frontiers in Education

ORIGINAL RESEARCH
published: 27 April 2021
doi: 10.3389/feduc.2021.666608

Check for updates

Teachers' Perspectives on Achieving an Integrated Curricular Model of Primary STEM Education in Ireland: Authentic or Utopian Ideology?

Thomas Delahunty[1,2*†], *Mark Prendergast*[2†] *and Máire Ní Ríordáin*[2†]

[1] *Department of Education and Social Justice, School of Education, University of Birmingham, Birmingham, United Kingdom,* [2] *School of Education, University College Cork, Cork, Ireland*

OPEN ACCESS

Edited by:
Olivia Fitzmaurice,
University of Limerick, Ireland

Reviewed by:
Maria Ryan,
Mary Immaculate College, Ireland
Veronica Ryan,
University of Limerick, Ireland

***Correspondence:**
Thomas Delahunty
thomas.delahunty@icloud.com

† *These authors have contributed equally to this work*

Specialty section:
This article was submitted to STEM Education, a section of the journal Frontiers in Education

Received: *10 February 2021*
Accepted: *26 March 2021*
Published: *27 April 2021*

Citation:
Delahunty T, Prendergast M and Ní Ríordáin M (2021) Teachers' Perspectives on Achieving an Integrated Curricular Model of Primary STEM Education in Ireland: Authentic or Utopian Ideology? Front. Educ. 6:666608. doi: 10.3389/feduc.2021.666608

Integrative science, technology, engineering and mathematics (STEM) education is heralded as a promising model for effective learning of 21st century STEM literacies and has been suggested as an approach that increases student motivation and engagement. In recent years Ireland has introduced policy with a renewed emphasis on integrated STEM education across all levels of schooling and paying particular attention to the early years and primary settings. The available international literature cites many concerns with potential barriers and failures to achieve authentic integration of the various STEM disciplines in educational contexts. An important determinant of the success of integrated STEM curricula are the backgrounds and attitudes of the individual teachers, as well as supports/experiences in designing and implementing an integrated curricular approach. In the Irish context, this is often in conflict with prescribed overloaded curricula and a subject focussed education system. Therefore, research is required into primary school teachers' perspectives on achieving a truly integrated model of STEM education, particularly in the Irish context. This study employed a qualitative approach using semi-structured interviews with a sample of practicing teachers ($N = 6$) to gather perspectives on the potential and challenge of integrating STEM in their respective experiences. These teachers were enrolled in a practice orientated module on STEM education as part of their postgraduate studies. The data gathered was analysed to ascertain these teachers' perspectives on the supports needed to overcome the challenges of integrating STEM subjects within their professional settings. Essentially, the findings of this study will discuss whether such an integrated STEM model is an authentic or utopian ideology.

Keywords: STEM education and learning, integrated curricular model, teachers' perspectives, primary level, Ireland

INTRODUCTION

Increasing participation rates in science, technology, engineering, and mathematics (STEM) education has become a global imperative for a variety of reasons including economic and societal advancement. This goal is echoed in most educational systems around the world and initiatives aimed at challenging issues such as gender equity (cf. Goy et al., 2018), low participation rates among socioeconomic classes (cf. Plasman et al., 2020), underrepresentation of sexual minorities (cf. Sansone and Carpenter, 2020) and people of colour (cf. Kang et al., 2019) in STEM education are prolific. This overall agenda, concerning the elevation of STEM participation, is well represented in the case of Ireland and can be seen in many governmental decrees and documents in recent years. In 2017, the Department of Education and Skills introduced a policy statement for STEM education in Ireland (cf. Department of Education and Skills [DES], 2017). This document sets out the aims of government in relation to the provision of high-quality STEM education across all levels of educational provision. The primary aim being to "ensure we have an engaged society and highly skilled workforce in place" (Department of Education and Skills [DES], 2017, p. 5) through the development of "curiosity, inquisitiveness, critical-thinking and problem-solving" (p. 5). In addition, the policy places special emphasis on interdisciplinary and transdisciplinary capabilities. Specifically, teachers are tasked with using "a cross-disciplinary approach incorporating pedagogical content knowledge and understanding developed in and across the four disciplines" (Department of Education and Skills [DES], 2017, p. 15).

While the approach of integrated STEM education is promoted in the national policy agenda, the definitions provided of STEM and the responsibilities placed on teachers neglects critical perspectives important to its realisation. The individual subjects comprising the STEM acronym contain discreet historical legacies that must be acknowledged and problematised. This is coupled with issues realising cross-disciplinary subject integration in a heavily mandated national curriculum, for both primary and secondary educational contexts. This places inordinate pressures on teachers and students at the best of times. Moreover, this policy, with an extensive list of requirements for the teacher, is currently placed in an educational landscape where no research is available on primary level teachers' perceptions of integrated STEM or discourse surrounding challenges implementing these policy goals in the classroom. Given the recent international literature and empirical evidence complicating definitions of integrated STEM (e.g., Kelley and Knowles, 2016) and exploring barriers to its effective implementation (e.g., Shernoff et al., 2017), it is prudent to address this dearth of research in the Irish context. This article aims to explore the perspectives of Irish primary teachers on the challenges of integrating STEM in their respective schools and classrooms. It provides initial evidence and critical analysis of the reality of integrated STEM education in the Irish educational context. The paper first considers the nature of integrated STEM education followed by a review which critically analyses the core challenges to the effective realisation of integrated curricular approaches, from the Irish perspective, before introducing the qualitative study.

LITERATURE REVIEW

Defining Integrated STEM Education

Integrated STEM has long been difficult to define (Honey et al., 2014). Nadelson and Seifert (2017) determine that there are many reasons for this which include the many varying contexts and the need for flexibility and inclusivity. They define integrated STEM as the effortless amalgamation of content and concepts from multiple STEM disciplines. The integration takes place in ways in which the knowledge and ideas of the various disciplines are considered together in the context of a problem, project, or task. Similarly, Stohlmann et al. (2012) assert that integrated STEM education is an effort to combine the various disciplines into one topic that is linked to a real-world problem. Notably, they determine that integrated STEM education does not always have to involve all four disciplines of STEM. In line with this, Sanders (2009) describes integrated STEM education as approaches that "explore teaching and learning between/among any two or more of the STEM subject areas" (p. 21). Likewise, Moore et al. (2014) defined integrated STEM education as "an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems" (p. 38). Thus, for the purpose of this research, and in keeping with the aforementioned authors, and the work of Kelley and Knowles (2016), we define integrated STEM education as the approach to teaching and connecting the STEM content of two or more STEM domains with the aim of enhancing student learning and applying to real-life contexts. This definition is also in keeping with the recently published Irish STEM Education Policy Statement (2017–2026) released by the Department of Education and Skills [DES] (2017) which highlighted the interdisciplinary nature of STEM and the importance of learners working within authentic contexts.

However, it is important to note that the extent of the interdisciplinary nature of integrated STEM can vary considerably. For example, Honey et al. (2014) provide a basic definition of integration as "working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines" (p. 52). A more comprehensive perspective on STEM integration is featured in Vasquez et al.'s (2013) work, where different forms of interdisciplinary incorporation are displayed along a continuum of increasing levels of integration, with progression along the continuum involving greater interconnection and interdependence among the disciplines. While it may be more difficult to achieve, greater integration can be more efficient as multiple STEM concepts and ideas may be effectively addressed simultaneously (Drake and Burns, 2004).

There are many other benefits associated with integrated STEM education. "Research indicates that using an interdisciplinary or integrated curriculum provides opportunities for more relevant, less fragmented, and more stimulating experiences for learners" (Furner and Kumar, 2007, p. 186). Instead of teaching content and skills and hoping students will see the connections to real-life application, an integrated approach seeks to locate connections between STEM subjects and provide a relevant context for learning the content (Kelley and Knowles, 2016). More broadly, Stevenson and Carr (1993) report that student interest and achievement benefitted from integrated instruction. An integrated approach requires that students and teachers are aware of when and how to apply knowledge and practices from across the STEM disciplines. Such application of knowledge allows the students to develop even deeper understanding of the STEM concepts and processes and how they are interrelated (Krathwohl, 2002). For example, studies have shown that integrating mathematics and science has a positive impact on students' achievement (Hurley, 2001). Other benefits include that it is student centred and improves higher order thinking and problem-solving skills (Stohlmann et al., 2012). Stohlmann et al. (2012) also note that integrated STEM activities allow teachers to focus on wider concepts that are connected between subjects, as well as being able to motivate students to careers in STEM fields. On the other hand, not all studies have determined such benefits. For example, Wallace et al. (2001) described a project based around the integration of mathematics, science, and technology in which connection-making, cooperation amongst students, and increased interest and excitement were not evident. More recently, Tytler et al. (2019) note how serious questions have been raised by many researchers about the capacity of integrated STEM models to support significant disciplinary learning across the various domains. These questions highlight the various challenges to achieving truly integrated STEM curricula.

Challenges to Achieving True Integration

As noted in the previous section, integrated STEM involves conditions that require the application of knowledge and practices from multiple STEM disciplines to learn about or solve transdisciplinary problems. Although the integration of STEM disciplines is increasingly advocated in the literature, studies that address multiple disciplines appear scant with mixed findings and inadequate directions for STEM advancement (English, 2016). Perspectives on how discipline integration can be achieved are varied, with reference to challenges involving sociohistorical issues, existing systems and structures, and matters involving teaching and learning.

Sociohistorical Issues and Subject Monopolies

Many attempts at a definition of STEM, even if for altruistic reasons, tend to ignore or misapprehend the individual subject characteristics (Takeuchi et al., 2020) and histories (McGarr and Lynch, 2017) within respective educational systems. This is certainly relevant to the current research, as the evolution of the Irish education system is itself a complex picture imbued with historical influences from imperialistic and colonial oppression. Limond (2010) sums this up concisely describing the Irish education system of the 19th century as "working to favour the interests of the British metropolitan centre over the Irish periphery by disciplining the Irish population and shaping the workforce through school structures and . . . curriculum" (p. 452). This is not even to mention the obvious influences of neoliberal and capitalist ideologies on forcing the issue of STEM education for economic growth and societal development (Carter, 2017). It is therefore necessary to consider the evolution and standing of the individual STEM disciplines in the context of the Irish education system.

While a comprehensive review of the sociohistorical evolution of the Irish education system is beyond the scope of this article, it is important to note at the outset that the evolution of each of the STEM disciplines, is drastically different. The fragmented treatment of the STEM disciplines as subjects in Irish education is not a unique global phenomenon. Mathematics has traditionally held greater esteem as a subject emerging from the classical-humanist orientation of education (McGarr and Lynch, 2017) whereas the science, technology, and engineering subjects were somewhat ignored under this tradition (Carr, 1998). In the Irish context, the classical-humanist orientation, with its emphasis on intellectual life and preservation of culture (Carr, 1998), held a large sway on the educational milieu of the 19th and much of the 20th centuries due to issues of colonialism, post-colonialism, national identity seeking, global capitalism, vocationalism, and neo-liberalism (Heraty et al., 2000; Coolahan, 2001, 2017; Barry, 2014). In addition, the dominance of the Catholic church in Irish education meant that for a significant period of time, STEM education was largely suppressed and treated with apathy and even hostility (Dowling, 1961; O'Leary, 2012).

In the latter stages of the 20th century changing economic and educational contexts as well as significant changes in policy relating to all levels of education in Ireland, meant that science, technology, and engineering found ostensibly better representation in the school curriculum. In particular, the study of science began to find a more central role in education, primarily due to the link between scientific advancements and economic competitiveness (O'Leary, 2012). While Wallace (1972) broadly asserts that "most countries, including Ireland, had long accepted that science was a useful and necessary school subject" (p. 58), this is not reflective of the true sociocultural tensions that existed during the 20th century between the catholic church and the progressive scientific movements of the time (O'Leary, 2012). From a historical perspective, the development of targeted initiatives in science in Irish education is a relatively recent (since 1960s) endeavour.

The curricular status of science and mathematics has been preserved and crystallised in more contemporary times due to the link with university entrance requirements (Young, 1999). In the Irish context, entrance to university for the majority of undergraduate applicants is based on the results of their formal grades in their summative examinations, the Leaving Certificate[1], at the end of second-level education. What is colloquially known as the "points" system (Hennessy et al., 2011) is responsible for a great deal of competitiveness in second-level education in Ireland, with a strategic approach adopted by students to maximise grades and points for achievement of a desired third-level course offer (Lynch and McGarr, 2016). The study of mathematics and science is culturally legitimised in the Irish second-level context due to the requirements of science and mathematics for many university undergraduate degree programmes (Hyland, 2011; McGarr and Lynch, 2017). The importance placed on science and mathematics is unsurprising when considering the neo-liberal and neo-vocational influences that have burdened education and curricula in Ireland since the 1960s (Kirwan and Hall, 2016; Lynch and McGarr, 2016). This neo-vocational ideology

[1] For more information on the Leaving Certificate in Ireland see Hyland (2011).

inserts a backwash effect upon schooling at lower secondary and primary levels and results in a cultural legitimisation of mathematics and science among students, teachers, and parents. Globally, mathematics and science studies, within primary and second-level education, have been espoused as critical for a solid foundation in STEM fields at university and subsequently for advancing economic concerns (e.g., Department of Education and Skills [DES], 2011). This is not the case when viewing the technology-based subjects (technology and engineering) in Ireland.

As the technology subjects have evolved from vocational educational paradigms (Kananoja, 2009; Seery et al., 2011; Clark, 2012), they are often considered as lower status subject offerings, particularly in the Irish context (Trant et al., 1999; McGarr and Lynch, 2017). Technology subjects, such as engineering, were not one of the Leaving Certificate study options prior to 1966 (Coolahan, 1981), and as such before this time the focus of technical subjects was on preparation for employment and economic contribution and were examined in the separate intermediate level "Group Certificate" (Seery et al., 2011; Clarke, 2014; Coolahan, 2017). This bi-partite system placed the technology subjects within vocational schools, with science and mathematics, at leaving certificate level, confined to academic secondary schools. Despite this changing in the latter half of the 20th century, and with the technology subjects offered at Leaving Certificate Level today, there remain significant differences in the curricular standing of the technology subjects when compared with those of mathematics and science. New technology subjects (Design and Communication Graphics and Technology) at Leaving Certificate level were introduced in 2007, and provided a radical curricular shift to design-based education as part of a general educational alignment (Seery et al., 2011). Despite this, there still remains aspects of the vocational heritage of these subjects through the preservation of hegemonic instructional practices (Delahunty et al., 2020). As McGarr (2011, p. 127) notes, "similar beliefs [about the value of technology education] exist within society where it continues to be seen as a masculine subject and suited to the more 'non-academic' students and those that are increasingly disengaged with school." The subordinate placing of technology and engineering at primary levels can also be seen in recent policy and reporting from government. For example, the report on the STEM education landscape in Ireland (cf. Stem Education Review Group., 2016) gives an overview of STEM subjects at primary level. Here, science, technology, and mathematics are signalled as key components of the curriculum however, technology in this context is conflated with ICT as a means of supporting learning which misrepresents the philosophy of technology education entirely.

In a recent paper, McGarr and Lynch (2017) take a perspective from Bernstein's curriculum coding theory to illustrate that technology and engineering have not had the same length of time, being relatively new to the Irish second-level landscape, to establish clear subject boundaries. This has resulted in opaque definitions of the technology subjects when compared to science and mathematics with a lack of value placed on technology subjects for matriculation purposes. Taking a curriculum design perspective, it is clear that the technology subjects have a very different make up and philosophy compared to those of mathematics and science. Indeed, moving briefly to a third level context, the likes of engineering and technology would be seen as having foundational knowledge based on science and mathematics and hence seen as somewhat subservient in the hierarchy (Lynch and McGarr, 2016). It is also important to note that curriculum does not exist in a cultural vacuum but reflects the values heralded by society (Westheimer and Kahne, 2004). With the dominance of the Leaving Certificate in the Irish national psyche (McCormack et al., 2020) and its maintenance of middle-class advantage (Canny and Hamilton, 2018), it is easy to see how the technology subjects, with their historical vocational alignment to the working classes (Clarke, 2014) are treated as unequal in the concept of STEM education.

While this section has sketched the sociocultural standing of the STEM subjects in the Irish context, it has not focussed on issues pertaining to the general design of school systems or the structuring of curricular provision. These issues which encompass factors such as the schools' autonomy to offer certain subjects over others, timetabling, and the insertion of prerequisites for certain levels of study can all impact on transdisciplinary thinking and subject uptake (Smyth and Hannan, 2006).

Systemic and Structural Perspectives

The process of integrating STEM subjects in authentic contexts is undoubtedly a complex challenge for all. The reality is formal education systems currently silo STEM subjects within a rigid structure with defined subject curricula, class times, and examinations (Kelley and Knowles, 2016). Central to the argument for the adoption of an integrative approach is the belief that this current silo approach does not allow for students to make connections across the various disciplines. Typically, students see subjects as isolated blocks of knowledge with little or no links. This view can be largely attributed to the practice of dividing the school week into timed sections of instruction of separate subjects. For example, in Ireland, there are eleven mandatory curriculum subjects at primary level, including mathematics and science. All Irish primary schools are required to allocate 8.5 h of instruction per week for language (Irish and English) and 4 h 10 min per week for mathematics (Department of Education and Skills [DES], 2011). The subject of science is contained within the primary curriculum under the subject grouping of *Social, Environmental, and Science Education*, which also caters for history and geography education (National Council for Curriculum and Assessment [NCCA], 1999). There is no specific mention of technology or engineering, as subject offerings, in the curriculum documents and any discussion of the concept of technology limits the scope to ICT and digital education. While these are times specified in curricular policy, it is hard to determine the actual time spent on individual subjects of STEM within the primary classroom. McCoy et al. (2012) utilised the Growing up in Ireland database to answer this question and found that on average, just 1 hour is devoted to science within the primary curriculum compared to English (over 4 h), Irish (approximately 3.5 h), and mathematics (approximately 3.75 h). Interestingly, they found an interaction effect of teacher gender on the time spent on mathematics and science, with female teachers spending less time than their male counterparts on these element of the curriculum (McCoy et al., 2012, pp.13–15). This points to an area of concern regarding the interaction of teacher characteristics with STEM instruction and aligns with the broader issues and concerns on gender equity in STEM education generally (e.g., Wang et al., 2017; Goy et al., 2018).

These subjects are typically taught by a generalist teacher and according to the Department of Education and Skills [DES] (2020) STEM Education report it is "considered good practice for these teachers to plan for linkage and integration of topics within and across subjects/curriculum areas" (p. 8). However, a study by the Irish National Teachers Organisation (INTO) found that due to time constraints, teachers often trade one subject against another in an attempt to prioritise teaching and learning in other areas (National Council for Curriculum and Assessment [NCCA], 2016). While the issues with such practice are recognised, efforts to change this are complex and challenging and would need to reconcile the historical structure of schools, curriculum, instruction, and assessment in an educational system in which subject segregation has long been established (Nadelson and Seifert, 2017). Such efforts may require movement to a more "problem-based" rather than "discipline-based" system. However, this is not an easy shift to make. Problems that require an integrated STEM approach are typically ill-structured, with multiple potential solutions, and require the application of knowledge and practices from multiple STEM disciplines (Nadelson and Seifert, 2017). This would require a restructuring of the curriculum along with significant shifts in instruction, and in assessments of student learning.

Teaching and Learning

The previous sections have problematised the curricular hierarchy and the social standing of the individual STEM disciplines as well as exploring systemic and structural issues in the provision of STEM education. However, despite these broader sociocultural and political influences, teachers and students exist within the requirements of national curricula. Their phenomenological perspectives and subjectivities (Winter, 2017) exist and create meaning within this landscape and have direct influences on the realisation of integrated curricular activities (Fischer et al., 2018; Dong et al., 2019).

From a teaching perspective, the most consistent determinants of instructional success are teachers themselves (Darling-Hammond, 2000). Taking this line of reasoning, if integrated STEM education is to become a reality of classrooms, the instructional practices of teachers will be a key factor. The effectiveness of a teacher will be impacted by a number of factors including content knowledge, of their discipline (Wilkins, 2008), and pedagogical content knowledge (PCK) (Shulman, 1987; Kleickmann et al., 2012). PCK, as delineated by Shulman (1986) pertains to knowledge of students' discipline specific conception/misconceptions and knowledge of teaching strategies and representations in the discipline. This immediately raises questions surrounding PCK for integrated STEM education, given the difficulty with establishing a universal definition of the area itself. This is supported by Vossen et al. (2019) who highlight a general dearth of research in PCK in integrated STEM educational contexts.

One of the key issues with developing appropriate forms of PCK, in the context of integrated STEM, is that the majority of teachers will not have studied each of the individual content areas (Dare et al., 2018) and, as a result of the well-established discreet subject offerings in curricula across both primary and second-level education, will likely not have experience of inter and transdisciplinary thinking either (Ryu et al., 2019). In a study with practicing teachers of K-12 (second level), Shernoff et al. (2017) found that lack of understanding and time for collaboration and planning were rated among the highest barriers to achieving an integrated approach. These issues were also found by Lestari et al. (2020) who illustrated that participants, in an intervention study to improve integrated STEM PCK, when tested in the pre-condition only had PCK relevant to one discipline of STEM. A lack of understanding of the concept of integrated STEM education and of the content knowledge of the individual disciplines is supported in numerous studies (e.g., Shernoff et al., 2017; Simoncini and Lasen, 2018; Yıldırım, 2020). Given the recency with which research and interventions in this space have occurred, it is understandable that teachers' (both pre-service and in-service) would have difficulties developing appropriate constructs of PCK in this area.

While developing appropriate conceptions of PCK is an important aspect of improving initiatives, teachers are the primary enacting agents of integrated approaches. This brings into question the role of attitudes among teachers for the implementation of integrated STEM approaches. Generally, there exists a positive disposition, among both pre-service and in-service teachers, to integrated STEM within the available literature. For example, Çiftçi et al. (2020) in a sample of pre-service early childhood teacher education students found positive attitude to integrated STEM for developing valuable 21st century skills and promoting supportive social learning environments in the pre-school setting. This trend was also found by Yıldırım (2020) among practicing early-childhood teachers. However, these studies are confined to pre-school education, which allows more autonomy to the teacher in terms of curricular practices and design. For instance, in Ireland the early childhood curriculum known as Aistear[2], is not statutory or inspected in pre-school contexts, which presents less external curricular pressure for teachers (Gray and Ryan, 2016).

There has been some research conducted on teachers' attitudes to integrated STEM in second-level contexts. One of the largest studies available is that of Thibaut et al. (2018) who issued a substantive questionnaire to 135 secondary teachers, each working in STEM. This work utilised social cognitive theory (Bandura, 1986) to model the contextual factors impinging on teachers' attitudes to teaching integrated STEM. Overall, they found that professional development (PD), personal relevance of science and social context (collegial support) strongly predicted positive dispositions to integrated STEM. Given the fact that teaching integrated STEM involves synthesising content and approaches from different disciplines, collegial support is likely

[2]For more information on the Aistear curricular framework see Murphy (2015).

a crucial factor in STEM contexts. This notion is also supported by Dong et al. (2019) who found a significant predicative relationship between collegial support and engagement in integrated STEM teaching, although the sample in this case did not distinguish between primary and second-level teaching contexts. This is an important factor as being able to explicitly highlight linkages between the sub-disciplines of STEM has been signalled as a challenge and important factor in integrated teaching success (Dare et al., 2018).

Present Research

In summarising the review of literature, it is clear that definitions of integrated STEM vary and there is limited research available on the implementation of initiatives or the development of rigorous models of PCK. From the available literature, there appears to be clear challenges among teachers in the international landscape such as curricular pressure and systemic issues where subject disciplines have a legacy of being offered in siloed formats. Additionally, there are sociohistorical legacies to the evolution of the individual disciplines comprising STEM which pits the classical-humanist against vocational schooling ideologies. This is very true in the Irish context and given that there is limited research available on teachers' perspectives on implementing integrated STEM initiatives, the present study derives its focus here.

In particular, the goal of the present research is to explore practicing teachers' experiences of and perceived challenges in implementing integrated STEM in the Irish primary school curricula. Despite the national STEM education policy (Department of Education and Skills [DES], 2017) advocating integrated approaches, there is a gap in the available literature investigating teachers' perspectives on the challenges such a policy presents. For the present research, we focussed primarily on the context of primary education. Despite there being clear curricular specifications, there are no formal state-run examinations at primary level in Ireland. It is well known that these requirements place significant pressures on teachers in the second-level context and significantly limit transdisciplinary treatment of subjects (e.g., Hennessy et al., 2011; Burns et al., 2018), therefore primary education in Ireland would offer a perspective not influenced by these challenges and an important starting point for future work in the area. The research questions were as follows:

1. What are primary school teachers' perceptions of utilising an integrated STEM approach?
2. What do primary teachers identify as key challenges to using an integrated STEM approach?
3. What supports do teachers feel would improve STEM integration at primary level education?

RESEARCH DESIGN AND APPROACH

The purpose of this study is to examine primary school teachers' perceptions of adopting an integrated approach to the teaching of STEM. Participants in this study were enrolled in a Masters of Education (M.Ed.) programme that is modular in nature, that is, students can choose from a variety of module offerings and build their Masters experience based on their own interests. Entrants into the M.Ed. are largely practicing teachers, either at primary or post-primary education in Ireland. The programme is delivered in the evening time and on a part-time basis. All modules, except for the Dissertation, are 15 ETCS and run for one Semester (12 weeks teaching). Eight students enrolled in the "STEM Education: Problem Solving and Instructional Design" module on offer during the academic year 2019–2020. Six of the eight consented to participate in this study, on completion of the module. All were teaching at primary level with varying years' experience. The youngest participant was 29 with the oldest being 57 and with years of teaching experience ranging from 7 to 37. Of the participants there were five females and one male.

Data Collection

A qualitative approach was adopted in this study using in-depth one-to-one interviews with the six participants. The interest in examining primary school teachers' perceptions about an integrated approach to STEM education is based on a theoretical assumption that teachers' beliefs and experiences impact on practices. In-depth interviews are salient in terms of gathering information but also in terms of stimulating understanding (Guest et al., 2013). Through the use of interviews, teachers were provided with an opportunity to share their teaching experiences, pedagogical choices, experiences, and school contexts and implementation of an integrated STEM approach (cf. Luft and Roehrig, 2007). Therefore, each interview afforded an invaluable viewpoint on the teachers' perspectives of an integrated STEM approach, challenges associated with it and supports needed.

A semi-structured approach was utilised with a flexible schedule of questions acting as a guide and a trigger for participant talk (Cohen et al., 2017). The structured feature allows for comparison across interviews, while the flexible nature allowed for better exploration of teacher perceptions and experiences (Guest et al., 2013). The review of literature informed the construction of the questions by defining areas of interest to be pursued in the interviews (ibid). In addition, the flexible schedule of questions was centred on the three key research questions driving this research project, i.e., examining teachers' perceptions of utilising an integrated approach, key challenges that they encounter and what supports could help improve STEM integration at primary level. Overall, the major challenge of interviews is to find the right balance between maintaining control of the interview and "allowing the interviewee the space to redefine the topic under investigation and thus to generate novel insights for the researcher" (Willig, 2013, p. 24). A carefully constructed interview schedule helped the interviewer not to lose sight of the original research questions. Each interview was conducted via MS Teams and audio recorded with electronic written agreement from the participants. Each interview lasted approximately 25 min but there were no fixed time limits. Ethical approval was sought and granted from the Social Research Ethics Committee at the authors' institution.

Data Analysis

All audio-recorded interviews were transcribed verbatim and organised for data analysis. A thematic analysis approach was adopted in order to identify, examine, and describe patterns within the data (Braun and Clarke, 2006). Microsoft Excel was utilised to code and track themes emerging from the qualitative data (Meyer and Avery, 2009). Each theme illustrates key insights emerging from the data. The six steps for thematic analysis outlined by Braun and Clarke (2006) were applied to the analysis of the interview transcripts. These steps are:

(1) Immersion in the data and becoming familiar with it. This involved reading the transcripts multiple times.
(2) Initial codes were generated to reflect key ideas emerging from immersion in the data.
(3) An initial examination of themes by organising the codes.
(4) Reviewing of themes and coded work for checking in relation to accuracy of the data.
(5) Defining and naming the themes.
(6) Reporting the themes and relating them back to the research questions.

The data is reported as a whole, drawing on examples and extracts from individual participants to support the claims being made.

FINDINGS

Perceptions of Utilising an Integrated STEM Approach

Overall, teachers in this study were positive about the benefits of utilising an integrated approach to teaching STEM subjects at primary level education. In particular, they acknowledge that the cross-curricular nature of the subjects would provide for "far greater learning opportunities to the students than they currently have." (Emma). The benefits centre on improved student learning of the four key subject areas and the life-long skills developed through problem-solving and collaborative learning. As noted by Sarah,

> "It would certainly I suppose develop all sorts of skills really: creative thinking, critical thinking, team building, teamwork, team collaboration – absolutely, it would be very positive especially to prepare students as well. I suppose the whole thinking behind STEM maybe – well a lot of it was to prepare students for the modern workplace – the 21st century workplace – and an integrated STEM program would certainly go a long way in doing that."

As a whole, the value for students' learning, experiencing new ways of teaching/learning and skills development is a motivation for these teachers, while fully acknowledged that this is best practice and what is promoted by curriculum documentation.

However, it is the interdisciplinary nature that is the most problematic for teachers in this study and impacts on their confidence to teach STEM in an integrated approach. Many of the teachers commented on the skills and knowledge required to implement such an integrated approach, as well as a need for school leadership in supporting such an approach within a school. Confidence in using an integrated approach stems from having completed the M.Ed. module and/or other PD courses – "At this stage for me, personally, I would be very confident now teaching STEM having done the STEM module as part of my M.Ed." (Sarah). However, teacher knowledge of the content areas is a concern, in particular "what exactly is technology, what exactly is engineering?" (Laura). They are more comfortable with mathematics and science content, but engineering and technology appear to be the content areas that these teachers are least confident in. In addition, they are struggling with understanding what an integrated approach actually means –

> "We knew the letters and stuff but we didn't actually know what that meant – to go out and teach STEM integrated science, technology, engineering and maths – it meant absolutely nothing." (Emma).

This was also connected to the subject focussed curriculum that they are expected to implement – "there is definitely pressure on teachers to complete what is in say the maths book in particular" (Claire) and the lack of clarity in curricular documentation where ambiguity exists in relation to the engineering and technology aspects. Overall, curricular expectations, a lack of knowledge of STEM subjects and a lack of understanding of an integrated approach can lead to being "caught up on product" (Laura) with further individual teaching of subjects – "we were incorporating all the STEM subjects into the activities but I would still go off and do a maths lesson as well." (Claire).

Key Challenges to Using an Integrated STEM Approach

The teachers in this study identified a number of key challenges in relation to implementing an integrated STEM approach. Many of the teachers conveyed how STEM "can send signals of fear in a lot of teachers" (Sarah). This is most likely connected to a lack of confidence in their teaching ability relating to the STEM subjects and a lack of experience of integrative teaching. It may also be connected to their lack of subject matter knowledge relating to STEM content – "I suppose we would be afraid as teachers as well of jumping too much in when we don't know much ourselves." (Laura), and in particular in relation to engineering and technology aspects. A clear need for PD to support the development of teachers' skills and knowledge in relation to STEM integration was conveyed by participants. This was also connected to the need for clear curriculum guidelines and approaches to providing an integrated STEM approach in their classrooms – "We need professional development, we need curriculum objectives and curriculum guidelines which means resources and methodologies and just hands-on experience." (Emma). Overall, teachers feel that they need clarity on how STEM integration should be implemented within existing curriculum specifications at primary level education. Having completed the M.Ed. module, it demonstrated how effective PD can help:

> "you get over the initial fear and engage with the project approach which is what we kind of learned in the module, really a teacher can see that it is a very successful way to go." (Sarah).

Similarly, many of the teachers referred to the already over-crowded curriculum and the challenge of so much being asked of primary teachers as it is. In particular, primary teachers feel pressure in relation to "getting the curricula aims fulfilled so like have I all this completed by the end of the year to hand it over to the next teacher." (Laura). There are additional pressures with key national testing known as the Drumcondra Tests and the preoccupation with:

> "teaching your English, Irish and maths – I don't teach the tests – not teaching towards the tests – but you are aware if you don't spend a lot of time teaching these subjects and getting everything done you know you'll have the parents on your back or at the end of the year." (Laura).

Consequently, STEM is not perceived as a priority area and generally only addressed at certain times of the year for example, during Science Week or Engineering Week and "then it is forgotten about for the rest of the year." (Anne).

Another key challenge for STEM integration identified by teachers in this study is the perception of others – either parents or colleagues in their schools. Parental influence in terms of curriculum implementation in the classroom is noteworthy –

> "I think some parents would find it [problem-based learning] extremely scary: 'she is inside now giving them a problem, they are doing that now for the next two weeks. What pages are they actually covering in the class, what is getting done?"' (Laura).

This may be due to a reliance on traditional approaches to teaching and learning, over-reliance on textbooks in the Irish context, or a lack of knowledge of more effective approaches to teaching and learning STEM. Likewise, the challenge highlighted by teachers in this study of the perceptions of other teachers in their schools is interesting. Comments ranged from "you need to cover what is in the books" (Claire), "that you are just doing a project" (Anne), and that they got "challenged a lot on the approach because, I think, I was the only person in the group who had done CPD in the area" (Adam). Overall, the findings convey a sense that teachers are expected to teach the regular curriculum and a key challenge exits in implementing alternative approaches to teaching in STEM.

The teachers in this study also identified a lack of resources to provide an integrated approach to STEM education. These included physical, monetary, time, curriculum, and human. Some of the teachers referred to the importance of having a key member of staff competent in the STEM subjects and with a passion for teaching them and supporting other teachers in the school. Others referenced time "is a barrier" (Claire) given the demands of an already over-crowded curriculum, and that this is further compounded by the lack of curriculum guides for implementing an integrated approach to STEM and that "there is no curriculum to follow." for engineering and technology (Adam). In addition, the lack of funding available to schools for STEM integration, as well as within schools is a challenge for teachers –

> "I don't know what my budget will be for this year but in my previous school I had €250 for Juniors to 2nd Class for the year. I always blew away through that like, you know."(Anne).

Without appropriate resources, it will be difficult for teachers to implement an integrated approach to STEM education.

Supports That Would Improve STEM Integration

Primary school teachers in this study believe that the development of a clear and coherent STEM integrated curriculum by the Department of Education and Skills, with teacher guidelines and resources, would improve the prospects of an integrated approach being implemented. In particular, they referred to the need for more clarity in relation to engineering and technology aspects of STEM integration –

> "I think what teachers struggle with is the fact that there are no guidelines for engineering or technology that are very clear cut for teachers; so I think some guidance on incorporating technology and engineering into their every-day classroom would be really helpful." (Claire).

In addition, some teachers raised the suggestion that planning should then take place at a whole school level and that it could be integrated with other subject areas already on the curriculum:

> "I would say would integrate in certain lessons, with music, with SPHE, with geography and obviously with maths and science but that is the only way we would be able to manage STEM at the moment." (Emma).

Moreover, in order for STEM integration to be embedded by teachers, it needs to be "part of their monthly plan or their yearly plan" rather than a "one-off event" (Adam). Ultimately, this relies on learning opportunities for teachers to develop their knowledge and skills in relation to an integrative approach to STEM education.

In order for such learning opportunities to arise, the teachers in this study all emphasised the importance of developing appropriate PD. They currently feel that there are not any appropriate PD opportunities available to them and have identified key issues with PD opportunities that they have availed of such as Summer Courses and sessions in local Education Centres. In particular, many commented on the fact the courses,

> "depending on the person that is delivering it, it will end up actually just being science or just being maths. There would be little places where they will say oh you can integrate that now with engineering or integrate that with whatever but the integration part of it seems to be kind of like a token thing." (Adam).

They also referred to a lack of consistency in terms of what STEM integration is and what it means in terms of the primary school curriculum. Overall, a well organised and consistent approach to PD is required to support an integrated approach to STEM education at primary level. A key recommendation in relation to this is a desire for in-school PD workshops, addressing subject knowledge in particular in relation to engineering and technology and how to incorporate STEM into the "every-day classroom would be really helpful."(Claire).

It is apparent from teachers' feedback that they found participating in the M.Ed. module to be extremely valuable and has built their confidence in terms of implementing STEM integration. As noted by Claire,

> "I definitely feel more comfortable with incorporating engineering and technology with science and maths and I would be more comfortable about letting the children find their own way as opposed to me kind of dictating what they should be doing."

It demonstrates how a successful partnership with a university and expertise may facilitate the development of successful STEM integration in Irish primary schools. It provided the teaches with a structure to examine how STEM can be integrated in their classrooms and supported them to "think outside the box" (Emma). However, most teachers acknowledged that a key aspect in developing support will be engaging the teachers, enticing them into PD courses and removing the element of fear. As Adam concedes "Once you have suspicion and fear amongst primary school teachers in Ireland, you might as well forget it, you know. Very slow to change."

DISCUSSION

Overall, teachers in this study were positive about the benefits of utilising an integrated approach to teaching STEM subjects at primary level education in Ireland. In line with Kelley and Knowles (2016), they recognised the benefits of an integrated approach in providing better learning opportunities for students in enabling them to see connections between the four STEM subjects. Furthermore, consistent with findings from the wider literature (e.g., Stohlmann et al., 2012; Çiftçi et al., 2020; Yıldırım, 2020), the teachers advocated the benefits of the life-long skills developed through problem-solving and collaborative learning within the integrated STEM approach. Such positive perceptions amongst this sample of participants may hardly be surprising given they had just self-enrolled and completed a STEM education module as part of their Masters of Education. As such, the authors are cognisant that these views may not be generalisable to the wider population of Irish primary school teachers. However, irrespective of any inherent biases that may have contributed to the positive perceptions held, the participants were also very clear in articulating many of the key challenges that come with implementing such an integrated approach.

For example, many of the teachers conveyed how STEM "can send signals of fear" amongst teachers. As noted in the findings, this is most likely connected to a lack of subject specific knowledge of individual STEM fields and confidence in their teaching ability relating to the STEM subjects. Teachers were particularly concerned with content knowledge in engineering and technology commenting "what exactly is" technology/engineering. This anxiety relating to technology and engineering is not surprising given the generally superficial treatment that these two disciplines commonly receive in discourse promoting STEM education (McGarr and Lynch, 2017). These subjects, with a very unique and distinct historical evolution to that of mathematics and science, contain significant legacy issues from their vocational pasts and suffer from a poorer public perception as subjects suited to the "less academic" (McGarr, 2010), as well as having less defined curricular boundaries. Knowledge in these disciplines is distinct, from the logical and deductive capacities of science and mathematics, in that knowledge is treated with a more speculative, pragmatic and utilitarian philosophy aimed at solving complex problems rooted in authentic contexts (cf. Delahunty and Kimbell, 2021). This lack of understanding of technology and engineering, by these participants, is further evidence of the dearth of priority given to these areas in the current educational climate. This is a broad sociocultural issue that must continue to be challenged if integrated STEM education is to become a reality. In addition to the issues of subject equalities, there are systemic issues to be considered. Despite the national policy (Department of Education and Skills [DES], 2017) asserting the need for teachers to adopt integrated approaches, it must be acknowledged that this interdisciplinary knowledge and way of thinking is per contra to both the curricular structure at primary level and the personal experience (within their own education and professional practice) of these participants. Therefore, the professional identity of a primary teacher in Ireland must be taken into account in any discussion of integrated curriculum and approaches.

In Ireland, there are eleven mandatory curriculum subjects at primary level, including Mathematics and Science. All of these subjects are typically taught by generalist class teachers. The ability of a generalist teacher to integrate learning across curricular areas is considered to be a particular strength, which provides a "broader and richer perspective" of learning to aid holistic development (Governmnet of Ireland, 1999, p.24). However, such a generalist approach has also been represented as a problem internationally, particularly in relation to STEM subjects. It has been argued that teachers have underdeveloped content knowledge and lack confidence in teaching science and mathematics due to the curriculum demands of their generalist teacher role (Teacher Education Ministerial Advisory Group [TEMAG], 2014), and this has obvious knock-on effects for their own students. The findings in this study align with this notion as participants generally demonstrated apprehensions to the integration of previously discreet subject disciplines. This emerged in discussions of definitions of integrated STEM where participants stated the knew what STEM meant but that it still "meant absolutely nothing." This was further complicated by the clear articulation of the burdens of working within a restrictive curricular system at primary level where there is "pressure on teachers" to complete the many discreet curricular units that comprise a working week in school.

It is evident that there is a perceived lack of clear direction from curricular documentation and policy regarding the definition of integrated STEM education. This is further complicated when teachers are forced to implement "cross disciplinary approach[es]" (Department of Education and Skills [DES], 2017, p. 15) within an already crowded curriculum at primary level. There are clear tensions here that need to be discussed at national levels in order for clear guidelines and effective policy to be implemented, regarding integrated approaches, at primary level. This is a pressing discussion as it is clear from these participants' experiences that the prioritisation of individual subject units works against initiatives aimed at integrated learning. As Thibaut et al. (2018) demonstrated in their work, the social context of each participant's lived experience is critically important to their attitudes and subsequent practice. A stark picture is generated when viewing the negative association these researchers found between attitudes to integrated STEM, years of teaching and experience teaching mathematics (ibid). In contrast, the participants in this study held positive attitudes towards integrated STEM education in the primary classroom, even with some of them having over 30 years' experience. However, participants did self-enrol and had just completed a module on integrated STEM which may have influenced this positive disposition, therefore Thibaut et al. (2018) still provide important impetus for reflection. The participants specifically mention the curricular pressure around the teaching of mathematics in the primary curriculum, and this undoubtedly presents a tension for practitioners interested in integrated STEM. It is possible that policy requiring cross-disciplinary approaches in STEM education represents a utopian goal in the national context. It is apparent, that without interventions, such as the postgraduate module offered in the context of this work, many teachers will not develop the confidence to effectively attempt integrated STEM education in their classrooms. Aligning with Thibaut et al. (2018) there may also be further individual differences in attitudes to integrated STEM education in the wider professional body of primary teachers in Ireland. Future work will be needed on this issue.

It is encouraging to observe the positive attitudes that the participants in this study exhibit towards integrated STEM education and the fact that they seem to have been positively influenced by their postgraduate studies. Teachers' attitudes to integrated STEM education are directly predictive of their subsequent instructional practices (Dong et al., 2020) so it is clear that PD initiatives that can enhance teachers' attitudes will have a positive impact on the implementation of integrated STEM approaches.

Similar to the findings of this study, the international literature notes the need for PD to support the development of teachers' skills and knowledge in relation to STEM subjects (Shernoff et al., 2017; Dare et al., 2018). The DES STEM Education report (2020) notes that work in this area at primary level is ongoing in Ireland. For example, the Professional Development Service for Teachers (PDST) is increasingly raising the awareness of STEM-related activities by providing ongoing CPD through a wide range of models including interdepartmental work at school level where teachers of different STEM disciplines plan and teach together. Such CPD work can only be welcomed and the interdisciplinary approach may address another challenge highlighted by participants of this study, namely, a lack of experience of integrative teaching. The Department of Education and Skills [DES] (2020) also note many positive initiatives supporting STEM in primary schools such as Discover Primary Science and Maths Programme, the Primary Science Fair, and ESB Science Blast. However, in keeping with the concerns of participants in this study, the unequal treatment of technology and engineering in these STEM initiatives, once again highlight the challenge of a truly integrated STEM approach.

CONCLUSION

This article set out to explore the experiences of practicing primary school teachers in implementing integrated STEM education in their schools in light of policy developments in Ireland since 2017. While the participants displayed positive dispositions towards the educational value of integrated STEM curricular approaches, they highlighted several areas of concern and challenges that will need to be addressed. It is important to note that the sample size in this study was small but was deemed appropriate in this study as we were interested in the experiences of practicing primary school teachers. The potential self-selection bias is also noted, however the fact that these participants were informed as to the nature of integrated STEM education was seen as a strength for this work given that participants could now make informed judgement and commentary on the authentic or utopian aims of integrated STEM education, as espoused in the national policy arena. Namely, the findings indicate significant anxieties exist around integrating different subject areas within a national curriculum that is heavily mandated. The unequal status of engineering and technology is noteworthy and as the data presented demonstrates, this is not being give due attention in curricular documentation or discourse. The importance of PD in this area is fore fronted by participants and this will be key to any initiatives moving forward. In confronting the question of whether integrated STEM education is an authentic goal for Irish education this article delineates a number of challenges, that must addressed at national levels and in discussion with relevant stakeholders, if it is to move from being ostensibly utopian thinking.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Social Research Ethics Committee, College of Arts, Celtic Studies and Social Sciences, University College Cork. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

REFERENCES

Bandura, A. (1986). *Social Foundations of Thought and Action: a Social Cognitive Theory, Social Foundations of Thought and Action: a Social Cognitive Theory*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Barry, F. (2014). 'Outward-oriented economic development and the Irish education system'. *Ir. Educ. Stud*. 33, 213–223. doi: 10.1080/03323315.2014.918296

Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology. *Qual. Res. Psychol*. 3, 77–101. doi: 10.1191/1478088706qp063oa

Burns, D., Devitt, A., McNamara, G., O'Hara, J., and Brown, M. (2018). 'Is it all memory recall? an empirical investigation of intellectual skill requirements in leaving certificate examination papers in Ireland'. *Ir. Educ. Stud*. 37, 351–372. doi: 10.1080/03323315.2018.1484300

Canny, A., and Hamilton, M. (2018). 'A state examination system and perpetuation of middle-class advantage: an Irish school context'. *Br. J. Sociol. Educ*. 39, 638–653. doi: 10.1080/01425692.2017.1377599

Carr, W. (1998). 'The curriculum in and for a democratic society 1'. *Curriculum Stud*. 6, 323–340. doi: 10.1080/14681360000200094

Carter, L. (2017). 'Neoliberalism and STEM education: some Australian policy discourse'. *Can. J. Sci. Math. Technol. Educ*. 17, 247–257. doi: 10.1080/14926156.2017.1380868

Çiftçi, A., Topçu, M. S., and Foulk, J. A. (2020). 'Pre-service early childhood teachers' views on STEM education and their STEM teaching practices'. *Res. Sci. Technol. Educ*. 1, 1–27. doi: 10.1080/02635143.2020.1784125

Clark, A. C. (2012). 'Excellence in STEM education'. *Technol. Eng. Teach*. 72, 33–36.

Clarke, M. (2014). "The implementation of the greater schools cooperation policy and vocational education committees in 1960s Ireland," in *Educating Ireland: Schooling and Social Change, 1700-2000*, eds D. Raferty and K. Fischer (Kildare: Irish Academic Press).

Cohen, L., Manion, L., and Morrison, K. (2017). *Research Methods in Education*, 8th Edn. London: Routledge.

Coolahan, J. (1981). *Irish Education:its History and Structure*. Dublin: Inst of Public Administration.

Coolahan, J. (2001). 'Education and ethnicity: education as cultural imperialism: the denial of the Irish language to Irish speakers, 1831-1922'. *Paedagog. Hist*. 37, 16–33. doi: 10.1080/0030923010370102

Coolahan, J. (2017). *Towards the Era of Lifelong Learning: a History of Irish Education, 1800-2016*. Dublin: Institute of Public Administration.

Dare, E. A., Ellis, J. A., and Roehrig, G. H. (2018). 'Understanding science teachers' implementations of integrated STEM curricular units through a phenomenological multiple case study'. *Int. J. STEM Educ*. 5, 1–19.

Darling-Hammond, L. (2000). 'Teacher quality and student achievement'. *Educ. Policy Anal. Arch*. 8:1. doi: 10.14507/epaa.v8n1.2000

Delahunty, T., and Kimbell, K. (2021). (Re)framing a philosophical and epistemological framework for teaching and learning in STEM: emerging pedagogies for complexity. *Br. Educ. Res. J*. doi: 10.1002/berj.3706

Delahunty, T., Seery, N., Dunbar, R., and Ryan, M. (2020). 'An exploration of the variables contributing to graphical education students' CAD modelling capability. *Int. J. Technol. Des. Educ*. 30, 389–411. doi: 10.1007/s10798-019-09503-x

Department of Education and Skills (DES) (2011). *National Strategy for Higher Education to 2030*. Dublin: DES.

Department of Education and Skills (DES) (2017). *STEM Education Policy Statement 2017-2026*. Dublin: DES.

Department of Education and Skills (DES) (2020). *STEM Education 2020: Reporting on Practice in Early Learning and Care, Primary and Post-Primary Contexts*. Dublin: DES.

Dong, Y., Wang, J., Yang, Y., and Kurup, P. M. (2020). 'Understanding intrinsic challenges to STEM instructional practices for Chinese teachers based on their beliefs and knowledge base'. *Int. J. STEM Educ*. 7, 1–12.

Dong, Y., Xu, C., Song, X., Fu, Q., Chai, C. S., and Huang, Y. (2019). 'Exploring the effects of contextual factors on in-service teachers' engagement in STEM teaching'. *Asia-Pac. Educ. Res*. 28, 25–34. doi: 10.1007/s40299-018-0407-0

Dowling, P. J. (1961). 'History of Irish education in the republic of Ireland'. *Pedagog. Hist*. 1, 213–224.

Drake, S. M., and Burns, R. C. (2004). *Meeting Standards Through Integrated Curriculum*. Alexandria, VA: Association for Supervision and Curriculum Development.

English, L. D. (2016). STEM education K-12: perspectives on integration. *Int. J. STEM Educ*. 3, 1–8.

Fischer, C., Fishman, B., Dede, C., Eisenkraft, A., Frumin, K., Foster, B., et al. (2018). 'Investigating relationships between school context, teacher professional development, teaching practices, and student achievement in response to a nationwide science reform'. *Teach. Teach. Educ*. 72, 107–121. doi: 10.1016/j.tate.2018.02.011

Furner, J. M., and Kumar, D. D. (2007). The mathematics and science integration argument: a stand for teacher education. *Eurasia J. Math. Sci. Technol. Educ*. 3, 185–189. doi: 10.12973/ejmste/75397

Governmnet of Ireland. (1999). *Primary School Curriculum*. Dublin: The Stationery Office.

Goy, S. C., Wong, Y. L., Low, W. Y., Noor, S. N. M., Fazli-Khalaf, Z., Onyeneho, N., et al. (2018). 'Swimming against the tide in STEM education and gender equality: a problem of recruitment or retention in Malaysia'. *Stud. High. Educ*. 43, 1793–1809. doi: 10.1080/03075079.2016.1277383

Gray, C., and Ryan, A. (2016). 'Aistear vis-à-vis the primary curriculum: the experiences of early years teachers in Ireland'. *Int. J. Early Years Educ*. 24, 188–205. doi: 10.1080/09669760.2016.1155973

Guest, G., Namey, E. E., and Mitchell, M. L. (2013). *Collecting Qualitative Data: a Field Manual for Applied Research*. Thousand Oaks, CA: SAGE Publications, Ltd.

Hennessy, J., Hinchion, C., and McNamara, P. M. (2011). "The points, the points, the points": exploring the impact of performance oriented education on the espoused values of senior cycle poetry teachers in Ireland'. *Engl. Teach. Prac. Crit*. 10:181.

Heraty, N., Morley, M. J., and McCarthy, A. (2000). 'Vocational education and training in the republic of Ireland: institutional reform and policy developments since the 1960s'. *J. Vocat. Educ. Train*. 52, 177–199. doi: 10.1080/13636820000200114

Honey, M., Pearson, G., and Schweingruber, H. A. (eds) (2014). *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. Washington, D.C: National Academies Press.

Hurley, M. M. (2001). Reviewing integrated science and mathematics: the search for evidence and definitions from new perspectives. *Sch. Sci. Math*. 101, 259–268. doi: 10.1111/j.1949-8594.2001.tb18028.x

Hyland, Á. (2011). Entry to Higher Education In Ireland in the 21st Century (Discussion Paper for the NCCA/HEA Seminar to be held on 21st Sep 2011, Issue. Available online at: https://hea.ie/assets/uploads/2017/04/Aine-Hyland_Entry-to-Higher-Education-in-Ireland-in-21st-Century-2011.pdf (accessed January 10, 2021).

Kananoja, T. (2009). "Technology education in general education in Finland," in *International Handbook of Research and Development in Technology Education*, eds A. Jones and M. deVries (. Rotterdam: Sense Publishers).

Kang, H., Calabrese Barton, A., Tan, E., Simpkins, S., Rhee, H. Y., and Turner, C. (2019). 'How do middle school girls of color develop STEM identities? middle school girls' participation in science activities and identification with STEM careers'. *Sci. Educ*. 103, 418–439. doi: 10.1002/sce.21492

Kelley, T. R., and Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *Int. J. STEM Educ*. 3, 1–11.

Kirwan, L., and Hall, K. (2016). 'The mathematics problem: the construction of a market-led education discourse in the republic of Ireland'. *Crit. Stud. Educ*. 57, 376–393. doi: 10.1080/17508487.2015.1102752

Kleickmann, T., Richter, D., Kunter, M., Elsner, J., Besser, M., Krauss, S., et al. (2012). 'Teachers' content knowledge and pedagogical content knowledge: the role of structural differences in teacher education'. *J. Teach. Educ*. 64, 90–106. doi: 10.1177/0022487112460398

Krathwohl, D. R. (2002). A revision of bloom's taxonomy: an overview. *Theory Pract*. 41, 212–218. doi: 10.1207/s15430421tip4104_2

Lestari, W. T., Saputro, S., Masykuri, M., Hastuti, B., Ulfa, M., Mulyani, S., et al. (2020). 'Item analysis of teachnological pedagogical content knowledge (TPACK). in pre-service chemistry teachers using the Rasch Model application'. *J. Phy. Conf. Ser*. 1511:12043.

Limond, D. (2010). "[An] historic culture. rapidly, universally, and thoroughly restored'? British influence on Irish education since 1922'. *Comp. Educ.* 46, 449–462. doi: 10.1080/03050068.2010.519479

Luft, J. A., and Roehrig, G. H. (2007). Capturing science teachers' epistemological beliefs: the development of the teacher beliefs interview. *Electron. J. Sci. Educ.* 11, 38–63.

Lynch, R., and McGarr, O. (2016). 'Negotiating subject hierarchies: neo-liberal influences on the comprehensive curriculum in Ireland'. *Educ. Policy* 30, 721–739. doi: 10.1177/0895904814550077

McCormack, O., Gleeson, J., and O'Donoghue, T. (2020). 'An analysis of national newspaper coverage relating to the leaving certificate programme in two newspapers in the republic of Ireland'. *Ir. Educ. Stud.* 39, 1–18. doi: 10.1080/03323315.2019.1664314

McCoy, S., Smyth, E., and Banks, J. (2012). *The Primary Classroom: Insights from the Growing Up in Ireland Study*. Available online at: https://ncca.ie/media/2087/gui_the_primary_classroom_esri_january_18_2012.pdf (accessed December 14, 2020).

McGarr, O. (2010). "The elephant in the room: the influence of prevailing pedagogical practice on the integration of design and communication graphics in the post-primary classroom," in *Graphicacy and Modelling*, eds E. Norman and N. Seery (Loughborough: Design Education Research Group, Loughborough Design School).

McGarr, O. (2011). "The elephant in the room: the influence of prevailing pedagogical practice on the integration of design and communication graphics in the post-primary classroom," in *Graphicacy and Modelling*, eds E. Norman and N. Seery (Loughborough: Design Education Research Group, Loughborough Design School).

McGarr, O., and Lynch, R. (2017). 'Monopolising the STEM agenda in second-level schools: exploring the power relations and subject subcultures'. *Int. J. Technol. Des. Educ.* 27, 51–62. doi: 10.1007/s10798-015-9333-0

Meyer, D. Z., and Avery, L. M. (2009). Excel as a qualitative data analysis tool. *Field Methods* 21, 91–112. doi: 10.1177/1525822x08323985

Moore, T., Stohlmann, M., Wang, H., Tank, K., Glancy, A., and Roehrig, G. (2014). "Implementation and integration of engineering in K-12 STEM education," in *Engineering in Pre-College Settings: Synthesizing Research, Policy, and Practices*, eds S. Purzer, J. Strobel, and M. Cardella (West Lafayette, IN: Purdue University Press), 35–60.

Murphy, R. (2015). Early childhood education in Ireland: change and challenge. *Int. Electr. J. Element. Educ.* 8, 287–300.

Nadelson, L. S., and Seifert, A. L. (2017). Integrated STEM defined: contexts, challenges, and the future. *J. Educ. Res.* 110, 221–223. doi: 10.1080/00220671.2017.1289775

National Council for Curriculum and Assessment (NCCA) (1999). *Primary School Curriculum*. Dublin: NCCA.

National Council for Curriculum and Assessment (NCCA) (2016). *Proposals for Structure and Time Allocation in a Redeveloped Primary Curriculum: for Consultation*. Dublin: NCCA.

O'Leary, D. (2012). *Irish Catholicism and Science: From 'Godless Colleges to the Celtic Tiger'*. Cork: Cork University Press.

Plasman, J. S., Gottfried, M. A., and Klasik, D. (2020). 'Trending up: a cross-cohort exploration of STEM career and technical education participation by low-income students'. *J. Educ. Stud. Placed Risk.* 25, 55–78. doi: 10.1080/10824669.2019.1670066

Ryu, M., Ryu, M., Mentzer, N., Mentzer, N., Knobloch, N., and Knobloch, N. (2019). 'Preservice teachers' experiences of STEM integration: challenges and implications for integrated STEM teacher preparation'. *Int. J. Technol. Des. Educ.* 29, 493–512. doi: 10.1007/s10798-018-9440-9

Sanders, M. (2009). STEM, STEM education, STEMmania. *Technol. Teach.* 68, 20–26.

Sansone, D., and Carpenter, C. S. (2020). 'Turing's children: representation of sexual minorities in STEM'. *PLoS One* 15, e0241596–e0241596. doi: 10.1371/journal.pone.0241596

Seery, N., Lynch, R., and Dunbar, R. (2011). "A review of the nature, provision and progression of graphical education in Ireland," in *Graphicacy and Modelling*, eds E. Norman and N. Seery (Loughborough: Design Education Research Group, Loughborough Design School).

Shernoff, D. J., Sinha, S., Bressler, D. M., and Ginsburg, L. (2017). 'Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education'. *Int. J. STEM Educ.* 4:13. doi: 10.1186/s40594-017-0068-1

Shulman, L. (1987). 'Knowledge and teaching: foundations of the new reform'. *Harv. Educ. Rev.* 57, 1–22. doi: 10.4324/9781351233866-1

Shulman, L. S. (1986). 'Those who understand: knowledge growth in teaching'. *Educ. Res.* 15, 4–14. doi: 10.3102/0013189x015002004

Simoncini, K., and Lasen, M. (2018). 'Ideas about STEM among Australian early childhood professionals: how important is STEM in early childhood education?'. *Int. J. Early Child.* 50, 353–369. doi: 10.1007/s13158-018-0229-5

Smyth, E., and Hannan, C. (2006). School effects and subject choice: the uptake of scientific subjects in Ireland. *Sch. Eff. Sch. Improv.* 17, 303–327. doi: 10.1080/09243450600616168

Stem Education Review Group. (2016). *STEM Education in the Irish School System: a Report on Science, Technology, Engineering and Mathematics(STEM). Education*. Dublin: Department of Education and Skills.

Stevenson, C., and Carr, J. F. (1993). *Integrated Studies in the Middle Grades*. New York, NY: Teachers College Press.

Stohlmann, M., Moore, T. J., and Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *J. Pre-Coll. Eng. Educ. Res.* 2:4.

Takeuchi, M. A., Sengupta, P., Shanahan, M.-C., Adams, J. D., and Hachem, M. (2020). 'Transdisciplinarity in STEM education: a critical review'. *Stud. Sci. Educ.* 56, 213–253. doi: 10.1080/03057267.2020.1755802

Teacher Education Ministerial Advisory Group (TEMAG). (2014). *Action Now: Classroom Ready Teachers*. Available online at https://www.dese.gov.au/uncategorised/resources/action-now-classroom-ready-teachers-report (accessed December 14, 2020).

Thibaut, L., Thibaut, L., Knipprath, H., Knipprath, H., Dehaene, W., Dehaene, W., et al. (2018). How school context and personal factors relate to teachers' attitudes toward teaching integrated STEM'. *Int. J. Technol. Des. Educ.* 28, 631–651. doi: 10.1007/s10798-017-9416-1

Trant, A., Branson, J., Frangos, C., Geaney, F., Lawton, D., Makinen, R., et al. (1999). *Reconciling Liberal and Vocational Education*. Dublin: CDVEC Curriculum Development Unit.

Tytler, R., Williams, G., Hobbs, L., and Anderson, J. (2019). "Challenges and opportunities for a STEM interdisciplinary agenda," in *Interdisciplinary Mathematics Education*, eds B. Doig, J. Williams, D. Swanson, R. Borromeo Ferri, and P. Drake (Cham: Springer), 51–81. doi: 10.1007/978-3-030-11066-6_5

Vasquez, J., Sneider, C., and Comer, M. (2013). *STEM Lesson Essentials, Grades 3-8: Integrating Science, Technology, Engineering, and Mathematics*. Portsmouth, NH: Heinemann.

Vossen, T. E., Henze, I., de Vries, M. J., and van el, J. A. S. (2019). Finding the connection between research and design: the knowledge development of STEM teachers in a professional learning community'. *Int. J. Technol. Des. Educ.* 30, 295–320. doi: 10.1007/s10798-019-09507-7

Wallace, J. (1972). 'Science teaching in Irish schools 1860-1970'. *Ir. J. Educ.* 1, 50–63.

Wallace, J., Malone, J., Rennie, L., Budgen, F., and Venville, G. (2001). The rocket project: an interdisciplinary activity for low achievers. *Aust. Math. Teach.* 57, 6–11.

Wang, M.-T., Wang, M.-T., Degol, J. L., and Degol, J. L. (2017). Gender gap in science, technology, engineering, and mathematics (STEM): current knowledge, implications for practice, policy, and future directions. *Educ. Psychol. Rev.* 29, 119–140. doi: 10.1007/s10648-015-9355-x

Westheimer, J., and Kahne, J. (2004). 'What kind of citizen? the politics of educating for democracy'. *Am. Educ. Res. J.* 41, 237–269. doi: 10.3102/00028312041002237

Wilkins, J. L. (2008). The relationship among elementary teachers' content knowledge, attitudes, beliefs, and practices. *J. Math. Teach. Educ.* 11, 139–164. doi: 10.1007/s10857-007-9068-2

Willig, C. (2013). *Introducing Qualitative Research in Psychology: Adventures in Theory and Method*, 3rd Edn. Maidenhead: McGraw-Hill Education, Open University Press.

Winter, C. (2017). 'Curriculum policy reform in an era of technical accountability: 'fixing' curriculum, teachers and students in english schools'. *J. Curriculum Stud*. 49, 55–74. doi: 10.4324/9781351008808-5

Yıldırım, B. (2020). 'Preschool STEM activities: preschool teachers' preparation and views'. *Early Child. Educ. J*. 49, 149–162. doi: 10.1007/s10643-020-01056-2

Young, M. (1999). "The curriculum as socially organised knowledge," in *Learn. Knowl*., eds R. McCormick and C. Paechter (Paul Chapman Publishing in association with The Open University), 56–70.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.