough in order for it to be useful in later years of science study	engaging, independant work with HOT qs posed by the teacher.	my biology teacher was very helpful, making the experiments easy to understand. she was just enough helpful to also make us think on ouor own without giving away too much information about expected outcomes but rather asked us to explain them.	Students were told what the experiment entailed and were then left to their own devices to complete the experiment and write a lab report with help from the teacher if needed/wanted.
What are you hoping to learn by doing this BI317 module?	A good was to promote enquiry based learning in laboratories.	Efficient, practical and approachable methods to teach students so it does not seem over complicated for students to understand	how to teach in a hands-on matter / student inquiry based learning	how to effectively teach biology practicals so that the students get the most out of them.	The proper ways of teaching and guiding students during practicals
What, do you think, is the purpose of practical lessons or why do we teach practical work?	To put what the students are learning in theory into practice.	To supply students with an insight into a more practical side of biology and to apply lessons and aspects of information that has been previously learned to practical use	some students like myself learn by applying theory based classroom work to practicals in order to develop a better understanding of the concept being taught	to portray any concepts learned in theory, and for students to visualise the concepts so that they can understand and learn them	To give the students hands on experience to back up the information they are being taught in non-practical classes
Have you ever taught a practical lesson at junior or senior cycle level?	Yes	No	No	Yes	No
If you answered yes to the previous question, how did you find the experience?	The students are mush more willing to get involved in hands on activities.			interesting and enjoyable	

What factors do you think are important to consider from a teacher's perspective when planning and preparing a Leaving Certificate practical lesson?	Safety of the students comes first always. The teacher must be aware of what supplies are on offer in the lab. Providing clear instructions is important. This allows students to work and figure out things for themselves with some assistance if needed.	That there is not too much information being given and too many tasks to undertake resulting in students rushing their work and some being incomplete	that the students have a certain amount of student led activity which may involve them making mistakes during their practical. learning from your errors is the best way to learn in my opinion	safety, fun, making sure to include any theory relating to the practical	How can I link this lesson to the theory we have covered, and how can I show then why such a thing happens in an experiment
What factors do you think are important to consider when teaching a LC practical lesson (i.e. during the lesson itself)	Safety is a priority at all times in a lab. Timing is also important. Rushing experiments can cause them to be inaccurate and leave little time for student analysis.	That the material is engaging, easily understood and the tasks and goals are achievable for all students	small group work to 'think pair share' before the lesson. Groups should have no more than 3 people when carrying out the experiment. When I was in LC chemistry the groups were too large and often times I wouldn't get to take part in the whole practical. Safety is important	to use the experiment to portray the theory behind the experiment and make sure the students can explain their results	Safety, PPE, ensure the students are properly briefed, ensure they know why they are doing the experiment
What factors do you think are important to consider after a LC practical lesson is complete?	It's important that everything is disposed of correctly. It's important that the students understand what the experiment was about and why they got the results that they did.	That not all students may have fully understood the material at hand and what their main objective was	drawing conclusions. applications to everyday life if possible. disposal of waste etc . wash hands	that students understand the results and can easily explain the conclusion of the experiment	Safety, ensure they know why what happened in the experiment happened
How long do you think is appropriate to spend planning and preparing a practical lesson for LC biology?	As much time as you need. It's important to have all the steps correct.	A full days work	Depends on the practical and how many different aspects there are to it. Anything from 1-5 hrs	approx 45 mins	depends on the practical lesson, but once they know the theory maybe one class of explaining what they should do
What do you understand by the term "enquiry based learning" as it applies to practical work?	Enquiry based learning is about letting the students be in charge of their own learning. Not spoon feeding all the information to them.	That you are learning through a hands on approach	Student led learning. learning from mistakes. forming a hypothesis and testing it	learning in an active way using many different methodologies rather than just a theoretical approach	You should be asking questions such as "why is this happening?" etc. during the practical to allow the students to learn for themselves

How much of your experience of practical work to date at second and third level has been "enquiry based"? (Give a percentage for each)	Second level not so much as the answers to everything was laid out in the text book. (20%) in third level I would say 75% was enquiry based learning and much more enjoyable.	Third level: 50% second level: 35%	50% LC. 80% third level	10 percent & 40 percent	not very much enquiry based, roughly 50/50

ID	6	7	8	9	10	11
Start time	9/25/20 13:15:11	9/25/20 13:55:16	9/25/20 15:56:42	9/25/20 16:42:30	9/25/20 18:52:30	9/25/20 21:01:09
Completion time	9/25/20 13:23:32	9/25/20 14:02:28	9/25/20 16:15:09	9/25/20 16:49:08	9/25/20 18:56:11	9/25/20 21:09:02
During LC practical work students learned to follow instructions step by step	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher
During LC practical work students learned new laboratory skills e.g. aseptic technique, preparation of solutions, measurement skills	Students completed this part with a little assistance form the teacher	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	My teacher mostly completed this part with some input from students	My teacher usually did this part without input from students
During LC practical work the students learned to make accurate observations e.g. when using measuring equipment	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Never	Students completed this part with some assistance from the teacher
During LC practical work students observed experimental phenomena i.e saw what was meant to happen	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher	My teacher mostly completed this part with some input from students	Students completed this part with a little assistance form the teacher	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher
During LC practical work students were encouraged to ask a question and to formulate a hypothesis regarding the answer to this question.	Students completed this part with a little assistance form the teacher	My teacher usually did this part without input from students	My teacher usually did this part without input from students	Students completed this part with a little assistance form the teacher	Never	Never
During LC practical work students collected data	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	My teacher usually did this part without input from students
During LC practical work students recorded data appropriately e.g.in table form, diagrams, photos etc.	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Most students completed this part with no	Students completed this part with some assistance	Students completed this part with some assistance

				assistance from the teacher	from the teacher	from the teacher
During LC practical work students analysed collected data in order to draw conclusions	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	My teacher mostly completed this part with some input from students	My teacher mostly completed this part with some input from students
During LC practical work students presented the findings of experiments in graph form or otherwise	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher
During LC practical work students applied experimental findings to new experiments	Students completed this part with some assistance from the teacher	Never	Never	Students completed this part with a little assistance form the teacher	My teacher mostly completed this part with some input from students	Never
During LC practical work students wrote an experimental report	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher
During LC practical work students got to design their own experiment	Never	Never	Never	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Never
Please sum up your experience of LC practical work in secondary school here:	I loved practical work as we were able to complete the experiments ourselves and the teacher would always ask questions and explain the experiment	Very focused on what the teacher wanted to get across. As students we were told what to do how to do it but never allowed explore outside the realms the experiment being completed. However what experiments were demonstrated and completed we fully understood	Wasnt very memorable as a very guided experience with little encouragement or incentive for students to make their own observations/ conclusions	Gained skills i was able to bring with me to college labs	overall enjoyable but didnt really give you a chance to explore, didint prepare for labs in college	We barely did any
What are you hoping to learn by doing this BI317 module?	How to collect and display findings	How to get the students to think outside the box and to apply what they've learned affectivly to other aspects	New ways to teach lab techniques to students and encourage scientific curiosity in students	New skills to bring with me to schools	methology for teaching	How to be the best teacher I can while also keeping students interested

What, do you think, is the purpose of practical lessons or why do we teach practical work?	So that the students can see for themselves how an experiments works which aids their understanding of the task	Theory doesn't necessarily drive home the information seeing it in person can really hone a students skill	To visualise the theory that has been taught, science is about seeing a theory for yourself and practical lessons allow the student to visualise and understand a theory as well as draw their own conclusions	To put theory into practice	give the student the opportunity to explore info learned	To see how biology works in the real world
Have you ever taught a practical lesson at junior or senior cycle level?	No	No	No	No	No	No
If you answered yes to the previous question, how did you find the experience?						
What factors do you think are important to consider from a teacher's perspective when planning and preparing a Leaving Certificate practical lesson?	How big the class is, behaviour of the class if they would be able to stay focused during a pratical class,	That's not all students have the same grasp of concepts so explain it from the basics and work up to the more complicated questions to keep students of all levels engaged in the experiment	Avoiding creating a lesson that does it all for the students, allowing them to be in control of their own experiments whilst still creating a lesson that manages the class appropriately. Also having a lesson plan that encourages students to question and further study the experiment they have carried out	Students prior knowledge on the topic	every student is catered for	To make sure students fully understand what they are doing and why and be ableTo ask questions/ relate it back to what they study
What factors do you think are important to consider when teaching a LC practical lesson (i.e. during the lesson itself)	Safety of the students, that the students stay focused, that they understand the task before completing the experiment and so they can complete their writeups with ease	Safety and understanding the correct use of equipment	It is important to remember that despite having to give the students the chance to do the experiment for themselves, safety is paramount so the teacher still has to be in control of the class and aware of all the students. Therefore careful grouping of students may be necessary and also not getting too distracted by one group of students. Its also important	Safety precautions	every student is catered for	That every student is involved and understands fully what we are doing

			to consider that science is about discovering new things so encouraging questioning and other theories to be discussed.			
What factors do you think are important to consider after a LC practical lesson is complete?	That students have enough information to be able to complete their write ups	That the student knows why they did each step in the experiment, that they can formulate a conclusion based on the results and that the expeirment itself has aided in the understanding of the topic	Discussing results and observations. If the experiment didnt have the expected results getting students to discuss why this may have been. Discussion is important and analysis and correct graphing of any data collected.	What the students were able to do and what needs work	students understand the reasons behind the results	Everyone understands what they did and carried out all safety procedures and are ableTo write it up
How long do you think is appropriate to spend planning and preparing a practical lesson for LC biology?	Depends on the experiment, maybe a double class	2 hours	I havent completed many lesson plans yet so I dont really have timing to compare to	An hour	30 mins	1 hour max
What do you understand by the term "enquiry based learning" as it applies to practical work?	Learning by asking questions	Asking a question and investigating it and it's results through experiments	Encouraging students to think for themselves about the practical and what they observed through careful questioning and encouragement to ask the teacher and peers research questions	Students applying their already existing knowledge to further their learning in a hands on experience	No	Learning while doing the work ourselves and asking questions about what is happening
How much of your experience of practical work to date at second and third level has been "enquiry based"? (Give a percentage for each)	30%	25%	For secondary 20%, third level 40%	80%	70%	Second level - 10% Third level - 30%

ID	12	13	14	15	16	17
Start time	9/26/20 1:01:38	9/26/20 10:55:12	9/26/20 16:04:36	9/27/20 12:55:07	9/27/20 18:32:08	9/27/20 19:55:02
Completion time	9/26/20 1:33:58	9/26/20 11:04:23	9/26/20 16:35:48	9/27/20 13:15:17	9/27/20 18:38:41	9/27/20 19:59:52
During LC practical work students learned to follow instructions step by step	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher
During LC practical work students learned new laboratory skills e.g. aseptic technique, preparation of solutions, measurement skills	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	My teacher usually did this part without input from students
During LC practical work the students learned to make accurate observations e.g. when using measuring equipment	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher	My teacher mostly completed this part with some input from students
During LC practical work students observed experimental phenomena i.e saw what was meant to happen	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher	My teacher usually did this part without input from students	Students completed this part with some assistance from the teacher
During LC practical work students were encouraged to ask a question and to formulate a hypothesis regarding the answer to this question.	My teacher mostly completed this part with some input from students	My teacher mostly completed this part with some input from students	My teacher usually did this part without input from students	My teacher usually did this part without input from students	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher
During LC practical work students collected data	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher
During LC practical work students recorded data appropriately e.g. in table form, diagrams, photos etc.	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher
During LC practical work students analysed collected data in order to draw conclusions	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	My teacher usually did this part without input from students	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher

During LC practical work students presented the findings of experiments in graph form or otherwise	Never	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher
During LC practical work students applied experimental findings to new experiments	My teacher usually did this part without input from students	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Never	Students completed this part with some assistance from the teacher	Never
During LC practical work students wrote an experimental report	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Never	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher
During LC practical work students got to design their own experiment	Never	Students completed this part with some assistance from the teacher	Never	Never	Never	Never
Please sum up your experience of LC practical work in secondary school here:	Copying and pasting, most information is given and then regurgitated during exam or write up. Not very interesting	Very informative and useful in understandin g the theory	The teacher moved through course work quickly. Some experiments were given more attention than others. Experiments relating to metabolism, respiration, photosynthesis were focused on in detail. However most experiments were demonstrated via video, time prodominantly spent on experiments was theory based rather than physical engagement with apparatus. Notes were provided on the procedure a d end result of each experiment and linked to other biological aspects on the curriculum.	When carrying out experiments our teacher let us do them ourselves in groups by following the instructions in the text book. We would ask for help if we got lost. When it came to writing up our experiments we mostly just copied what was in the book		
What are you hoping to learn by doing this BI317 module?	How to go about teaching a practical lesson to students in an interesting way	How best to teach and demonstrate and a practical biology class	I am looking to gain insight and further knowledge in how to instruct/conduct LC Biology practicals in a teaching capacity.	I hope to learn how to teach Biology to my students in a fun and understanding way. I want to be able to teach my students in	How to conduct an efficient biology practical class.	How to teach biology in a fun and interesting way

				such a way that they will be able to draw their own conclusions and not to rely on the textbook as much.		
What, do you think, is the purpose of practical lessons or why do we teach practical work?	To provide an understanding of how science proves theory through easily replicable experiments	So students can see real life experiments which help them to understand the subject matter by putting theory to practice	Practical work helps the learner engage with the theory they learn. It helps the learner develop scientific skills that equip them to work on an individual bases to form their own hypothesis/theories in future.	I think practical lessons help enforce information learned from a chapter and encourage good practice using equipment and writing up what happened during experiments	To give a better understanding to the ideas covered in theory classes.	To help students understand the theory of biology
Have you ever taught a practical lesson at junior or senior cycle level?	No	No	Yes	No	No	No
If you answered yes to the previous question, how did you find the experience?			Time management was difficult especially with big class of junior cycle e.g first years. However the older more experienced students were the more efficient they were at setting up equipment and focused on linking theory to practical. Overall practical work in class is challenging at times but very rewarding and excellent at helping the student relate to course work.			
What factors do you think are important to consider from a teacher's perspective when planning and preparing a Leaving Certificate practical lesson?	What will clearly show relation to theory and how to present the experiment in a entertaining way	Safety, timing, enough equipment and materials, class layout	Safety, Organisation, Time Management, Collecting Data, Forming a Conclusion, presentation of findings.	I think it is important to consider how much time you have, the ability of the students in your classroom, what resources are available to you and the students and how the practical fits in in their scheme of learning.	Time management, Having the equipment ready, Having a theory class beforehand explaining the experiment that will be taking place	Time and resources

What factors do you think are important to consider when teaching a LC practical lesson (i.e. during the lesson itself)	That the experiment connects to what is taught in class	Safety, using suitable language which students can understand, clear instructions	Safety, Providing clear pre Lab theory/relating practical aspects to the theory being taught, Presenting Clear instructions to students, allowing the students to work together, collect data, form hypothesis/conclusions, recap, provide assessment on practical aspects.	It is important to think of safety in the lab, the ability of the students, the availability of equipment and that you are moving around each bench to see how students are progressing/if they need help	Time management, Behavioral management	Student engagement
What factors do you think are important to consider after a LC practical lesson is complete?	That students understand the subject matter that the experiment relates to and that they had fun	Clean up, setting exercises or homework, conclusion	Draw a conclusion, provide practical assessment, correlate to chapter/wider ranges of biology course.	I think it is important to consider how the practical lesson went was it successful, did we achieve the expected outcome/ if not what does that mean instead. I think it is also important to discuss how the practical went did the students learn new techniques/information.	Give appropriate homework, Plenty of reflection	Student understanding
How long do you think is appropriate to spend planning and preparing a practical lesson for LC biology?	A day in advance for a hour, maybe more	1 hour	Depending on situation, roughly a full class previous, then allow a full class to engage in practical work with students. For teacher individual planning could vary. Planning and preparation for me would take 1-2hrs of attention. Focusing on instructional aspects, time management ect.	1-2 hours	40 minutes	30 mins
What do you understand by the term "enquiry based learning" as it applies to practical work?	An individual investigates a issue or experimental results and comes to their own conclusion from them	Learning by asking questions about a subject mater and investigating	Active learning, psoising questions, getting students to collaborate and figure out problems posed by various questions, students explore material on their own, draw personalised conclusions backed up by	I think it means actively learning new information as you carry out an experiment, students can ask questions as they think of them and are able to observe what is happening in the practical. its aim is to trigger	Preforming experiments to gain a better understanding	Using experimentation to learn and apply biology in real life situations

			relevant facts relwtaing to course work in focus/covered.	the students to think more about the topic and ask more questions		
How much of your experience of practical work to date at second and third level has been "enquiry based"? (Give a percentage for each)	Second (20%) Third (70%)	50%	30% second, 50% Third.	second level 30%. third level 70%	Second level 20% Third level 40%	Second level: 30% college: 80%

ID	18	19	20	21	22
Start time	9/28/20 8:43:44	9/28/20 9:59:09	9/28/20 12:12:30	9/28/20 11:02:44	10/1/20 15:22:36
Completion time	9/28/20 8:57:56	9/28/20 10:01:26	9/28/20 12:23:34	9/28/20 14:25:17	10/1/20 15:34:52
During LC practical work students learned to follow instructions step by step	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	My teacher mostly completed this part with some input from students	My teacher usually did this part without input from students	My teacher usually did this part without input from students
During LC practical work students learned new laboratory skills e.g. aseptic technique, preparation of solutions, measurement skills	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Never	Students completed this part with some assistance from the teacher
During LC practical work the students learned to make accurate observations e.g.when using measuring equipment	Students completed this part with some assistance from the teacher	My teacher mostly completed this part with some input from students	Students completed this part with a little assistance form the teacher	Never	Students completed this part with a little assistance form the teacher
During LC practical work students observed experimental phenomena i.e saw what was meant to happen	My teacher usually did this part without input from students	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	My teacher usually did this part without input from students	Most students completed this part with no assistance from the teacher
During LC practical work students were encouraged to ask a question and to formulate a hypothesis regarding the answer to this question.	Never	Students completed this part with a little assistance form the teacher	My teacher usually did this part without input from students	Students completed this part with some assistance from the teacher	My teacher mostly completed this part with some input from students

During LC practical work students collected data	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Never	Students completed this part with some assistance from the teacher
During LC practical work students recorded data appropriately e.g. in table form, diagrams, photos etc.		Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Never	Students completed this part with some assistance from the teacher
During LC practical work students analysed collected data in order to draw conclusions	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	My teacher mostly completed this part with some input from students	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher
During LC practical work students presented the findings of experiments in graph form or otherwise	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Never	Students completed this part with a little assistance form the teacher
During LC practical work students applied experimental findings to new experiments	Never	My teacher mostly completed this part with some input from students	My teacher mostly completed this part with some input from students	Never	Never
During LC practical work students wrote an experimental report	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Never	Most students completed this part with no assistance from the teacher
During LC practical work students got to design their own experiment		Never	Never	Never	Never
Please sum up your experience of LC practical work in secondary school here:	Most experiments were done in order to prove facts we already knew rather than doing experiments to discover new things. In Physics this a graph was made with almost every experiment and the findings were analysed. This sometimes occured in chemistry as well. I did not student leaving certificate biology so I cannot comment on that.	In my school we had a large biology class so we did experiments in groups of 4 or 5, which meant that we never really took in too much of the information from the teacher as we learnt from each other	I was very focused on getting my points so ididnt mind that my teacher just did the experiment and told us what we needed to know from it	I went to a grind school for both 5th and 6th year and never did any practical work as they were not mandatory. We were usually just told how the experiment was carried out and provided the results and conclusions to go with it.	Just had to go through the tasks of the experiment to get it done and complete it

What are you hoping to learn by doing this BI317 module?	How to teach leaving certificate biology experiments.	In this course, we study the in depth side of Biology, however biology in JC and LC is simplified. I hope to learn the basics again, the simplified biology	im hoping to understand why enquiry based methods are better	To gain knowledge and the skill set of setting up experiments, asking higher order questions and learning different method how students can be kept entertained and both grasp the concept of the experiment and how they might apply these concepts to the knowledge they have learned.	How to get the students to understand why this experiment is done and to come to their own understanding on why this experiment is carried out
What, do you think, is the purpose of practical lessons or why do we teach practical work?	In order to teach experimental technique.	Many students are kinaesthetic learners and we cannot assume that everyone learns the same way. An experiment allows them to put the knowledge into practice	to put theory into practice	To help students gain the skills, abilities and the knowledge of lab work if they may wish to continue in the branch of science as a profession.	To help the students to better understanding on the material their learning
Have you ever taught a practical lesson at junior or senior cycle level?	No	Yes	No	Yes	No
If you answered yes to the previous question, how did you find the experience?		It was quite nerve wracking however it was encouraging to see how the students were learning from the experiment, examining mono and dicot leaves. After the first ten		I thought it was good. However it could of been better as I didn't have a lot of experienc	

		minutes, the nerves left		e with teaching and carrying out an experime nt.	
What factors do you think are important to consider from a teacher's perspective when planning and preparing a Leaving Certificate practical lesson?	If the experiment relates to the idea being taught, safety and student understanding.	Any learning disabilities in the group making sure you are teaching to include all the learning styles	To make sure the students achieve the learning objectives	Learning outcomes , What you hope the students will know at the end of the lesson. Hopefully that the students can apply these results to other topics.	Should be prepared for accidents or students misbehaving, and to also have the students prepared for the experiment before hand so when they come in they know what their doing and get to work straight away
What factors do you think are important to consider when teaching a LC practical lesson (i.e. during the lesson itself)	Safety and if students are correctly understanding the aim and method of the experiment.	Watching the group to make sure no one is left behind or confused, ensuring safety throughout the practical	to make sure everyone is following the lesson and understands what is going on	Health and safety. Student engagem ent. Student understat ement.	Making sure that the students know that your there if they need a little helping hand but they should also know they are capable of completing the experiment by themselves
What factors do you think are important to consider after a LC practical lesson is complete?	Studetns understand how a conclusion was obtained and what it was.	Ensuring a activity is given to make sure the students understand the practical side of the experiment and understand the lesson	how the lesson could have been improved	That students with any misconce ptions are solved and answered	Make sure that the students can accumulate their own ideas about why this experiment was carried out and why
How long do you think is appropriate to spend planning and preparing a practical lesson for LC biology?	2hrs	At least an hour, to include all information	around an hour and a half	4hours	3/4 classes??

What do you understand by the term "enquiry based learning" as it applies to practical work?	Learning through asking questions and performing experiments to find the answers.		the students understand what question needs to be answered by doing the practical	Research	learning and asking questions as carrying out the practical
How much of your experience of practical work to date at second and third level has been "enquiry based"? (Give a percentage for each)	Second level - 25% Third Level - 10%	50/50	second level 10% third level 5%	45%	Secondary - 25% Third level - 70%

Appendix 7.2.2 PST Post Module Survey

ID	1	2	3	4	5	6
Start time	12/14/20 11:21:13	12/14/20 11:22:20	12/14/20 11:21:09	12/14/20 11:21:11	12/14/20 11:21:19	12/14/20 11:21:37
Completion time	12/14/20 11:23:16	12/14/20 11:25:08	12/14/20 11:25:58	12/14/20 11:26:35	12/14/20 11:26:49	12/14/20 11:27:07
Following instructions step by step	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	My teacher usually did this part without input from students	Students completed this part with a little assistance form the teacher
Learning new laboratory skills e.g. aseptic technique, preparation of solutions, measurement skills	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher
Accurate observation e.g. when using measuring equipment	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher
Observation of the experimental phenomenon i.e. did you see what was meant to happen?	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	My teacher usually did this part without input from students	Students completed this part with some assistance from the teacher
Forming an hypothesis	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	My teacher usually did this part without input from students	My teacher usually did this part without input from students
Collecting data	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	This was not a feature of the experiments I did	Students completed this part with a little assistance form the teacher
Recording data appropriately e.g. in table form, diagrams, photos etc.	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher
Analysing data collected in	Students completed this part	Most students completed this part with no	Most students completed	Most students completed this part with no	My teacher usually did this part without	Students completed this part

order to draw conclusions	with some assistance from the teacher	assistance from the teacher	this part with no assistance from the teacher	assistance from the teacher	input from students	with some assistance from the teacher
Presenting the findings of experiments in graph form or otherwise	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher
Applying experimental findings to new experiments	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	This was not a feature of the experiments I did	This was not a feature of the experiments I did
Writing an experimental report	This was not a feature of the experiments I did	This was not a feature of the experiments I did	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher
Designing an experiment	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	This was not a feature of the experiments I did	This was not a feature of the experiments I did
Please sum up your experience of practical work for biology in BI317 here:			The start of the labs were grand. The extension exercises will not be used in secondary schools realistically as the bio course is already so long there is barely enough time to do the bare minimum	Informative and helpful in preparing to teach lc biology	We learned a lot about getting students thinking and how to make classes more interesting and just getting involved and thinking more which was so helpful! In school I used to just sit there barely participate or just think what's she doing	I feel like I've come away with new skills to use in my teaching of biology
What did you learn about teaching practical biology by doing this module?		That teaching labs needs to be imptoved for students to engage and understand more	It acted as a refresher for the heart dissection	That you can do extension activities based on inductive exp	We learned a lot about getting students thinking critically and how to interpret results to form new hypothesis etc	I Learnt to let students try something for themselves before telling them what to do.

What, do you think, is the purpose of practical lessons? (i.e. why do we teach practical work?)		To help them get a first hand experience on whag is being tsught and to enhance understanding and make links to tesl life connections	For students to get involved	Reinforce scientific principles	To get into the role of being a scientist and see how things work for ourselves	To learn new laboratory skills that will help proving hypothesis
Did you teach a practical lesson at junior or senior cycle level during the course of BI317?	No	No	Yes	No	No	Yes
If yes, did your experience with BI317 assist you with your practical teaching? Please elaborate			No. I didn't have time to do any extension exercises		I didn't teach a practical due to covid but I definetely used some of the things I learned when teaching	Yes actually, I didn't notice at the time but I definitely let the students create their own experiment.
What factors do you think are important to consider from a teacher's perspective when planning and preparing a Leaving Certificate practical lesson?		To see if there are SEN students	Safety	To not get distracted with what is expected of students in the exam but allow them to develop their experimental techniques and if a result occurs that is not "expected" to discuss it	The students knowledge and abilities and misconceptions	The ability of the class must be considered. Inquiry can be difficult to grasp
What factors do you think are important to consider when teaching a LC practical lesson (i.e. during the lesson itself)			Safety	Time management. Ability of pupils. Availability of equipment etc	To make sure students know what they're doing and why they're doing it and if they can use this knowledge to do more	That students are more able than we give them credit for
What factors do you think are important to consider after a LC practical lesson is complete?			For students to understand why they're doing something	To make the connection with other topics (linked learning) and relate to exam qs	Evaluating the students knowledge by asking them to interpret data and to form a hypothesis or see what would happen if they	We need to make sure students know what they did but also why they did it

					did it differently	
How long do you think is appropriate to spend planning and preparing a practical lesson for LC biology?			An hour	1-2hours	40 mins	An hour, but as you do the practical a few times you can make small changes which will come over time
What do you understand by the term “enquiry based learning” as it applies to practical work?			Asking questions and finding your own answers	Students learning through different levels of enquiry where they form questions, hypotheses and experiments to reinforce the principles they've learned	Thinking critically and wondering what this means and how it can change things	Allowing students to be drivers of their own learning!
ID	7	8	9	10	11	12
Start time	12/14/20 11:20:59	12/14/20 11:22:15	12/14/20 11:23:30	12/14/20 11:21:59	12/14/20 11:24:28	12/14/20 11:21:47
Completion time	12/14/20 11:28:50	12/14/20 11:29:48	12/14/20 11:30:55	12/14/20 11:31:14	12/14/20 11:32:07	12/14/20 11:34:00
Following instructions step by step	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher
Learning new laboratory skills e.g. aseptic technique, preparation of solutions, measurement skills	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher
Accurate observation e.g. when using measuring equipment	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher
Observation of the experimental phenomenon i.e. did you see what was meant to happen?	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher
Forming an hypothesis	Students completed	Most students completed this	My teacher mostly	Students completed this	Students completed this	Most students

	this part with a little assistance form the teacher	part with no assistance from the teacher	completed this part with some input from students	part with some assistance from the teacher	part with a little assistance form the teacher	completed this part with no assistance from the teacher
Collecting data	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher
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Analysing data collected in order to draw conclusions	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher
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Writing an experimental report	This was not a feature of the experiments I did	This was not a feature of the experiments I did	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	This was not a feature of the experiments I did
Designing an experiment	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	This was not a feature of the experiments I did	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher
Please sum up your	Educational	Really insightful	Very teacher-led	The practical work has made		Very educational

experience of practical work for biology in BI317 here:		experience, the deductive experiments make the leaving cert course a lot more understandable and engaging		me more confident in my skills for when I have to teach these experiments myself in school.		way of teaching biology practical's. it ensured that students were active in their learning and were learning what was intended.
What did you learn about teaching practical biology by doing this module?	The experiments abs further investigation	Different preparation techniques such as making agar	That the students should take control of their learning more	Make the lesson more enquiry based.	It's not all about getting the expected phenomenon, students need to understand the science that underlies	Inquiry is the way to go.
What, do you think, is the purpose of practical lessons? (i.e. why do we teach practical work?)	They were good	To aid students in their learning of a concept, they can visualise and create for themselves a result	to reinforce theory, and to let students see what they are learning in a book	So the students can learn with a more hands on approach. Science is more than just learning off information it's important for the students to see how it works.	So students get the opportunity to apply their knowledge to a real life situation	Develop the skills of students and also to connect coursework with real world ideas.
Did you teach a practical lesson at junior or senior cycle level during the course of BI317?	Yes	No	No	Yes	No	Yes
If yes, did your experience with BI317 assist you with your practical teaching? Please elaborate	No, no time to do			I found it aided the students learned with the topic. Time management is an issue with junior cycles as it takes them longer to complete practicals and with covid there is more cleaning that takes up time.		It was the first week so I didn't know enough about inquiry just yet.
What factors do you think are important to consider from a teacher's perspective when	Framework, lesson plan, equipment for further investigation	The learning abilities in the class, the resources available, the time available	time, resources, the level students are at	Think of every aspect of the practical so you are prepared. And think how the students will benefit from the practical without	I think ensuring that students aren't following a procedure is the most important take away from the lecture style	You have to anticipate what questions the students will ask.

planning and preparing a Leaving Certificate practical lesson?				too much input from the teacher		
What factors do you think are important to consider when teaching a LC practical lesson (i.e. during the lesson itself)	That every student understands in some level of the content, why they are carrying out this investigation and for them to drawn their own conclusions based on the results recorded.	Different paces of students, monitoring student safety	being clear to students about the reason for the experiment and what the experiment proves/shows	To try and let the students figure out the experiment themselves and to ask questions.	Making sure students stay on topic	Make sure that the students are working on task and are not lost.
What factors do you think are important to consider after a LC practical lesson is complete?	Do students know why based on experience and not memory a experiment took place.	Evaluation of the practical, what worked and what didn't, interpretation of the results and conclusion	to collect data, analyse data and put this data into appropriate graphs and tables	Evaluation is important so you know if the students benefitted from the experiment	Like the practical back to the underlying theory	What did we learn?
How long do you think is appropriate to spend planning and preparing a practical lesson for LC biology?	Week (depends on the experiment) e.g Pond weed needs to be gotten.	5-6 hours	45 minutes	2 - 3 hours	1 hour	one hour for a lesson plan, one hour to set it up.
What do you understand by the term "enquiry based learning" as it applies to practical work?	Learning through active learning in a practical manner	It refers to asking questions to promote the students thinking, allowing the students to create their own hypothesis and question, it's all about promoting student independent learning	students leading their own learning in the lab		Not teacher led, students get the opportunity the investigate there own questions	Learning by being given the freedom and the tools to explore and asking your own questions.

ID	13	14	15	16	17	18
Start time	12/14/20 11:22:11	12/14/20 11:25:24	12/14/20 11:28:57	12/14/20 11:21:43	12/14/20 11:22:50	12/14/20 11:21:43

Completion time	12/14/20 11:34:14	12/14/20 11:35:17	12/14/20 11:35:21	12/14/20 11:36:42	12/14/20 11:37:26	12/14/20 11:37:55
Following instructions step by step	Students completed this part with some assistance from the teacher	My teacher mostly completed this part with some input from students	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher
Learning new laboratory skills e.g. aseptic technique, preparation of solutions, measurement skills	Most students completed this part with no assistance from the teacher	This was not a feature of the experiments I did	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher
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Observation of the experimental phenomenon i.e. did you see what was meant to happen?	Students completed this part with some assistance from the teacher	My teacher mostly completed this part with some input from students	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher
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Collecting data	Most students completed this part with no assistance from the teacher	My teacher mostly completed this part with some input from students	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher
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Analysing data collected in order to draw conclusions	Students completed this part with a little assistance form the	My teacher mostly completed this part with some input from	Students completed this part with a little assistance form the	Students completed this part with a little assistance form the	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the

	teacher	students	teacher	teacher		teacher
Presenting the findings of experiments in graph form or otherwise	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher
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Writing an experimental report	This was not a feature of the experiments I did	Students completed this part with some assistance from the teacher	This was not a feature of the experiments I did	Most students completed this part with no assistance from the teacher	This was not a feature of the experiments I did	Most students completed this part with no assistance from the teacher
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Please sum up your experience of practical work for biology in BI317 here:	Loved the labs - was very hands on	experiements helped prepare me for doing them in schools	I enjoyed practical work for BI317. It was definitely the most relevant to teaching out of all the biology we have done during college.	The labs were my favourite. I don't really have anything to say other than keep going as you are with the labs	I think it was a good experience. I will definetely try to incorporate the method of teaching used in the labs, not only in biology, but also chemistry. I think I have a good idea as to what I'm going to do them	It was very helpful in presenting a new way of teaching where the student is allowed to explore different topics in science. They become more independent and take responsibility for their own learning as well as forming links of their own to help with retention of information.
What did you learn about teaching practical biology by doing this module?	To allow students to form their own ideas	how to put most of the work onto students to allow them figure it out with some guidance	I learned more about how to teach in an inquiry based way	To make connections between diagnostic experiments and applied experiments, to teach/learn through enquiry	We have to let students come up with their own ideas on how things work in the experiment.	Students should be allowed to explore and discover new applications for diagnostic experiments.

What, do you think, is the purpose of practical lessons? (i.e. why do we teach practical work?)	To gain a better understanding of what is being thought	to put your learning into practice	They are engaging, they help with motor skills, they prepare us for later life, the list goes on	To gain a deeper understanding of theory work, to make connections, to gain laboratory skills that can be applied to daily life, to learn how to communicate in a scientific matter with peers	To help studenta develop their scientific methods.	To show how we as teachers could structure our lessons for optimum student learning.
Did you teach a practical lesson at junior or senior cycle level during the course of BI317?	Yes	Yes	No	No	Yes	Yes
If yes, did your experience with BI317 assist you with your practical teaching? Please elaborate	Yes I let the students form their own ideas	yes because i let the students take control of their learning			Yes, I was teaching particles in solution to first years. I used some methods from enquiry based teaching and it has worked pretty well. Students were able to link in what they learned from the lessons to the experiment, even if I did not tell them what would result in evaporation/filtrati on	Yes. Experiments ran smoothly during the labs as students were eager to learn and get involved as much as possible. Students were happier as they got to pick the applied experiment they wanted to investigate.
What factors do you think are important to consider from a teacher's perspective when planning and preparing a Leaving Certificate practical lesson?	The needs of the students their ability	be prepared for all circumstance s as some students may need more elaboration and help than others	Safety. Keeping it interesting. Trying not to spoon feed them. Keeping it relevant.	incorporating as much enquiry as possible	Teachers have to do a lot of preparation in order to execute a successful enquiry-based class	
What factors do you think are important to	That students understand what's gong on	to be aware if students are falling behind to	Keeping the students engaged.	To be as prepared as possible with all materials	I think the ability to visualise what they are learning is important.	Allowing them to experience science and its topics outside

consider when teaching a LC practical lesson (i.e. during the lesson itself)		give them a hand to catch up	Letting them discover for themselves but monitor the situation to ensure they stay on task	and equipped for possible applied experiments		of what is in the book. They can easily form links with the material and therefore even learn the information better as it is more memorable. For students who may not enjoy science the lab work can make it nicer for them too and the students who do enjoy science can challenge themselves.
What factors do you think are important to consider after a LC practical lesson is complete?	That students can form a link between theirknowledge and the practical	that they are aware of the key ideas and learned more about the topic after doing the experiment than they did before the practical	Gather what they have learned in some manner so that they don't forget it	To gather evaluation from students, to gather misconceptions and identify problem areas in order to be prepared when teaching again	To make sure that the students actually remember/know what they experienced, make sure to ask them to reflect on how they did and why they did the experiment	Checking for student understanding as well as allowing the class to communicate their findings with one another. That can help them develop communication and problem solving skills that can aid them in further learning and in their future as an individual is society.
How long do you think is appropriate to spend planning and preparing a practical lesson for LC biology?	A double class	half an hour realistically because there are so many other lessons to plan but using inquiry teaching this would not happen as it would take much longer	I don't really have a timeline, but to begin it will take longer and then as time goes on you will just be adjusting past practicals based on student	2-3 hours planning and a further hour preparing all materials in the lab	Perhaps a week ahead. Sometimes though, such as the yeast experiment, you have to think of it months ahead.	I usually spend a long time as I review them all the time and we are relatively new to planning. Mine take about 2-3days as I want to be prepared to aid the students learning as

			feedback			best as possible.
What do you understand by the term “enquiry based learning” as it applies to practical work?	Being able to form your own ideas about a topic and relate it to practical work	it gives students a chance to put learning into their own hands and lets them figure stuff out for themselves instead of being spoon fed	It allows students to carry out experiment s in their own way. Instead of following recipe style instruction s to get a set outcome they are allowed to discover things for themselves	Applying diagnostic experiment data to design an applied experiment. This allows us to make connections	Students are not fed everything on what they need to do in an experiment. They are asked to think about why they are using some steps in the experiments, and asking them to question theit results and conclusions, rather than just accepting the fact that that's just how it's supposed to be	Learning that is student led and allows students to investigate and use their curiosity as an aid for learning rather than being spoon fed the information by the teacher which isn't as beneficial.

ID	19	20	21	22	23	24
Start time	12/14/20 11:22:43	12/14/20 11:21:59	12/14/20 11:31:59	12/14/20 11:21:00	12/14/20 11:30:08	12/14/20 11:23:38
Completion time	12/14/20 11:38:50	12/14/20 11:40:22	12/14/20 11:42:02	12/14/20 11:43:08	12/14/20 11:44:09	12/14/20 11:44:50
Following instructions step by step	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher
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Forming an hypothesis	Students completed	Students completed	My teacher mostly	Students completed	My teacher mostly completed this part	Most students

	this part with a little assistance form the teacher	this part with a little assistance form the teacher	completed this part with some input from students	this part with a little assistance form the teacher	with some input from students	completed this part with no assistance from the teacher
Collecting data	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher
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Designing an experiment	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	My teacher mostly completed this part with some input from students	Students completed this part with some assistance from the teacher	My teacher usually did this part without input from students	Students completed this part with a little assistance form the teacher
Please sum up your experience of practical work for	The practical work for BI317 was very well conducted. I	I think the labs were an effective way to show us	I thought i understood leaving cert biology but from doing	The practical work was very engaging, we got to take the initiative		Quite heavy on the workload but otherwise enjoyable and

biology in BI317 here:	felt the in person lab sessions to be very engaging and that I left the lab with more of an understandin g of the topics being discussed and investigated.	how inquiry can be brought into the experiment s in biology	BI317 it gave me an even further understand of the pratical work in an interesting way	much more than ever before in a lab environment, this was daunting at first but once the fear of being wrong in front of a teacher passed it was very enjoyable to come up with our own hypothesis and ask our own questions. Overall it was very educational and fun and will stay with me as I go on in my teaching career.		interesting <3
What did you learn about teaching practical biology by doing this module?	To let the students come up with their own experiments and hypothesis.	i learnt it is important to let the students do majority of the work give them an outline but let them carry it out themselves	the preparation that is nedded	The importance of having your own educated questions that you can then answer	I learned a lot about deductive experiments	How to include inquiry based teaching into my future lessons
What, do you think, is the purpose of practical lessons? (i.e. why do we teach practical work?)	To give the real life application of the theory covered in class.	I think it is important that practical work is carried out because it helps students see what they are learning working in real life. I also think it is important because carrying out practical work some students can find it easier to	give students a deeper understandin g of the work	To prepare students for a possible career in science and research, and to provide a deeper understandin g of where information and facts come from	To provide a students with a deeper understanding than they would acquire from recipe style and regurgitation of information	So that teachers can present students with the opportunity to explore scientific phenomena at their own pace and perhaps get a feel for how scientists actually do their research and how they present their findings

		remember the topic				
Did you teach a practical lesson at junior or senior cycle level during the course of BI317?	No	No	No	Yes	Yes	No
If yes, did your experience with BI317 assist you with your practical teaching? Please elaborate				Yes I believe so, the experiment was very simple as it was a first year class, I was conscious of the questions I was asking them and I tried to make connections in their mind with other experiments or practical work in the hopes that in the next experiment they might do the same for themselves	Yes it helped me to plan my acids and based experiment with 2nd years by including students in the hypothesis process to come up with the experiment and to include more questions to pose to students	
What factors do you think are important to consider from a teacher's perspective when planning and preparing a Leaving Certificate practical lesson?	The questioning. I think it is important that teachers think up all possible questions that can be asked throughout the lab. This will be beneficial if you are struggling to get any feedback from the students on the day.		the questions that could be askd	Whether a class group would be used to the inquiry based model or the more traditional "spoon fed" model, also their prior knowledge of this experiment and others is more important now in order to make connections to ask questions etc.	Timing, risks, materials,questions ,	How to allow students to engage with the material and be sure that the students have everything they need to find the properly explore a given phenomena
What factors do you think are important to consider when teaching a LC	Do not suppy the students with a recipe. Have the students come up with	I think teachers need to be aware of what students	question that could be asked	During practical classes you will have several students	It should be student led, where students are posed questions to help them come up with the experiment rather	Time management is a very important factor that must be

practical lesson (i.e. during the lesson itself)	their own ideas on how to conduct the experiment.	are doing and making sure each student has an idea on what they need to be doing		carrying out the experiment, it is important to take the data from each student and present it as a class group set of data, this way is something different happens or a question is asked then the whole class group is informed	than spoon feeding it to them	carefully managed if you want to get everything across to students at a reasonable level
What factors do you think are important to consider after a LC practical lesson is complete?	The clean up of the equipment and then the evaluation exercises that the students have to complete as these will further enhance the students newfound knowledge from the lesson.	i think it is important that students gather the information from the practical and understand the why and how they got the information they did	the worksheet	There should be a discussion about the experiment in which students should feel comfortable asking questions and making links like the one we did with the catalase and yeast, this conversation should be in an attempt to avoid tunnel visioning on experiments and the hope would be that students will see the bigger picture	Where learning outcomes met, do students understand this experiment and material, do student know how to present results	Engaging with the findings and data that the students collected so as to connect everything together again
How long do you think is appropriate to spend planning and preparing a practical lesson for LC biology?	Anywhere between 1 and 3 hours.	i think depending on the practical that you are preparing some will take longer to organise then others. I do think however it is important to plan ahead so you are organised	3 hours	How long is a piece of string? As long as is needed to do the students justice	2-3 hours	A day of solid work should be ample time

		for your students				
What do you understand by the term "enquiry based learning" as it applies to practical work?	I understand that it involves stimulating the students to question more of what they are being told in the classroom. It is a more student centred approach to teaching and learning. The students formulate their own hypothesis, making their conclusions more impactful and significant to them.	inquiry based learning in practical work is a method of teaching labs were students think for themselves and teachers are there to assist if needed. students are given the basic information they need and do the rest for themselves	students think for their selves	Means greater involvement on the students behalf during practical classes, encouraging asking questions and broadening their vision on the application of experiments	Student focused learning which students are encouraged to explore, and question material	Learning that gives students freedom to explore a given topic and be able to think for themselves rather than being spoon feed material with heexpectatio n that students can regurgitate the material back in exam form

ID	25	26	27	28	29	30
Start time	12/14/20 11:27:05	12/14/20 11:39:43	12/14/20 11:25:46	12/14/20 11:37:33	12/14/20 14:41:23	12/14/20 11:41:43
Completion time	12/14/20 11:46:39	12/14/20 11:47:17	12/14/20 11:52:13	12/14/20 11:55:42	12/14/20 14:46:57	12/15/20 15:34:12
Following instructions step by step	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	My teacher usually did this part without input from students
Learning new laboratory skills e.g. aseptic technique, preparation of solutions, measurement skills	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	My teacher mostly completed this part with some input from students
Accurate observation e.g. when using measuring equipment	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher
Observation of the experimental	Most students completed this part with no	Most students completed	Students completed this part with some	Students completed this part with a	Students completed this part	My teacher mostly completed

phenomenon i.e. did you see what was meant to happen?	assistance from the teacher	this part with no assistance from the teacher	assistance from the teacher	little assistance form the teacher	with some assistance from the teacher	this part with some input from students
Forming an hypothesis	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	My teacher mostly completed this part with some input from students
Collecting data	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	My teacher mostly completed this part with some input from students
Recording data appropriately e.g. in table form, diagrams, photos etc.	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with some assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	My teacher mostly completed this part with some input from students
Analysing data collected in order to draw conclusions	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	My teacher mostly completed this part with some input from students
Presenting the findings of experiments in graph form or otherwise	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	Most students completed this part with no assistance from the teacher	Students completed this part with a little assistance form the teacher	This was not a feature of the experiments I did
Applying experimental findings to new experiments	Most students completed this part with no assistance from the teacher	Most students completed this part with no assistance from the teacher	This was not a feature of the experiments I did	Students completed this part with a little assistance form the teacher	Students completed this part with a little assistance form the teacher	This was not a feature of the experiments I did
Writing an experimental report	Most students completed this part with no assistance from the teacher	This was not a feature of the experiments I did	Most students completed this part with no assistance from the teacher	This was not a feature of the experiments I did	This was not a feature of the experiments I did	This was not a feature of the experiments I did
Designing an experiment	Most students completed this part with no assistance from	Most students completed this part	This was not a feature of the experiments I did	Students completed this part with a little assistance	Most students completed this part	This was not a feature of the experiments I did

	the teacher	with no assistance from the teacher		form the teacher	with no assistance from the teacher	
Please sum up your experience of practical work for biology in BI317 here:	I found the labs very beneficial and how enquiry can be introduced to the leaving certificate, however I will need to put this to practice in my lessons in schools to really find out if it is beneficial and useful. But thanks to BI317 module I now know how to do that to check if it will be effective.	I enjoyed the practical work in this module.	I really enjoyed the labs for BI317. I felt the environment was less stressful than other labs and I liked the structure of the lab.	I enjoyed the practical work involved in Bi317, More time to complete the deductive experiments would have been better.		I really enjoyed BI317 because it gave me a new insight into a teaching biology through inquiry based learning. My enquiry in the lessons, it was chalk and talk and so were the practical's but BI317 has taught me to the importance of student discovery and student input. I need to take a step back in the class and let the students figure out the experiment and the results for themselves.
What did you learn about teaching practical biology by doing this module?	It can be very interesting and applied to many different situations not just the ones of the syllabus.	How to teach by inquiry.	I think that's a really hard question. I think the answer is different depending on if you take just the readings that were prescribed or if you take a more holistic look at all the research from the 1950s on wards on PBL education or enquiry-based education. I think some of the research is conflicting and is it hugely dependent on a series of	That leaving cert biology can be made inquiry based using an inductive and deductive experiment.	should have inductive and deductive elements	As mentioned in teh last section, it is important to take a step back as a teacher and observe, don't give the students all the answers, let them figure it out for themselves.

			other factors (societal). I definitely learned a new way to teach LC biology and also say that the students would have to learn in a new way too.			
What, do you think, is the purpose of practical lessons? (i.e. why do we teach practical work?)	to portray different concepts and broaden critical thinking skills of students and many more different skills i.e. lab skills, planning skills, timing skills, questioning skills	To show students the real life applications of biology.	I assume you mean in relation to biology, my answer might be slightly different in relation to physics or chemistry, but I think for biology we want to teach effective lab skills, show when theory is applied to real-life scenarios, be able to make scientific observations and deduce a rational conclusion.	To allow students to discover scientific theories themselves and build on information they already know.		Practical work is just as important as the theory because if any student chooses to study science in college, then it will be the practical work they will need for a profession
Did you teach a practical lesson at junior or senior cycle level during the course of BI317?	No	Yes	No	No	No	No
If yes, did your experience with BI317 assist you with your practical teaching? Please elaborate		Somewhat - it was most helpful with TY's but I found it hard to implement it when I'm only new to teaching.				
What factors do you think are important to consider from a teacher's perspective when planning and preparing a Leaving	questioning, students abilities, equipment available, planning organizing and timing skills(length of class)	To get students to implement their knowledge by designing a practical by themselves.	Is it efficient in terms of time. Is it practicable, can we apply the "theory" to real life classes.	The academic level of their class.		You want to make sure that the extension exercise is relatable to the course. Plan for the two lessons to run side by

Certificate practical lesson?						side and correlate to each other
What factors do you think are important to consider when teaching a LC practical lesson (i.e. during the lesson itself)	Questioning, checking students work to ensure they are on the right track with their experiment, hypothesis and conclusions		Is is suitable in terms of the time needed to cover the material?	The academic level of the class, the equipment available in the school, the length of the class.	Do the students understand why theyre doing what theyre doing	It is important to take a step back and allow the students to work through the problem. There is no point explaining everything to them so you must sit back and make sure the students come to their own conclusion or it is a waste of an experiment
What factors do you think are important to consider after a LC practical lesson is complete?	giving students feedback, seeing what went well and what did not, assessment of students understanding, clearing up of any misconceptions	That students understand what they observed and why it occurred	Can the students describe what they observed? Did they learn a new lab skill? Reinforce an old, previously learned lab skill?	Assess student understanding of the practical they have completed, through a quiz or lab report or Homework activity.		Ensure that the students understood what they did, why they did it and what the results were, make sure they came to the right conclusion on their own
How long do you think is appropriate to spend planning and preparing a practical lesson for LC biology?	an hour at least	2 hours	I don't know really, but if you are on a 22 hour contract and are commuting to work, you want an efficient, effective method that does not waste time.	about 1hour depending on the experiment and if anything must be made up for student use such as agar plates.	Would probably take like 2 hours but I think teachers would only have time to spend around an hour	I think in the first few years, it would be necessary to spend a minimum of 2 hours planning the lab to ensure you have planned a risk assessment and framework so the experiment is planned to its capability
What do you understand by the term “enquiry basedlearning” as it applies to	My understanding of Enquiry based learning is the involvement of the learner	Getting students to question why something is occurring	Richard Feynman said that we should teach our students to think, to	Student lead learning and investigation that allows students to question,		Enquiry based learning is the students taking control and using the knowledge

practical work?	which is the key process that aids in the learning and understanding of concepts of that learner. In enquiry-based teaching it is crucial for the teacher to plan appropriate and effective questions to support the use of enquiry in practical science and promote the higher order thinking of the students	and investigate	question, to doubt. Enquiry-based education, or problem-based education (PBL) or minimal guidance education are all constructivist educational theories which encompass more than just what Feynman said. I think it is possible to have an effective teacher who makes students think and question what they are doing in practical work while still teaching in the traditional way.	design and carry out activities themselves to further their learning and understanding.		the teacher has given them to conduct practicals.

Appendix 7.2.3 Summary SEOS for pre- and post-module surveys.

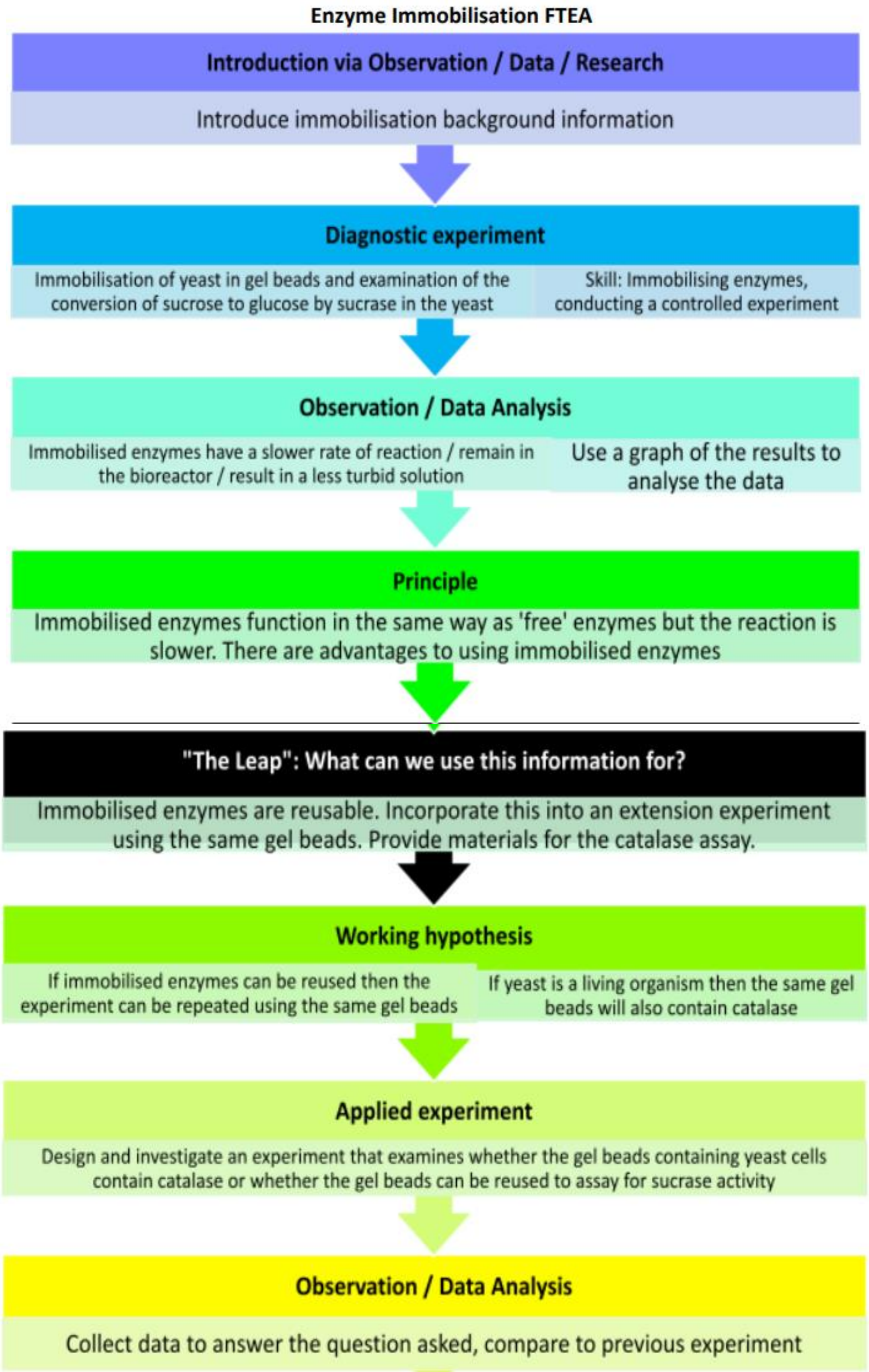
	Pre-PBTM (21 respondents)						Post-PBTM (30 respondents)					
SEOS number	0	1	2	3	4	5	0	1	2	3	4	5
1. During LC practical work students learned to follow instructions step by step	0	9.5	5	**52**	29	5	0	6.6	6.6	40	33.3	13.3
2. During LC practical work students learned new laboratory skills	4.76	9.5	14.3	52.4	19	0	6.6	0	3.3	23.3	43.3	23.3
3. During LC practical work the students learned to make accurate observations e.g. when using measuring equipment	9.5	0	14.3	28.6	47.6	0	0	0	6.6	16.6	33.3	43.3
4. During LC practical work students observed experimental phenomena i.e saw what was meant to happen*	0	14.3	23.8	28.6	14.3	14.3	0	3.3	10	36.7	33.3	16.6
5. During LC practical work students were encouraged to ask a question and to formulate a hypothesis regarding the answer to this question.	14.3	28.6	19	19	19	0	0	10	13.3	13.3	30	33.3
6. During LC practical work students collected data	4.76	4.76	0	33.3	33.3	23.8	3.3	0	10	13.3	20	53.3
7. During LC practical work students recorded data appropriately e.g. in table form,	4.76	0	0	38	33.3	19	0	0	10	20	20	50

diagrams, photos etc*												
8. During LC practical work students analysed collected data in order to draw conclusions	0	4.76	23.8	42.9	19	9.5	0	3.3	10	13.3	40	33.3
9. During LC practical work students presented the findings of experiments in graph form or otherwise	9.5	0	4.76	33.3	38	14.3	3.3	0	3.3	16.6	30	46.7
10. During LC practical work students applied experimental findings to new experiments	38	4.76	19	33.3	4.76	0	20	0	6.6	13.3	36.7	23.3
11. During LC practical work students wrote an experimental report	9.5	0	0	14.3	33.3	42.9	43.3	0	3.3	13.3	23.3	16.6
12. During LC practical work students got to design their own experiment*	71.4	0	9.5	9.5	4.76	0	20	3.3	6.6	16.6	26.7	26.7

Rating Scale:
0 = recommended by syllabus documents but not a feature of this experiment
1 = Teacher completes this part with no input from students
2 = Teacher mostly completes this part with a little input from students
3 = Most students complete this part with some assistance from teacher
4 = Most students complete this part with a little assistance from teacher
5 = Most students complete this part without assistance from teacher
* Teacher showed a data set to class because the phenomenon was not produced

Most common response highlighted in yellow

Appendix 7.3 Enzyme Immobilisation FTEA with Lesson Plan



FTEA Lesson Plan

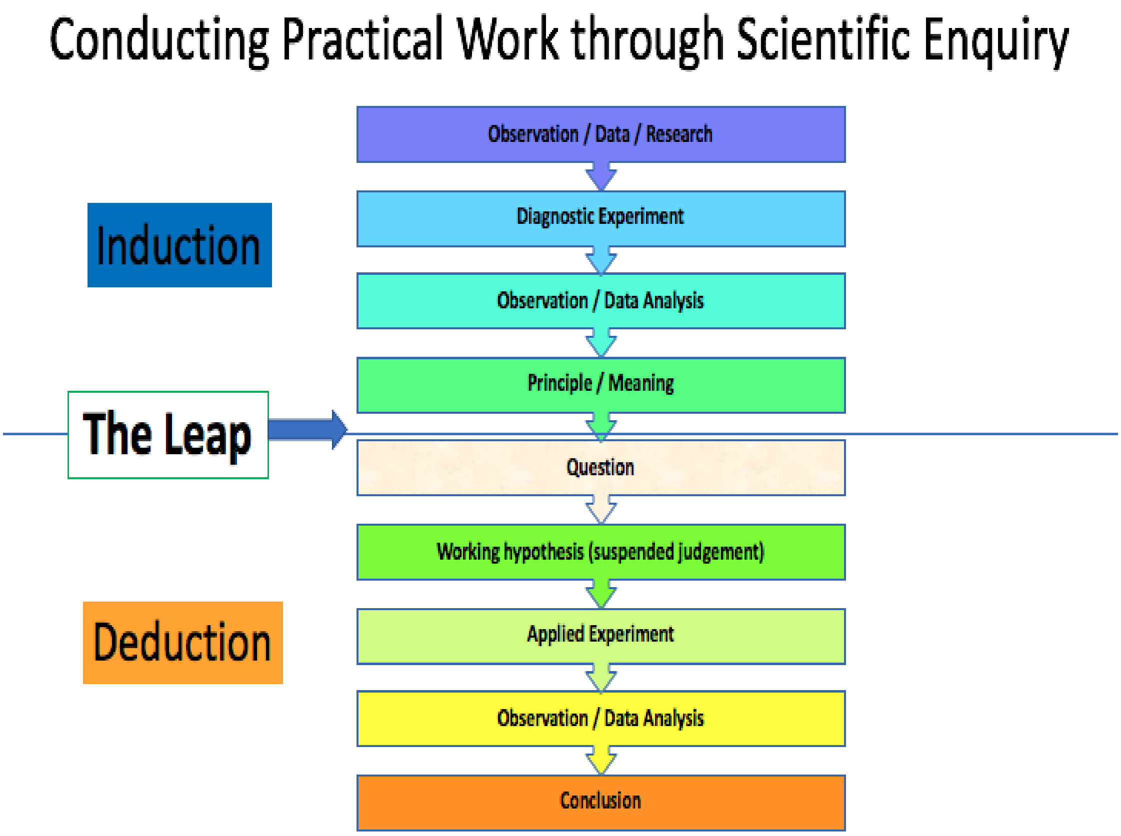
Title of Experiment: Prepare one enzyme immobilisation and examine its application.

<table>
<tr><th colspan="2">Induction</th></tr>
<tr><td><u>Introduction</u></td><td>Students need some understanding of
Everyday uses of enzymes
How enzymes can be trapped in an inert material and still carry out their function
The industrial benefits of immobilising enzymes
The economic importance of enzymes / the continuous flow process</td></tr>
<tr><td><u>Diagnostic experiment</u></td><td>Prepare one enzyme immobilisation and examine its application.</td></tr>
<tr><td>1. Preparation for Experiment</td><td>Gather equipment for each group
Photocopy worksheet (see this folder)</td></tr>
<tr><td>2. Laboratory skill attainment</td><td>Teacher: making up a 1%w/v solution of sucrose (1g/100ml)
Student:
Using an electronic balance to weigh masses of chemicals
Preparing solutions for immobilisation
Use of syringe
Graphing collected data</td></tr>
<tr><td>3. Risk assessment</td><td>Risk assessment carried out by teacher beforehand and sheet filled in and signed (see this folder)</td></tr>
<tr><td>4. List of equipment needed</td><td>Yeast (without $CaSO_4$) — Hot water (around 35^oC)
Sodium alginate — Graduated cylinders (100ml) x 2
Calcium chloride. — Beakers (100cm^3) x4
Sucrose solution (1%w/v) — Beaker (500cm^3)
Distilled water. — 2 separating funnels
Glucose test strips — 3 glass rods
Labels. — 3 Thermometers
Electronic balance — Weigh boats
Syringe (20cm^3) — Sieve
Spatulas — Wash bottle
Timer — Needle for syringe</td></tr>
<tr><td>5. Teaching methodology</td><td>1. Students conduct the experiment without immobilising the beads (this is the control experiment) and record the length of time it takes for the enzyme to carry out its function
2. Students immobilise the beads and collect data on the length of time it takes for the immobilised enzyme to convert the substrate into product – half the class makes large beads and half the class makes small beads

Guide students through the experiment using whiteboards with quantities of chemicals written in.
Use a worksheet (see this folder)</td></tr>
<tr><td>6. Data collection</td><td>Students collect data recording the colour of the glucose strip every 2 minutes
Students also note the turbidity of the solution collected in the separating funnel</td></tr>
<tr><td><u>Principle</u></td><td>Students gain an understanding of the difference between immobilised enzyme activity compared to non-immobilised (free) enzyme activity.</td></tr>
<tr><td>Data</td><td>Students present a line graph of time vs the amount of sugar</td></tr>
</table>

presentation analysis	present in the solution Class comparison of results
The Leap	
<u>What can we use this information for?</u>	Immobilised enzymes can be reused. Make the connection that the yeast in the bead contains many enzymes apart from sucrase. Think of an enzyme that has already been investigated and reuse the beads to investigate of this enzyme is also in yeast.
Deduction – (real world application)	
<u>Working hypothesis</u>	Students come up with a working hypothesis Students share the questions and the hypotheses they have come up with Teacher then scaffolds the lesson by providing specific materials that direct students in a particular direction or directions based on the reading <u>Examples</u> • Students can investigate if the beads are indeed reusable and if they still function at the same rate by repeating the same experiment • Students can investigate if any other enzyme can be immobilised – encourage students to think of experiments they have already conducted and to modify them for immobilisation (Catalase!!)
<u>Applied experiment</u>	Students design and investigate an aspect of enzyme immobilisation using the same technique they have learned in the diagnostic experiment - or a variant of this technique
<u>Observation</u>	Collect new data to answer the question asked
1. Data collection	Students collect data from their own experiment relating to question they have asked
2. Data presentation and analysis	Students present the results of their own experiment in a manner that they choose - graph / bar chart etc. They can then refute or confirm their hypothesis
3. Data reporting	Students create a comparative write up of the entire investigation (diagnostic and applied experiments)
<u>Evaluation</u> LC exam questions relating to enzyme immobilisation	Teacher evaluates the teaching during the lesson under the following headings: <u>What worked</u> – what aspects of the lesson did students understand <u>What needs improvement-</u> where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge <u>What will I do differently next time</u> Teacher evaluates the student learning by examining the student report or poster for evidence of understanding and by giving students exam questions 2020 Q7 2009 Q9 2018 Q12 c 2005 Q7

Appendix 7.4.: Food Tests FTEA with Accompanying Resources by Nic (PST)



Introduction via Observation / Data / Research

Chapter was taught via powerpoint and students were asked to fillout a pre-lab worksheet.

Diagnostic experiment

Testing for Starch, Protein, Reducing sugars and lipids

Using Iodine,Benedicts,Biuret,Emulsion test and brown paper.

Observation / Data Analysis

Students will observe a positve result of the different molecules in different food sources.

Class data will be represented in a table by the teacher.

Principle

Students have learned the skill of testing food sources for starch, protein, Reducing sugars and lipids.

"The Leap": What can we use this information for?

This lab skill can be used to further test foods for the presence of molecules working towards proving some hypothesis.

Question

Is starch used as

Do different sources give different levels of protein?

Is sugar free really sugar free?

Is the emulsion test more reliable?

Working hypothesis

Starch is used as Storage in plants

Different sources contain different protein levels.

Sugar free means Sugar free.

The emulsion Test is better.

Applied experiment

Using the same skills as above to test new sources and compare the results against eachother.

Observation / Data Analysis

Students should be able to accept or refuse their hypothesis based on the experimental results

Conclusion / next steps

Confirm /refute hypothesis

Share data with class

Prepare a report

Segue into *(next experiment)* .

Framework for Planning Practical Work

Title of Experiment: Food Tests

Induction	
<u>Introduction</u>	Students need some understanding of : Different types of nutrients found in food and where they can be found. Balanced diet and some photosynthesis knowledge is required for the deduction.
<u>Diagnostic experiment</u>	
6. Preparation for Experiment	• Pre-lab worksheet and learning checklist to be completed for students to be allowed take part. • Food samples were to be gathered by the students and by the teacher. All solutions needed for the practical were to be sourced. Teacher will have extra resources for the extension exercise. • Prepare a methodology powerpoint. • See: Resources (this folder)
7. Laboratory skill attainment	Skills learnt by students: • Skill attainment involves testing food for different nutrients. • Using and measuring chemicals in the laboratory safely. • Making solutions using solids. • Using a hot plate.
8. Risk assessment	Completed: risk low.
9. List of equipment needed	Food samples Knife Mortar and pestle Water Test tubes Beakers Hot plate Thermometer Iodine Brown paper Ethanol Biurets solution Benedict's reagent

	Camera/phone Extension worksheet
10. Teaching methodology **Induction** **Leap** **Deduction**	Teacher: Will go through methodology slides first so students understand the procedure. Ensure each student has their food sources. Ensure the students have the correct indicators and amounts. Students: Will learn to prepare solutions of a food source and measure out indicators. Will learn how to conduct food tests . We will analyse class data together and an extension worksheet will be handed out to the class. Ask students to come up with a question they would like to investigate. Students will be asked to formulate a hypothesis and accept or deny it with the results of their experiment. The students will gain more practice of the experimental skills. They will relate the use of food tests to real life. The will then make a meal plan for one day for one healthy adult, using the learnt knowledge and their knowledge of a balanced diet.
11. Data collection **Inductive**	Data will be collected in this experiment by analysing indicator colour changes. Also by analysing translucent spots on brown paper. Students will be asked to make comparisons between tests.
<u>Principle</u>	Students now know how to test food for different nutrients and can apply this knowledge in real world applications and are familiar with what foods contain each nutrient
The Leap	
<u>What can we use this information for?</u>	Students can use this knowledge to expand and compare data using new foods or comparing different tests and types of foods.
Deduction – (real world application)	
<u>Question</u>	1) Do plants store energy as starch? 2) Is sugar free really sugar free? 3) Are we picking the best protein sources? 4) Can we trust the brown paper test alone?

Working hypothesis	Expected hypothesis formed by students: 1) Plants store energy as starch. 2) There is no sugar in foods that are labelled sugar free. 3) Some protein sources have more protein than others. 4) Yes, the brown paper test can be trusted. Results found by teacher: 1) Accept hypothesis. 2) Refuse hypothesis (sugar was detected in sugar free seven-up) 3) Hypothesis accepted. 4) Refuse Hypothesis (The Emulsion test showed lipids in foods that didn't show on paper)
Applied experiment	Students will conduct experiments with little assistance. Skills have already been acquired. 1) Students will be given leaf samples. The samples will be boiled. The starch test will be conducted. 2) Sugar free and regular samples of drinks, beans etc will be tested using benedict's reagent. The results will be compared and a conclusion drawn. 3) Multiple sources of protein will be tested. Results will be analysed and compared. The students are looking for a more drastic change in colour for foods with higher protein levels. 4) The brown paper test will be conducted for food samples that we know contain fat. (by labelling) The same foods will be tested using the emulsion test and results recorded and compared.
Observation	Students will observe colour changes and translucent spots.
4. Data collection	Data collected by students will be the colour changes of the indicators and the presence of translucent spots on brown paper. The emulsion test data will be collected by analysing the cloudy material in the water.
5. Data presentation and analysis	As students record data analysis, they should place the results in clear tables. The class will then compile data to back up everyone's information
6. Data reporting	Data will be reported using a picture story to show results. The students will also create a meal plan for a healthy adult using their new knowledge of nutrients.
Evaluation	Teacher evaluates the teaching during the lesson under the following headings: <u>What worked</u> – what aspects of the lesson did students

	understand What needs improvement- where are there gaps in the students' knowledge, where are the gaps in the teacher's knowledge What will I do differently next time Teacher evaluates the student learning by examining the student report or poster for evidence of understanding and by giving students exam questions
LC exam questions relating to this experiment	In separate attachment.

Food tests investigation

Testing for starch

1) Place your food on a dropping tile.
2) Drop a few drops of iodine solution onto the food.
3) Record your results and answer the questions.

Food	Colour	Is starch present?

1) What colour do you see when starch is present?

2) What colour do you see when starch is not present?

Testing for Protein

1) Put your food in a test tube.
2) Add a few drops of the biuret solution.
3) Record the results and answer the questions.

Food	Colour	Is protein present?

1) What foods had protein in them?

2) What colour change did you see when protein was present?

Testing for glucose (a sugar)

1) Add the food to a test tube.
2) Add the Benedict's solution.
3) Put in a water bath and leave for 5-10 minutes.
4) Record your results and answer the questions?

Food	Colour	Is glucose present

1) What colour changes did you see when glucose was present?

2) What did you see when no glucose was present?

Testing for fat

1) Rub the food on the greaseproof paper.
2) Record your results and answer the questions.

Food	Does it turn transparent? (see through)	Is fat present?

1) How could ethanol be used to test for fat?

2) What food contained fat?

Extra Resources for food tests:

The Food Test Mambo - YouTube

Leaving Cert Biology - Chapter 3 (Food) Flashcards | Quizlet as a prelab exercise.

https://www.youtube.com/watch?v=sLP8dcnWnJg video of food test, skip vitamin c step unless it is an extension exercise.

Extra activity: Students prepare a meal plan for a healthy adult after testing the foods with emphasis on a balanced diet.

Pre-Lab worksheet – Food Tests.

1. What are the four functions of food?

2. What is a balanced diet?

3. Describe hoe the test for starch is carried out.

4. Should a control be used in this experiment?

5. Give two sources of starch in a human diet.

6. Give the four functions of carbohydrates in the diet.

7. What are reducing sugars? Name the most common types.

8. Describe how you test for reducing sugars.

9. What elements are always present in proteins?

10. Describe the test for protein.

11. Name a structural protein and state where it is found.

12. What is the composition of a lipid?

13. Describe two tests for lipids.

14. Which lipid test do you think is better? Why?

15. In which food test/s is heat required? Why is this the case?

1.3.1 – 4 Food, Elements, Biomolecules & Sources

Self Assessment

Where is your learning at?

Green: I know it all
Orange: I have some idea – check the answers
Red: I need to start studying this section

	Can You	Green	Orange	Red
1	State the function of food			
2	Name three reasons for requiring food			
3	Name six common chemical elements in food			
4	Name five elements present in dissolved salts			
5	Name 3 trace elements required			
6	Define Biomolecular Structures			
7	Give, in simple biomolecular units, the ratio of the combination of elements?			
8	State the general formula for a carbohydrate?			
9	Name the element components, biomolecular components and sources of: carbohydrates, fats & oil and proteins.			
10	Give examples of the indivisible units that carbohydrates are composed of			
11	State what a vitamin is			
12	Name one water-soluble vitamin Name one water in-soluble (fat-soluble) vitamin			
13	List the sources of these vitamins			

Appendix 7.4.6

Extra Resource: Analysis of completed result.

The majority of the students came up with a hypothesis for each experiment after reading the extension worksheet. When asked, the students were mostly interested in doing the sugar experiment but each group undertook two extension exercises.

The experiment went well. Each student had already mastered the skills to carry out the testing of different food sources and required little to no help to complete the tests.

The result of the starch test on a leaf was as expected. The leaf turned blue/black in the presence of starch. In future I would boil and prepare the leaves before class, the students did need to be guided on how to do this. We used leaves of different trees and bush varieties.

The protein test was disappointing. The Biurets reagent, we think may have been out of date so the results were inconclusive although there were slight colour changes. This was a big lesson to me. In future, when I have my own classes I will always check the date.

The brown paper vs emulsion test was a success. We tested and compared food samples that we knew contained fat because of their packagings nutritional information. One food that did not produce a translucent spot, was positive for lipids in the emulsion test. The results are as follows in the pictures.

Some students came to the conclusion that the brown paper only works to a certain level of fat content. This could be expanded further using foods of varied fat content.

Students tested seven up against seven up free. The test worked well and showed a slight positive test in the sugar free sample, which students were shocked at. The nutritional information stated there was 0% sugar in the seven up free. The colour change is miniscule but apparent when compared to the control.

RISK ASSESSMENT FOR SCHOOL SCIENCE ACTIVITIES

Name and nature of activity	Food Tests – To test food samples for starch, proteins, lipids and reducing sugar.		
Location and date of activity			
Name of teacher(s)	Nicole Lawlor		
Activity type	☐ Teacher demonstration X Student activity		
General equipment	**Type of hazard**		**Control measures**
	☐ Radiation ☐ Electrical ☐ Thermal ☐ Projectiles X Sharps X Other		☐ Relevant signage ☐ Perspex safety shield X Sharps container ☐ Glassware free from crack or chips X Safety glasses ☐ Thermal gloves X Other – see below
Risk rating	Medium		
Chemicals used and produced	**Type of Hazard**		**Control measures**
Iodine Benedict's reagent Ethanol Biurets solution	☐ Explosive ☐ Flammable ☐ Oxidizing ☐ Gases under pressure ☐ Corrosive X Irritant	☐ Acute toxicity X Healthhazard ☐ Chronic health hazard ☐ Environmental ☐ Other	X Limit quantity ☐ Perspex shield ☐ Ventilation ☐ Fume cupboard X Safety glasses X Lab coat X Gloves ☐ Safety shower ☐ Other
Risk rating	low		
Biological materials	**Type of Hazard**		**Control measures**
Food sources Be aware when cutting food samples.	☐ Biohazard ☐ Dust/aerosols X Sharps ☐ Manual handling ☐ Other		☐ Autoclave/sterilize ☐ Disinfectant X Sharps container ☐ Dust mask ☐ Safety glasses ☐ Gloves ☐ Other – see below
Risk	Low		

rating	
Waste produced	**Waste disposal procedure**
Food waste mixed with chemical indicators.	☐ Pre-treatment of waste X Sink with water ☐ Regular waste ☐ Licenced hazardous waste ☐ Other
Risk rating	
Standard operating Procedures	
X I have read the relevant Standard Operating Procedure X I am experienced/trained in using all the equipment listed X All chemicals used and produced are approved for use X I have read the current safety data sheets (SDS) for all chemicals used and produced X I am aware of safety guidelines for using all chemicals, materials and equipment X I will follow approved guidelines for waste disposal X I am aware of first aid procedure if required	
Other comments: If the experiment is carried out during covid, it is important that students do the work by themselves. Always wearing masks and the equipment to be sanitised before and after use by the teacher.	
Conclusion: X Risks not significant now and not likely to increase ☐ Risks significant but effectively controlled at the moment ☐ Risks significant and not adequately controlled at the moment ☐ Uncertain about risks, more detailed assessment required	
Assessment carried out by:Nicole Lawlor	
Assessment approved by:**(experienced lab teacher)**	
This risk assessment assumes that the activity will be conducted in a science teaching area with the following facilities: shut-offs for electricity, gas if applicable, water and regular testing and tagging of portable appliances; emergency contingencies such as evacuation/emergency plans, appropriate fire extinguishers and fire blankets, spill kits, hand washing facilities, eyewash/safety shower and first aid supplies.	

RISK RATING	BROAD CATEGORIES OF COMBINATIONS OF SEVERITY AND LIKELIHOOD. Considering existing controls
LOW RISK	1. Injury or material loss unlikely though conceivable. 2. Exposure unlikely to cause health problems but if it did would be such as to be easily treated with no lasting effects e.g. minor first aid injuries
MEDIUM RISK	1. Unlikely possibility of fatality, serious injury or significant material loss. 2. Possibility of minor injury (first-aid) to a small number of people or ‘3 day illness/injury to one person. 3. Exposure may have acute (immediate) effects which may have lasting effect
HIGH RISK	1. Possibility of fatality, serious injury or significant loss. 2. Possibility of minor injury to a larger number of people. 3. Exposure may have chronic (long-term) effects or could result in death.

	4. Direct breach of legislation, Approved Code of Practice or HSA/HSE(Irl)/HSE(UK) guidelines.

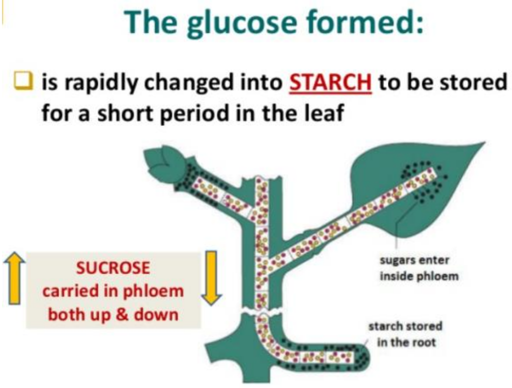
RISK RATING	ACTION REQUIRED
LOW RISK	No additional controls are required, Consideration may be given to a more cost-effective solution that will not increase the risk and will not impose any additional financial or organisational burden (Reasonably Practicable).
MEDIUM RISK	Efforts should be made to reduce the risks but the costs of prevention should be carefully measured and limited. Increased supervision, training may be required.
HIGH RISK	Stop the activity, evacuate the workplace. Work should not be restarted until the risk has been reduced by additional control measures.

GHS - Hazard Pictograms and Related Hazard Classes

		
Exploding Bomb • Explosives • Self-reactives • Organic Peroxides	**Corrosion** • Skin corrosion/burns • Eye damage • Corrosive to metals	**Flame Over Circle** • Oxidizing gases • Oxidizing liquids • Oxidizing solids
		
Gas Cylinder • Gases under pressure	**Enviroment** • Aquatic toxicity	**Skull & Crossbones** • Acute toxicity (fatal or toxic)
		
Exclamation Mark • Irritant (eye & skin) • Skin sensitizer • Acute toxicity • Narcotic effects • Respiratory tract irritant • Hazardous to ozone layer (non-mandatory)	**Health Hazard** • Carcinogen • Mutagenicity • Reprodcutive toxicity • Respiratory sensitizer • Target organ toxicity • Aspiration toxicity	**Flame** • Flammables • Pyrophorics • Self-heating • Emits flammable gas • Self-reactives • Organic peroxides

Starch gives humans energy, what about in plants?

The test for starch in food is useful to examine what foods are good sources of the nutrient. Starch Is a carbohydrate that is vital to humans but also very important in plants. Starch is the main energy storage in plants as we know from the study of photosynthesis. Most green plants store energy as starch. The extra glucose is changed into starch which is more complex than glucose (by plants). Young plants live on this stored energy in their roots, seeds, and fruits until it can find suitable soil in which to grow. Plant cell walls are strong and can not be penetrated by solutions which may be a limiting factor in testing.



Protein Levels, Are we eating the best sources of protein?

Protein is an essential nutrient, responsible for multiple functions in your body, including building tissue, cells and muscle, as well as making hormones and anti-bodies. Everyone needs protein in their diet, but if you do endurance sports or weight training you may benefits from increase your protein intake, as well as factoring it into your training routine at specific times to reap its muscle-building benefits. As protein is so important for bodily functions, how are we sure we are getting enough and choosing the best sources? Are some sources of protein better for athletic people.

Balanced diets are important, especially when it comes to sugar.

There are some damaging effects that sugar can have on your body. Sugar increases the Risk of Diabetes, Heart Disease, and Obesity. It makes your blood sugar unstable. If you eat too much sugar, your glucose level will spike and plummet and this could lead to diabetes. Too much sugar is not good for you, but this doesn't mean we can cut it out altogether. There are many advantages to sugar in our diet too including giving us energy. Everyone likes a sweet treat now and again! But how can we be sure we are consuming the amount of sugar that it says on the label.

Two types of testing.

The brown paper test for lipids is a great way of visualising if foods contain any lipids in an oil form! The emulsion test is also a great indicator to lipids being present in foods. A lipid is a macrobiomolecule that is soluble in nonpolar solvents such as ethanol. Having two methods of testing for a nutrient is helpful as we can compare results and come to a scientific conclusion that is greatly backed up with experimentation. Sometimes one form of testing may not give the results we expected. Why would this be the case?

To test for:

- Starch
- Protein
- Reducing Sugar
- Lipids

Balanced Diet

- It is important for people to have a balanced diet to maintain healthy lifestyles.
- Different molecules can be found in different types of foods.

Practical Objective:

Objective: from Syllabus,

Conduct a qualitative test for:

- starch
- fat
- a reducing sugar
- a protein.

Extra task:

So far we have not talked about where to find each molecule, using the four food tests today we will group together foods and come up with a food plan for one day for a healthy adult. Keeping the idea of a balanced diet in our preparation.

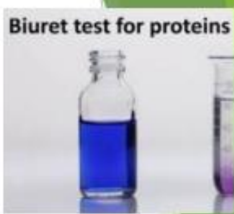
Test For starch:

Chemical Indicator used: Iodine

Safety precautions: Wear gloves, lab coat and goggles.

1) Prepare some samples of different foods.
2)
3) Using a dropper, add two or three drops of iodine to each food source.
4)
5) Examine each specimen closely and observe for any indication that starch is present.

Test for Protein:



Chemical indicator used: Biuret solution.

Safety precautions: Gloves, lab coat, goggles.

1) Place the food samples into test tubes.
2)
3) Ensure the samples are in solution form.
4)
5) Add an equal volume of Biuret solution to each sample.
6)
7) Examine for any presence of protein.
8)

Test for Reducing Sugars:

Chemical Indicator used: Benedict’s Reagent.

Safety precautions: Gloves, goggles, lab coat, hot water danger.

1) Place food samples solutions in test tubes.
2)
3) Add equal volume of Benedict's Reagent to each sample.
4)
5) Heat the samples in a water bath but do not boil them, for ten minutes.
6)
7) Analyse the samples for indication of the presence of reducing sugars.

Test for lipids:

Method 1: Emulsion Test

1) Add food source to a test tube with some ethanol.
2) Pour the solution into a test tube of water leaving the food residue behind.
3) Look for any changes that may indicate lipids are present.

Method 2: Brown Paper test

1) Rub food source on brown paper.
2) If Lipids are present a translucent spot will appear.

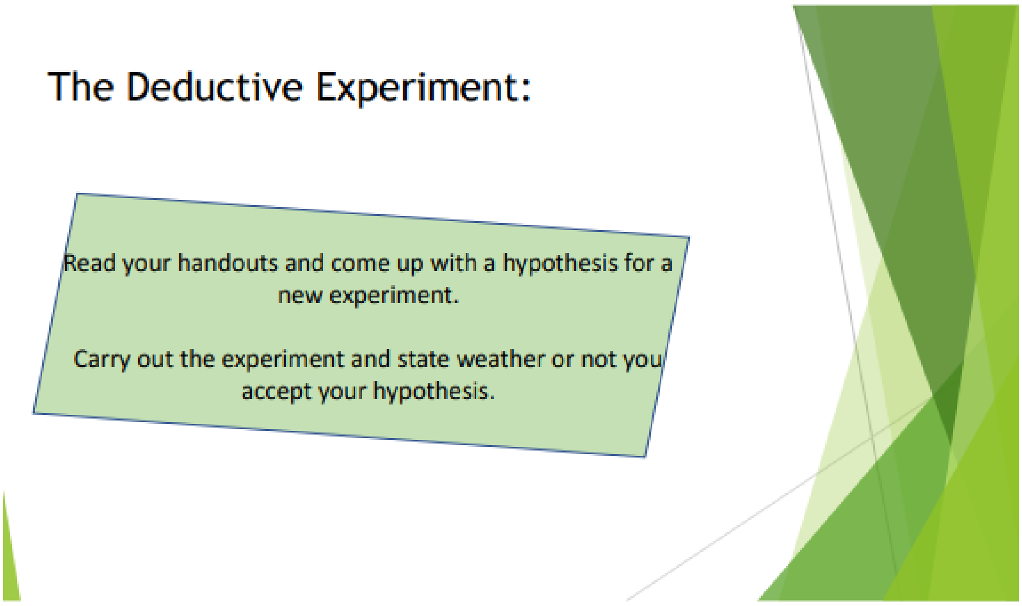
Extra Questions

- 1)Why does the Benedict's reagent turn different colours when sugar is present?
-
- 2) Were there any foods that contained more than 1 nutrient? Why is this?
-
- 3) Should a balanced diet contain all these foods? Give your reasons why/why not.
-

Compiling Class Data:

Place a tick where the molecule is present. (multiple ticks per box)

FOOD:	STARCH	PROTEI N	LIPID	REDUCI NG SUGAR

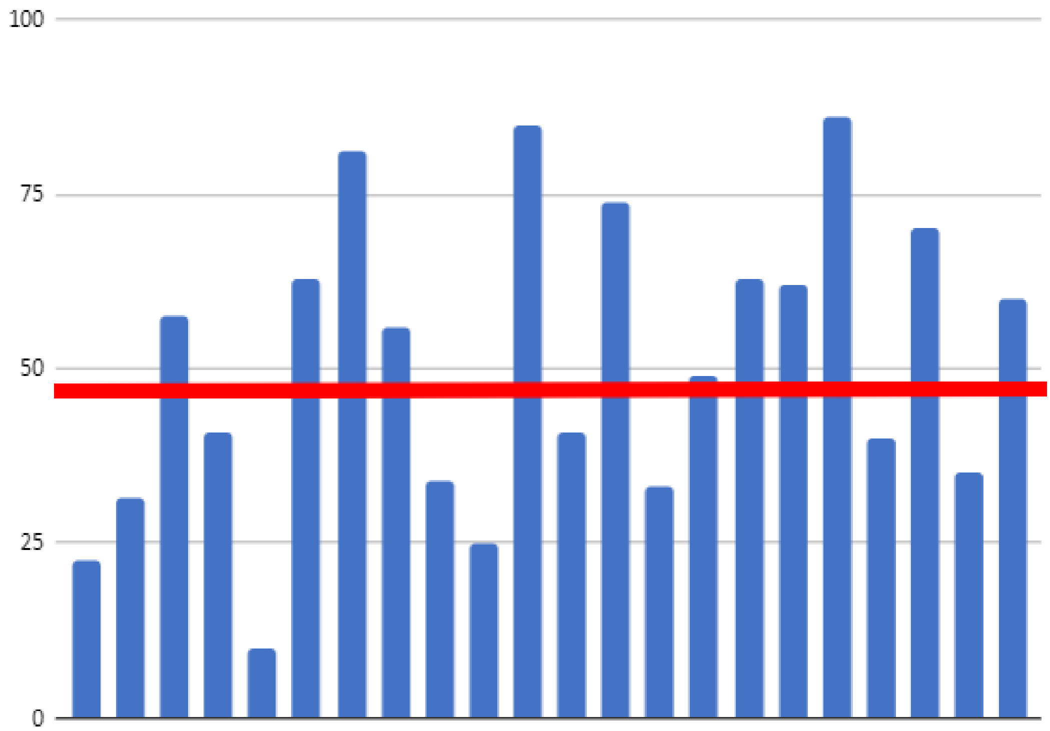

The Deductive Experiment:
Read your handouts and come up with a hypothesis for a new experiment.
Carry out the experiment and state weather or not you accept your hypothesis.

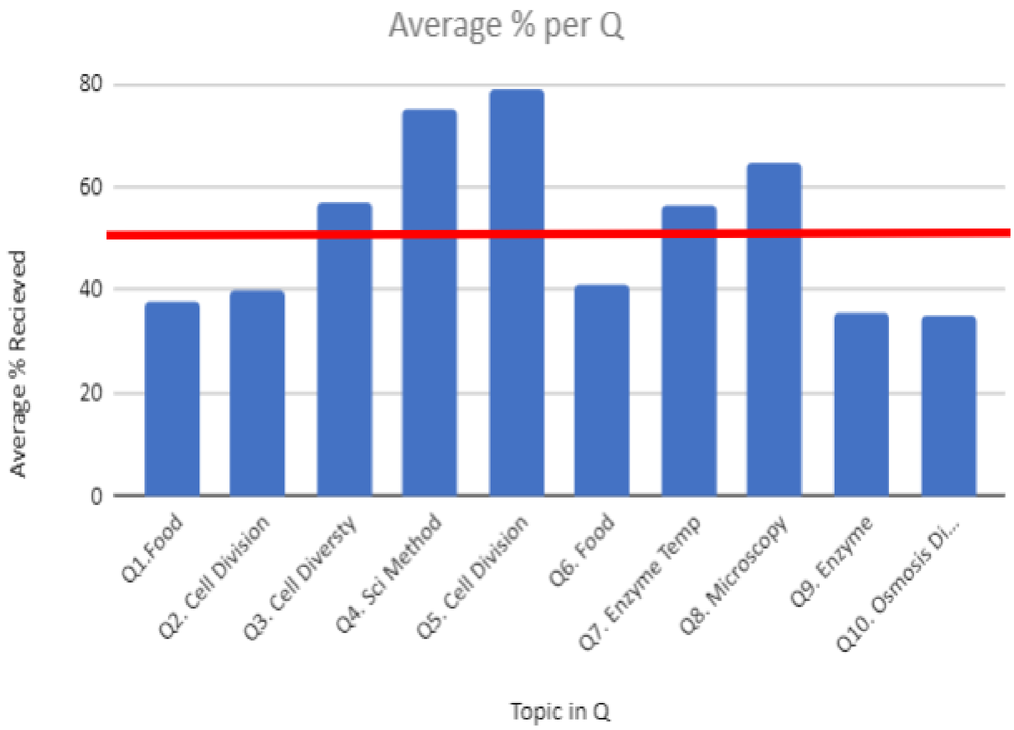
Appendix 7.5 Pete's Exam Analysis of Students

Sci Method & Char of Life	The Cell and Microscope	Osmosis & Diffusion	Cell Division	Enzymes

Christmas Exam Overall HL		Q1.Food	Q2. Cell Division	Q3. Cell Diverstiy	Q4. Sci Method	Q5. Cell Division	Q6. Food	Q7. Enzyme Temp	Q8. Microscopy	Q9. Enzyme	Q10. Osmosis Diffusion
22.5		8	0	9	15	15	8	24	30	12	0
31.6		12	15	6	12	18	4	15	15	9	0
57.5		8	0	15	9	15	0	6	24	0	12
41		4	6	0	12	17	4	12	30	18	9
10		16	9	20	20	17	16	30	24	18	12
63		4	9	12	18	18	12	18	27	15	6
81		4	3	15	15	17	0	21	0	3	18
56		0	0	9	10	17	0	24	15	9	15
34		8	12	12	20	15	18	6	30	27	15
25		4	0	9	12	17	6	24	6	9	15
85		0	15	3	15	16	20	27	21	18	0
41		8	12	20	18	15	8	24	24	6	21
74		8	6	9	18	8	2	21	30	12	6
33		20	15	20	12	18	8	6	9	12	15
49		4	9	9	12	16	4	24	12	0	3
63		12	0	3	6	18	0	0	19	0	0
62		16	18	9	18	8	8	12	24	9	15
86		4	17	20	20	17	20	21	24	30	24
40		8	6	12	17	18	10	24	3	6	24
70		6	0	0	18	18	14	6	18	18	0
35		12	12	20	15	15	2	21	21	0	4
60		0	12	18	18	15	16	6		3	17
Average %		Average	Average	Average	Average	Average	Average	Average	Average	Average	Average
50.89090909		7.545454545	8	11.36363636	15	15.81818182	8.181818182	16.90909091	19.33333333	10.63636364	10.5
	Average %	37.72727273	40	56.81818182	75	79.09090909	40.90909091	56.36363636	64.44444444	35.45454545	35
		Short Q Average		Exp Q Average		Long Q Average		Average % Per Q			
	Mark/20	10.98484848	Mark/30	18.12121212	Mark/30	10.56818182		52.08080808			
	Av%	54.92424242	Av%	60.4040404	Av%	35.22727273					

Average student above 40									
61.9									





Appendix 7.6 The SEOS for the target setting observations

Skills as outlined in the syllabus document	Breakdown of syllabus skills	Micro-scopy	Enzymes - Investigation of catalase activity	Enzymes - Effect of temperature	Enzymes - Investigation of catalase activity	Enzymes - Assessment	Average score from scoping stages
Following instructions	Follow instructions step by step	4	5	5	5	5	3.6
	Listen carefully to the teachers instructions	5	5	5	5	5	4.9
Correct manipulation of apparatus	Labelling solutions and equipment	0	5	5	0	0	2.8
	Using given apparatus in the correct manner	5	5	5	5	5	2.5
	Correct preparation of solutions and mixtures	4	5	5	5	5	2.1
	Using and/or measuring time as a variable	n/a	5	5	5	5	0.25
	Correct use of a measuring instrument	5	5	5	5	5	2.7
	Take an accurate reading	5	5	5	5	5	0.4
Observation	Accurate observation (using equipment)	4	5	5	5	5	2.7
	Appropriate observation of the phenomenon under study – (was the correct aspect of the phenomenon observed)	3	5	5	5	5	3.2
	Complete observation of the phenomenon under study (producing the correct phenomenon)	3	5	5	5	5	1
Recording	Careful recording of data	5	5	5	5	5	1.9
	Write up the procedure	5	5	5	5	5	3.5
	Perform calculations as required	n/a	5	5	5	5	3
	Tabulate results	n/a	5	5	5	n/a	2
	Draw diagrams or graphs to represent data collection	n/a	5	5	5	0	1.9
Interpretation	Draw reasonable conclusions from your observations and results	4	5	5	5	5	1.6
	Conclusions should ensue from hypothesis being tested	4	5	5	5	5	0
	Coherent final interpretation that explains how results are reached	2	5	2	2	5	1
Application	Awareness of any other application of what was learned	1	5	2	4	5	0.9
	Consider the results in a wider context	2	4	2	3	n/a	0.2
	Identify an activity that serves as a model for further investigation	4	4	1	4	n/a	0.4
Practical enquiry	Consideration of ambiguous results	3	n/a	n/a	3	5	0.7

	Repetition of activity if necessary	5	n/a	n/a	5	5	0.6
	Design of a new activity	4	5	5	5	5	0.4
Use of the scientific method as outlined in the syllabus documents	Making initial observations	4	5	5	5	5	0
	Forming an hypothesis						
	Designing a controlled experiment	4	5	5	5	5	0
	Reporting and publishing results	3	5	5	5	5	0
	Appreciation of errors	4	5	5	5	5	0
	Use of controls to reduce errors	4	2	2	2	5	0.7
	Collecting data	5	0	0	0	5	1.3
	Interpreting data & reaching conclusions	5	5	5	5	5	1.9
	Placing conclusions in the context of existing	3	5	3	5	5	1.6
	knowledge & development of theory and principal	3	5	4	5	5	0.9

Rating Scale:
0 = recommended by syllabus documents but not a feature of this experiment
1 = Teacher completes this part with no input from students
2 = Teacher mostly completes this part with a little input from students
3 = Most students complete this part with some assistance from teacher
4 = Most students complete this part with a little assistance from teacher
5 = Most students complete this part without assistance from teacher
* Teacher showed a data set to class because the phenomenon was not produced