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(Re)framing a philosophical and epistemological framework for teaching and learning in STEM: Emerging pedagogies for complexity

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Today's learners are engaging in study where access to knowledge is easier than it ever has been in human history. Rapid advancement of technology and the increasing ease with which communication and interaction can occur has dramatically changed the landscape in which teachers of science, technology, engineering and mathematics (STEM) operate. The contemporary skills that students are required to possess include *inter alia* problem solving, creativity, teamwork abilities, communication skills and emotional intelligence. Despite the universal acceptance of their importance, these skills are commonly cited as underdeveloped and in addition, are still accompanied by outmoded 'traditional' forms of teaching and assessment. While the approaches of twentieth-century education were successful in developing knowledge stores, the ubiquity of access to knowledge—coupled with the constantly changing nature of the world today—requires alternative conceptions of teaching and learning. This article focuses primarily on an exploration of learning metaphors and teaching with the overall lens of creating self-regulated and furthermore, self-determined learners. The article begins with an exploration of learning in STEM education and a critique of the pedagogical perspective, discussing why this epistemology may be insufficient for contemporary STEM learning. The article then considers an alternative and potentially more contemporary notion; the emergent pedagogic space. The article presents a theoretical model to conceptualise learning in STEM education, with the goal of informing both practice and research. The realisation of this proposed emergent pedagogical space is explored through an applied case study from a design and technology context.

Keywords: STEM education; Learning metaphors; Complexity; Adaptive emerging pedagogies

Introduction

A fluid world

The current landscape of educational provision and discourse is one that is characterised by rapid change. The world itself is a complex sociocultural fusion impacted and shaped by trends such as globalisation, capitalism, religious debate, neo-liberalism and the rapid onset and development of digital technologies, among others.

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These complex elements have multiple and varying implications for education in the twenty-first century.

> These elements combine and connect with worries about declining trust and growing political and social unrest. There is an important role for education to play in improving civic and social participation and fostering democratic citizenship. However, difficult questions remain. Key questions for the future include how we strike a fair balance between all parties in a diverse society, and what this means for fostering social cohesion and trust. (Burns *et al.,* 2019, p. 10)

Clear in the above quote is not only the impact that these elements can have on the educational landscape, but also the crucial role that education itself has in preparing our students for this fluid world. Education has the responsibility for not only cultivating students' knowledge and skills, such as problem-solving abilities, critical thinking and creativity, but also catering for their overall human development (Barak & Hacker, 2011). Human development, according to Alkire (2002), consists of multiple dimensions, including basic human functional capabilities, universal values, well-being, axiological categories, quality of life factors, universal psychological needs and basic human needs. Following this line of reasoning, it is clear that if education's role is to develop students to be successful in this multifaceted and fluid world, then the teaching of subject knowledge is but a single aspect of the provisory landscape. The impact of the rapid changes in society has not only impacted on the types of knowledge and skills that are necessary in today's educational climate, but also the contexts, spaces, times and manners in which learning takes place and how learning as a process is conceptualised (Gros *et al.,* 2016).

An educational response

Stoyanov *et al.* (2010) identified 12 key themes that are posited to be to the fore in shaping educational provision. Themes that emerged as the most important posited areas of education for the future included, *inter alia*: individual and social natures of learning; individual and professional driven education; informal educational opportunities and lifelong learning (Stoyanov *et al.,* 2010). Aligning with many authors' espousals of the importance of lifelong learning (e.g. De Fur & Korinek, 2008; Romero, 2015; Gros *et al.,* 2016), the report by Stoyanov *et al.* (2010) highlights the central importance that most professionals now place on the concept of lifelong learning and relatedly, the social nature and opportunities for formal and informal educational contexts. A pervasive theme in much of the literature on educational development and change is the role of technology in enhancing the learning experience (Levin & Wadmany, 2005; Viberg *et al.,* 2019). The Stoyanov *et al.* (2010) report uncovers a very important theme in this regard: considerations for the epistemological (and ontological) assumptions underpinning methods of teaching. This is an important inclusion as it is often the case that the allure of technological innovation supersedes the very notion of teaching as a practice in itself. Clear evidence of this very point is the difficulty in evolving teaching practices, in light of information and communication technology (ICT) integration in classrooms (Levin & Wadmany, 2005; Orlando, 2009).

Science, technology, engineering and mathematics (STEM) education sits as an educational offering that promises to develop much of the twenty-first-century skills desired by society, such as problem-solving skills, technological literacy, and advanced analytical skills (Mioduser, 2009; Barak, 2011; Williams, 2011; Breiner *et al.*, 2012), as well as augmenting economic imperatives. A core idea at the heart of STEM education is the development of capabilities as opposed to competencies. Capability has been defined as the 'capacity to use one's competence in novel as well as familiar circumstances' (Blaschke & Hase, 2016, p. 26), or as simply the 'power to produce an effect' (Kimbell & Stables, 2008, p. 18). It not only emphasises the importance of knowledge acquisition, but also knowledge utility. The purpose of this article is to present an exploration and analysis of the analogies of learning and teaching in an integrative STEM education with the overarching theme of sustainable lifelong learning as a key consideration. In particular, we focus on the metaphors for learning applicable to integrated STEM and the purpose and focus of pedagogy as the dominant philosophy. In doing so, the authors draw on related work from the fields of complexity and heutagogy to demonstrate the necessity for a dynamic epistemological adaptation of teaching approaches in order to ultimately cultivate the self-determined and lifelong learners of the twenty-first century. Following a detailed analysis of the pertinent literature, this article will present a theoretical representation of the emergent pedagogic space which is unpacked throughout the article. It is envisaged that the discussion presented in this article will be of interest to teachers, teacher educators and researchers in STEM.

Views of learning and capability in STEM

Highlighting a need to move from competence to capability as the goal for education foregrounds the debate centring on the appropriate analogies for learning in STEM education. The discipline of education is often characterised by the analogies one employs to describe learning (Davis, 2018). As summarised by Reynolds *et al.* (1996), many analogies of learning have framed different eras of educational scholarship—such as the experience-centred sociocultural perspectives to the mind-centred information processing theories of learning. This dichotomy, of two of the most dominant frames for learning, is useful to this article as it focuses on how learners are conceptualised in the act of learning itself. In the information processing tradition, learning is defined as the development of long-term memory (Sweller *et al.*, 2011) through the assimilation, accommodation or adaptation of cognitive schema (Bormanaki and Khoshhal, 2017) as the individual acquires knowledge. This is the typical perspective of traditional education, where students are imparted with knowledge from the teacher. But the definition and nature of knowledge is extremely contested, and this is further problematised when attempting to unpack a deeper understanding of knowledge within STEM education as the area itself often struggles with its multidisciplinary nature and individual disciplinary heritages (McGarr and Lynch, 2017).

The problem of 'knowledge'

Defining knowledge and learning in STEM is a persistent issue and is unlikely to be resolved given the plurality of perspectives within each of the individual subject disciplines, let alone the acronym of STEM itself. In a recent article, Seery *et al.* (2018) sketch considerations for a holistic STEM teacher and highlight that an integrated conception of STEM 'should not bound knowledge as with traditional subjects' (p. 2) and that programmes to develop holistic STEM teachers must ultimately complement a directive for developing 'STEM capable learners' (p. 5). These are ambitious considerations, despite their meritorious characteristics, given the nature of the individual subjects comprising the STEM acronym.

Each of the sub-disciplines of STEM have associated characteristic knowledge types, such as the propositional knowledge of science and the procedural or pragmatic knowledge associated with technology (Banks and Barlex, 2014). This article does not go into depth on the debate of subject monopolies or prestige (McGarr and Lynch, 2017), but it is important to note that the characteristic knowledge types of a discipline often speak to their heritage and dominant epistemology, which can inform the associated teaching approach (Shulman, 2005). DeVries (2016, p. 24) draws on the philosopher Alvin Plantinga to demonstrate a more functional vision of knowledge. Plantinga (cited in DeVries, 2016) claims that knowledge is predicated on proper cognitive functioning in an environment aimed at truth, emphasising that it can never be entirely internal to an individual and must be pursued externally. This aligns with treatment of knowledge by various authors in technology and engineering advocating the iterative dialect between internal and external modalities (Kimbell & Stables, 2008). The varied conceptualisations of knowledge are further amplified when one attempts an all-encompassing definition of the learning process and learners. This foregrounds a need to consider how learning as a process is analogised.

Learning as information processing or as socially constructed

Learning, as defined by the likes of Sweller (1988) and Sweller *et al.* (2011), is potentially dissonant with the more complex view of knowledge and learning characteristic of STEM education. The definition of learning provided by Sweller *et al.* (2011) naturally resonates with his influential 'cognitive load' theory, which has provided rigorous considerations for instructional design and which is now a lens that many in STEM disciplines apply as a framework for learning analyses (e.g. Guttormsen & Zimmerman, 2007; Anderson *et al.,* 2011; Delahunty *et al.,* 2014; Seery *et al.,* 2018). However, analysis of the traditional theory reveal some limitations critical to how learning is analogised and treated in reference to the complexity of STEM education. In particular, the original theory is founded on the sole objective of schema development (Kalyuga & Singh, 2016) and the finite capacity of working memory (Baddeley & Hitch, 1974; Sweller, 1988) within the information processing view of learning. This presents a limited conceptualisation of the learner if used as the sole perspective (Mayer, 1996) and does not represent a view of learning typical of the complex problem-based images one cogitates when focusing on STEM education. The misfit of this theory as an analytical lens with which to view learning in STEM is further amplified when considering the difficulty of defining knowledge in an integrated vision of STEM education. Over-adherence to mechanistic schema automation, characteristic of teaching for competence, has negative impacts on students' creative problem-solving capabilities (McCormick &

Davidson, 2009), resulting in rigid approaches with little epistemic and conceptual flexibility (Delahunty, 2019).

Many arguments against the information processing perspectives of learning tend to draw on the social constructivist theorists such as Dewey or Vygotsky to present knowledge as that which is constructed by the user (Woolfolk *et al.,* 2008). The constructivist theories of learning place importance on the application and use of past experiences in constructing new meanings and understandings (Fox, 2001; Snowman & Biehler, 2006), which aligns well with the applied focus of integrated STEM education and foregrounds discussions of developing students' capability in applied complex problem situations (Kelley & Knowles, 2016). Social constructivism has done much to elucidate our understanding of learning as an active process, but Fox (2001) argues that it may be more 'hopeful' than useful and that ultimately many argue for social constructivist accounts of learning as a radical opposition to the information processing perspectives. This line of thought places the two perspectives in opposition, which ultimately is tantamount to a form of reductionism that may be limiting our understanding of the holistic learning process (Hager & Hodkinson, 2009). This polarisation is supported by Reynolds *et al.*'s (1996) analysis of information processing theories as mind-centred, while social constructivist perspectives are classed as experience-centred. This review of the literature presents the ostensible conclusion that neither analogy of learning alone can encapsulate the complexity of learning within STEM education. It is critical that we consider the appropriate fit of these analogies for STEM.

Where does STEM fit?

This is not a trivial discussion in contemplating the notion of teaching for capability in STEM, as the metaphor used to characterise learning impacts directly on the realisation of the opportunities provided to the learner (Donaldson & Allen-Handy, 2019). STEM education is typically characterised by project-based learning environments where students are tasked with solving complex problems in collaboration (Banks & Barlex, 2014). The notion of learning within STEM cannot be entirely captured by a lens of information processing or social constructivism alone, and requires a metaphor that synthesises both. For example, while the collaboration we as educators envisage students' engaging with in solving a design task frames learning in the social constructivist sense, there will undoubtedly be times when students, either directed by the teacher within a scaffolded pedagogical strategy or self-directed, will need to acquire new knowledge or skills.

Views from the field of complexity have led to a surge in contemporary metaphors for learning as those of complex systems (cf. Holland, 2006; Jacobson *et al.,* 2019; Reigeluth, 2019). This is clarified by Jacobson *et al.* (2016), who consider a need to move away from viewing learning as 'something that is' and towards something viewed as emergent (p. 212). They define learning as

> ... changes in human cognitive processes involved with the encoding and capacity to manipulate and engage with symbolic representations, formalisms, and sociocultural practices that emerge from interactions with a variety of complex systems an individual may

> experience over time that lead to enhanced performance in intellectual, physical, and affective realms of life. (Jacobson *et al.,* 2016, pp. 212–213)

This complex systems conceptual framework (CSCF) of learning emphasises the inadequacy which a view of learning based solely on schema development or social constructivism contains. Instead, *a focus on developing capability through the reality of complexity is required*. This section has presented two of the most common metaphors for learning that have been employed in the educational literature, summarised by Sfard (1998) as learning by acquisition or learning by experience. The issue here is not to suggest that either frame is incorrect as to how learning is analogised, but to focus on the frame itself, for it is this frame that allows us to transform the unfamiliar into meaningful shared constructions of particular phenomena (Davis, 2018); in this case, learning in STEM education. This foregrounds a necessity to consider learning in STEM as complex.

A complex adaptive systems perspective on learning

Complex adaptive systems is a way to view both of these perspectives in an interactive manner, building on the respective research heritages that both the social constructivists and cognitivists have provided and facilitating their extension in the complex reality that is learning in the twenty-first century. Complex adaptive systems (CASs) are derived from theories from the field of complexity or chaos theory. Put simply, CASs consist of multiple agents that interact with each other and their environment, with feedback activity which results in *self-organisation* (Holland, 2006; Jacobson & Wilensky, 2006; Jacobson *et al.,* 2016; Reigeluth, 2019). The key to the idea of CAS self-organisation is *emergence* (Reigeluth, 2019), where collective behaviour emerges from the interaction of individual elements but cannot be predicted by focusing on the isolated elements alone (Morrison, 2008; Kloos *et al.,* 2019). This emergent behaviour occurs in a nonlinear fashion and involves interaction between agents, resulting in more complex learning than could be achieved in linear individualistic fashions (Jacobson *et al.,* 2019). A typical biological example of a CAS is the murmuration of birds, where collective behaviour is clearly evident in the system's lack of collisions and whereby it would be impossible to explore or understand the phenomenon by observing an isolated agent.

CASs can be viewed as nested and consisting of other complex systems (Jacobson *et al.,* 2016; Reigeluth, 2019). For example, within a school context, students can be seen as making up the CAS of the school, a class can be viewed as one system within this larger one, the individual student brain could be viewed as another, and so on. This multi-level characteristic means that the CAS perspective need not be at odds with the vast empirical evidence from information processing or social constructivist accounts of learning, instead it provides a new frame for learning within STEM education; one which integrates the mind-centred and experienced-centred tenets of Reynolds *et al.*'s (1996) typologies of learning. In discussing the implications of CAS views of learning for research methodologies, Jacobson *et al.* (2019) highlight the distinction between linear dynamics and nonlinear dynamics. They go on to discuss that most educational research and policy to date has focused on linear elements which view learning as the sum of parts (p. 114), as in the information-processing tradition. The nonlinear dynamics of learning, characteristic of CAS conceptions, remain unemphasised. While linear elements, such as the established relationship between spatial ability and success in STEM education (Wai *et al.,* 2009; Sorby *et al.,* 2013), are clearly important insights into learning in the field, explaining nonlinear phenomena —such as the posited sudden and unexpected restructuring of cognitive representations involved in insight problem-solving (Weisberg & Alba, 1981; Bowden *et al.,* 2005)—remains uncertain and extremely hard to approach with traditional frames for learning.

Most importantly, a CAS view of learning treats its agents (students) as a set of interacting elements in which the system is perpetually generating its potential future as continuity and transformation (Ovens *et al.,* 2013). In these circumstances of interaction, self-organisation occurs through processes of emergence, such as is the case in problem-based learning when a group (CAS), consisting of very different CASs in the form of individual students, produces an innovative solution to a complex problem (Mennin, 2007). This is an experience that typifies teaching and learning in STEM education, where students are provided the opportunity to collaborate and engage in these interactions. An important point raised by Ovens *et al.* (2013) is that a CAS is not a single unified theory, and those advocating CASs as a theory of learning commonly only agree on what constitutes complex phenomena. CASs give us a way to conceptualise the complexities and characteristics of learning in STEM education, but do not necessarily give us the tools to operationalise or investigate. These become nested phenomena of complexities themselves (Jacobson *et al.,* 2019). This point is critical in relation to practice: if we adopt the learning metaphor of CASs for STEM education, how do we operationalise practice? Moreover, if the manner in which we frame the process of learning is central to the construction of meaning (cf. Davis, 2018; Donaldson & Allen-Handy, 2019), then there is consequentially an effect on the pedagogical epistemology and philosophy of the teacher who constructs the learning opportunity for their students. This necessitates a focus on the concept of pedagogy itself.

Teaching and learning: traditional pedagogy and its essential nature

Pedagogy was originally conceived of during the Middle Ages and, although it is differentially described in much of the literature, often it is described as pertaining to the theory of teaching and the study of teaching methods (Wang & Huang, 2018). In his description of teaching, Shulman (1987, p. 7) emphasises that a 'teacher can transform understanding, performance skills, or desired attitudes or values into pedagogical representations and actions'. Shulman (1987) is best known for his contributions to the notion of pedagogical content knowledge (PCK): a core underpinning concept in much of teacher education globally. PCK facilitates a meaningful synthesis of pedagogy and content for the act of teaching. However, a noteworthy consideration in Shulman's (1987) characterisation of pedagogical content knowledge is his distinction of knowledge as the domain of scholars, while pedagogy is claimed to be the domain of teachers. The two are inherently described as independent, a notion which Segall (2004) identifies as problematic since 'knowledge is always by someone and for someone, always positioning and, consequently, is always *already pedagogical* [emphasis added]' (p. 491). Knowledge or content, therefore, is always shaped by and shaping the pedagogical act, emphasising the core place that content holds in conceptions of pedagogy. This becomes increasingly problematic if knowledge and definitions of capability in STEM education are contested in the first place.

In ideologies of good teaching, the teacher or 'pedagogue' holds the responsibility for adapting and transforming curriculum content and holds the central role in engaging in the pedagogical reasoning process to transform their learners' understandings (Dobson, 2012). In the UK and other Western countries, Watkins & Mortimore (1999) argue that there has been a predominant focus on character formation, as opposed to holistic intellectual development, in conceptions of pedagogy. It is important to note that interpretations of pedagogy are not universal and predetermined, but the manner in which one defines pedagogy will determine the type of PCK, and ultimately the learning (on the part of the students), that emerges (Segall, 2004). In an extreme example of a restrictive interpretation of pedagogy, Freire (1996) gives the banking concept of educational transaction, where the teacher is perceived as the all-knowing master controlling the entirety of the educational process. Thankfully, critical approaches to the subject of pedagogy and learning have shed light on this notion, and the idea of Locke's *tabula rasa*—where students are seen as empty vessels awaiting delivery of knowledge from the teacher—is no longer the dominant conception of pedagogic practice. This connotation of pedagogy has permeated much of Western thinking on pedagogy. Fox (1972) traces this notion of pedagogy back to Descartes and his adamance that any knowledge conceived of as probabilistic does not constitute true knowledge. This has leant itself to the development of didactics, where the all-knowledgeable teacher holds the control of learning. Fox (1972) sketches the pedagogical philosophy of Giambattista Vico in her analysis and highlights his much-forgotten treatise that heralded true knowledge as manmade and hence always negotiated between speculative erudition and scientific reason. Western perspectives have often distinguished between the logico-rational and rhetorical-pathetic, and in the case of Cartesian pedagogy, the rhetorical-pathetic was frowned upon (Davis, 2014).

Vico's thoughts on pedagogy are particularly relevant to an integrated vision of STEM education as it balances the logico-deductive and speculative modes of thought, suggesting that progress occurs in the space between.

Pedagogy and power

The sketch of pedagogy thus far could be conceived of as overly restrictive, with undercurrents of negative connotations, but there are many different conceptions of and adoptions of pedagogy. However, still inherent in the concept of pedagogy is teachers' central role and arguably their hold on the learning process (McAuliffe *et al.*, 2009). The teacher-centric nature of pedagogy brings to the fore the concept of Foucauldian power, where the teacher is the holder and translator of knowledge for their students. Consequently, knowledge represents the values of those with the power and the ability to circulate them (Foucault, 1990; Levitt, 2008), which aligns with the shaping power that knowledge has on pedagogy. Even when teachers hold an accurate understanding of this notion of power, and although their goals may be the emancipation of learners, the adoption of traditional conceptions of pedagogy as the sole philosophy for teaching can still be a limiting factor. Related to this idea, Bonawitz *et al.* (2011) conducted an experiment where pre-school children viewed an adult demonstrating the functionality of a novel toy across three different conditions. The first condition was classed a pedagogical demonstration, where the experimenter instructed on its use; the second condition violated pedagogic assumptions as the toy was unfamiliar to the demonstrator; and the third condition involved the demonstrator being interrupted mid-demonstration. In the latter two conditions, children tended to explore and uncover undemonstrated functions of the toy, whereas those in the first condition restricted their exploration to only those functions demonstrated by the instructor. However, this study was restricted to pre-schoolers and a moderating variable of cognitive development is certainly in question. Nonetheless, extending this idea, Gweon *et al.* (2014) demonstrate that adults and adolescents negatively evaluate their teachers for omitting aspects of content knowledge, indicating a reliance on the pedagogue and the validation of their power over the learning process.

So far, this section has focused on the content-driven aspects of pedagogy, but it is also widely accepted that the overarching aim of any pedagogical approach is the development of attitudes or disposition. Here, there are also potential limitations of the pedagogical approach in cultivating these aptitudes. Anwaruddin (2015), in discussing Ranciere's emancipatory intents of pedagogy, gives the example of a teacher highlighting to his/her student the fact that they are oppressed and that they (as teacher) can instruct them in ways not to be so. In this example we once again see the reliance that an (in this case oppressed) individual has on the teacher and their knowledge reinforcing the power relation. Jacques Ranciére provides scathing critiques of the notion of pedagogy and centrality of the teacher in the process of learning. His work is a radical indictment on the centrality of the teacher, but there is not sufficient space to go into this here (see Lambert, 2012 for a useful account).

This article does not argue against the notion of the teacher and pedagogy being important to the learning process, and it also does not advocate an entirely naïve vision of fully unguided exploratory education. It is well established that content knowledge is a fundamental aspect of developing expertise, and that explicit instruction through appropriate pedagogy is needed in many circumstances. However, what is apparent in some of the critical stance of pedagogy sketched in the preceding paragraphs is the potential for a lack of *learner agency* associated with traditional conceptions of pedagogy, which are critical in facilitating the emergence of learning in a CAS view of STEM education.

The role of human agency in the learning process

Considering pedagogy as a teacher-centred epistemology for educational provision forces a reflection on the notion of agency in the learning process. Agency emerges quite apparently in well-established educational learning theories such as social constructivism, where sociocultural interaction is encouraged and utilised (Lave, 1988; Reynolds *et al.*, 1996). In the era of lifelong learning, agency is considered an especially important characteristic for students to develop (Charteris, 2016). Agency has a plethora of definitions that are often quite contested. 'Free will' is a common notion associated with the idea, but suffers as a thorough underpinning due to its failure to conceptualise the interacting elements of culture, beliefs and action (Ahearn, 2001). Agency, as a concept, is constantly in flux and is shaped by the discourses contained within the classroom or school milieu (Charteris, 2016). As such, it is situated and embodied within the sociocultural world of the student and the teacher.

> Agency is at once the possibility of imagining and asserting a new self in a figured world at the same time as it is about using one's identity to imagine a new and different world. (Barton & Tan, 2010, p. 192)

Here, agency is drawn into focus within the figured world of the classroom, emphasising the interpretability, by the student or teacher, of the social structure in place, as well as the values placed on certain activities and outcomes over others (Holland *et al.*, 2001). Much of the work on agency draws upon Bourdieu's structure–agency dialectic, which views the realisation of agentic behaviours as mediated by the social and cultural structures in which they are situated (Lakomski, 1984; Nash, 1990). Reflecting back on the studies by Bonawitz *et al.* (2011) and Gweon *et al.* (2014) earlier in the article, one can see the potential for an oppressive structure suppressing students' potential agency. In this case, it is related to a traditional conception of the pedagogic epistemology. Dakers (2011, p. 27) summarises this restrictive conception of pedagogy, and its suppression of student agency within an action framework where the teacher (subject) acts upon their students (objects) with some form of mediation (pedagogical method) to achieve an outcome (see Figure 1).

This structural model corresponds to the figured world of teacher-centric pedagogy, which has been and still is the dominant model for teaching. In the recent TALIS report from 2018, there is still a considerable emphasis placed by teachers on strategies for managing classroom order and clarity of instructional transmission, with much less belief focused on strategies for cognitive activation and enhanced activities —including the use of ICT and digital learning or project-based approaches (OECD, 2019). Although authors have criticised this focus within our educational systems, it is clear that this traditional view of pedagogy is still dominant in teaching and learning today, which highlights some issues of note in the pursuit of lifelong learning aptitudes and the cultivation of STEM capable learners.

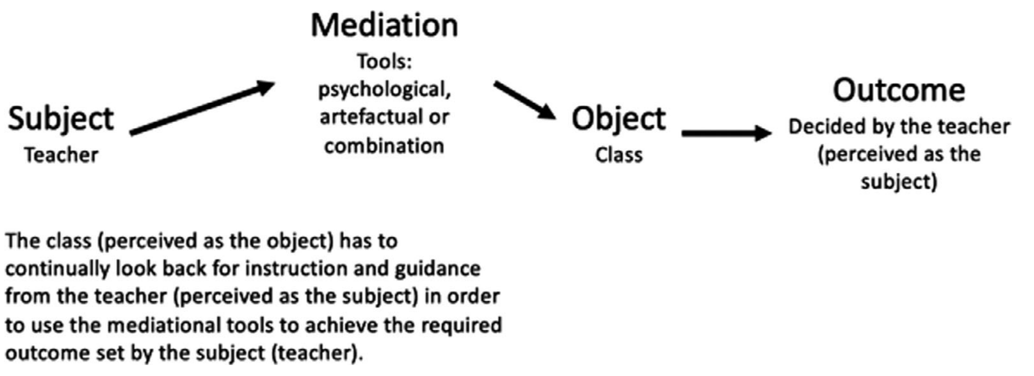

Figure 1. Teacher-directed model of instruction (Dakers, 2011).

Agency, motivation and self-determination

Achieving personal agency over one's learning is predicated on appropriate motivational underpinnings. In this vein, agency is possibly best thought of in relation to self-determination theory (SDT) which, as a macro theory of learning and motivation, encompasses a wide range of necessary factors for lifelong learning (Blaschke, 2012). The central focus of the model is on the psychological needs for overall well-being, which then allows for an analysis of individual differences in motivation on the level of causality orientations and aspirations/life goals (Deci and Ryan, 2008). This is particularly important in the present article, with the focus on teaching, as motivation is without question a key etiological factor in the learning process. Causality orientations are a useful frame to consider the concept of agency in the learning process. Causality is considered to encompass three distinct orientations: autonomous, controlled and impersonal (Deci & Ryan, 2008). Of the three, the most pertinent to consider in the context of this article are autonomy versus controlled orientations. Individuals with causality autonomy orientations perceive actions as emerging from within and behave in self-determined ways, whereas those with a causality control orientation tend to be motivated by external pressures and seek rewards or the satiation of deadlines (Roth *et al.,* 2007; Hagger & Chatzisarantis, 2011). It is clear to see that control orientations would be the most likely to manifest themselves within the traditional conception of pedagogy, which is disenfranchising to the student as it is posited to cater for only the human needs of competence and relatedness while neglecting autonomy (Sánchez de Miguel *et al.,* 2017). Such a model of pedagogy tends to be catered towards extrinsic rewards such as exam results and, as research has shown, causality orientations are both situated and effected by the environmental design and ethos (Ryan, 1982; Deci *et al.,* 1991). This presents some considerations for a contemporary approach to teaching within STEM education, and in particular the approach to instructional design. While the combination of intrinsic and extrinsic motivators is important, it is the over-emphasis on extrinsic rewards that has characterised many educational systems globally, and often predetermined the teacher-centric conception of pedagogy that typifies many images of classroom life.

Emerging pedagogies as an alternative framework in STEM education

These images of the teacher as the master and students as the apprentice are remnants of values that evolved from the Industrial Revolution (Blaschke & Hase, 2016) and were appropriate conceptions for educational development in their time. Holding vast amounts of knowledge in one's repertoire was the gold standard but as alluded to by Blaschke & Hase (2016), the current era of learning could be classified as one of knowledge emancipation. In this vein, students are now expected to be critical thinkers with the abilities to access, collate, critique and synthesise knowledge which foregrounds the necessity for increased agency and autonomy in the teaching and learning process. All of this, coupled with the increased risks to psychological well-being that evolution and access to digital technologies brings, reveals a necessity to cater for the development of knowledge but also both self-regulated and self-determined capabilities (Claxton, 2008; Canning, 2010; George-Walker & Keeffe, 2010).

Andragogy and self-regulation

Pedagogy is not the only theory available to address epistemological conceptions of the teaching and learning process. Andragogy is another well-established theory that refers to adult learning contexts (Knowles, 1972). Sharifi *et al.* (2017) present a contextual differentiation between pedagogy, as children-focused, and andragogy, as adult-focused education that emphasises ownership of the learning process under the guidance of the teacher. In his model, Knowles discusses the idea that as learners mature, their self-concept evolves from a mode of dependency to independency informed by societal roles and life experiences (Knowles, 1972; Knowles *et al.*, 2005). In the model of andragogy the focus becomes more metacognitive in nature, actualised in the negotiation of learning processes (Luckin, 2010; Luckin *et al.*, 2011). Knowles is most commonly associated with the concept of andragogy, but his conception of this theory is only one of many and there are stark differences in its historical development. In a review paper, Loeng (2018) summarised a key difference in Knowle's North American andragogy being focused on individual self-sufficiency whereas the European conception contains a more explicit social dimension. The important point to note here is that, like pedagogy, the concept of andragogy may also be differentially defined and has even been conceived of as a component of pedagogies (Loeng, 2018, p. 9).

In andragogy, teachers still hold much of the power in the learning relationship as it is they who normally determine the learning content but it is students that regulate their own learning (Knowles *et al.*, 2005; Blaschke, 2012). This represents an increased level of agency over the traditional pedagogic view of learning and places the learner as more central to their personal development. Self-regulated learning is a key emphasis in the androgogic epistemology and comprises a synthesis of metacognitive, cognitive and motivational variables (Sharifi *et al.*, 2017). It is a critical area for success both within and beyond the boundaries of formal schooling. Arguably, however, given the complexities of the educational landscape of the twenty-first century, being a self-regulated learner is no longer in and of itself sufficient if knowledge is considered to be in flux, and this is even more pertinent for learning in an integrative STEM education.

The emergence of heutagogy

One of the key consequences of the CAS view of learning in STEM education is what Gros (2015) calls the 'fall of the walls of knowledge'. In other words, subject boundaries now become blurred and knowledge in many cases cannot be predetermined. Kimbell & Perry (2001) describe designing as 'a restive and itinerant non-discipline', where task-driven exploration supplants the purity of academic distinctions. A key area of development in this regard is self-determined learning (Ashton & Newman, 2006). Heutagogy has emerged in the last 20 years as a theory concerned with self-determined learning, and is differentiated from andragogy as control over the learning process is placed on the student to make his/her own decisions on what and how to learn (McAuliffe *et al.*, 2009). Heutagogy is defined as an extension to andragogy and pedagogy in its original introduction by Hase & Kenyon (2000), and has since gained popularity as an approach to teaching in web and technology-mediated contexts (Canning, 2010; Agonács & Matos, 2019). According to Blaschke (2012), heutagogy:

- requires double-loop learning;
- emphasises the development of capability rather than competence;
- is learner determined;
- is a learner-managed approach;
- has a nonlinear learning process in contrast with linear instructor-led models;
- focuses on promoting students' understanding of the ways in which they learn.

Blaschke & Hase (2016) further develop the theory of heutagogy by summarising the principles involved in the theory. Critical to the theory is that it is learner-centred and learner-determined, therefore building on work such as the importance of autonomous motivation for learning (Roth *et al.,* 2007). It is an approach premised on the development of capability and acknowledging the importance of knowledge utility and creative problem solving (Banks & Barlex, 2014; DeVries, 2016). Knowledge utility is differentiated from knowledge acquisition through its emphasis on integration, synthesis and application in complex tasks. This aligns with the generally well understood distinction between declarative (knowledge of facts and meaning) and procedural (understanding of relationships and problem solving) knowledge (Anderson *et al.,* 2001; Binder *et al.,* 2019) It requires self-reflection and metacognition as part of a recursive, double-loop process of reflexivity (Argyris, 2002; Carless, 2019). Lastly, it incorporates both linear and nonlinear teaching (Peters, 2002), thus embracing core characteristics of CAS. In its treatment of knowledge, heutagogy shares an ethos similar to Wenger's (1998) communities of practice, emphasising knowledge sharing as opposed to acquisition and hoarding (Canning, 2010). The social interaction within a frame of heutagogy allows learners to build connections with others, which allows the development of capability but also personal learning identity (Wenger, 2015), augmenting capacity for lifelong learning. These characteristics are themselves emergent rather than established since heutagogy, as a theory, is recent and there remains a need for research (Agonács & Matos, 2019). It does, however, give a useful frame in which to operationalise teaching practice under the CAS metaphor for learning in an integrated STEM context, and as the case study in the next section will discuss, it is something that is commonly practiced in STEM contexts, albeit tacitly.

Case study: the emergence of heutagogic practice within technology education

It would be possible to focus on any area of the curriculum to explore the emergence of heutagogic practice, but there are some distinctive features of the STEM curriculum that make it a good case to study. Relatedly, it is also possible to focus on any particular instance of national curriculum globally in order to interrogate the emergence of heutagogic practice. This section will take the example of design and technology education within the English national curricular context as our exemplar case study. Specifically it is in the development of design portfolios as *thinking tools* that we are able to observe the evidence of autonomous decision-making by learners, and—more broadly—the evidence of learners taking responsibility for the direction and management of their own work (Archer, 1980; Kimbell *et al.*, 1996; Hope, 2004; Gaver & Bowers, 2012).

Design and technology, as it originally emerged in England, grew from craft practices (e.g. woodwork, metalwork, needlework) in which learners acquired the practical skills of making products (Penfold, 1988). The relationship of learners to teachers was akin to master/apprentice, as skilled and experienced teachers passed on expertise to the novice. But increasingly, from the 1960s, a view of design emerged and was blended into these traditional practices such that learners not only made objects, but also designed them. They made decisions about users, functions, forms, materials, technical systems and manufacture. And it soon became clear that this new focus carried with it a profound shift in teaching and learning agendas in schools' design studios and workshops. While the current section focuses on exploring the emergence of heutagogic practice through a case study of a learner's engagement in design, it is valid to question the effect of such activities in cultivating the dispositions (e.g. creativity, cognitive flexibility, reflection, etc.) desired by contemporary education. There is ample evidence from the discipline, particularly research studies exploring portfolio assessment in design and technology, to support their utility in achieving contemporary skills and dispositions (e.g. Kimbell & Stables, 2008; Seery *et al.*, 2012, 2019).

Concerning the issue of agency, the emerging formation of design and technology dramatically changed the teacher/learner dynamic, placing increasing responsibility on learners to manage and direct themselves and at the same time transforming it in relation to teachers' responsibilities for preparing learners for this profound shift. The two pictures here illustrate the outcomes of this shift in a STEM context. In the first (Figure 2), a 15-year-old student has designed a fish feeder to allow him to keep his fish fed during his absence for a week. It relies on a hopper filled with food granules, feeding into a slowly rotating drum so that (once every 24 h) a known and measured quantity of granules is dropped into the tank.

In the second (Figure 3), a 17-year-old student has designed a test rig to analyse the flight of arrows. The rig allows for adjustments to be made to the alignment and power setting of the bow—and then to be able to replicate those same conditions over and over again. The purpose is to explore the effects of different forms and types of 'flight' on the behaviour of the arrow.

Whilst the outcomes are important, it is in students' design portfolios that their thinking and motivations in relation to such outcomes are revealed. Why is it like that? Why choose those materials? How might it have been different, and what would have been gained/lost if it were to be different? The illustrations in Figures 4 and 5 are of parts of a student's portfolio in a project to develop a skateboard for use on a farm or over rough ground. Traditional skateboards are an urban development for use on hard paved surfaces. They use small wheels with a built-in steering system so that by transferring weight the rider can steer the board. But for rough and soft ground big wheels become necessary and—amongst many other things—a new steering system has to be developed.

Figure 2. Student design of a ‘fish feeder’. [Colour figure can be viewed at wileyonlinelibrary.com]

Figure 3. Test rig for the analysis of arrow flight patterns. [Colour figure can be viewed at wileyonlinelibrary.com]

At this point the student is exploring a number of approaches, motivated to find a solution to the steering problem, and is working towards the idea of a ‘rack and pinion’ mechanism to allow the angle of the board surface to control the direction of the

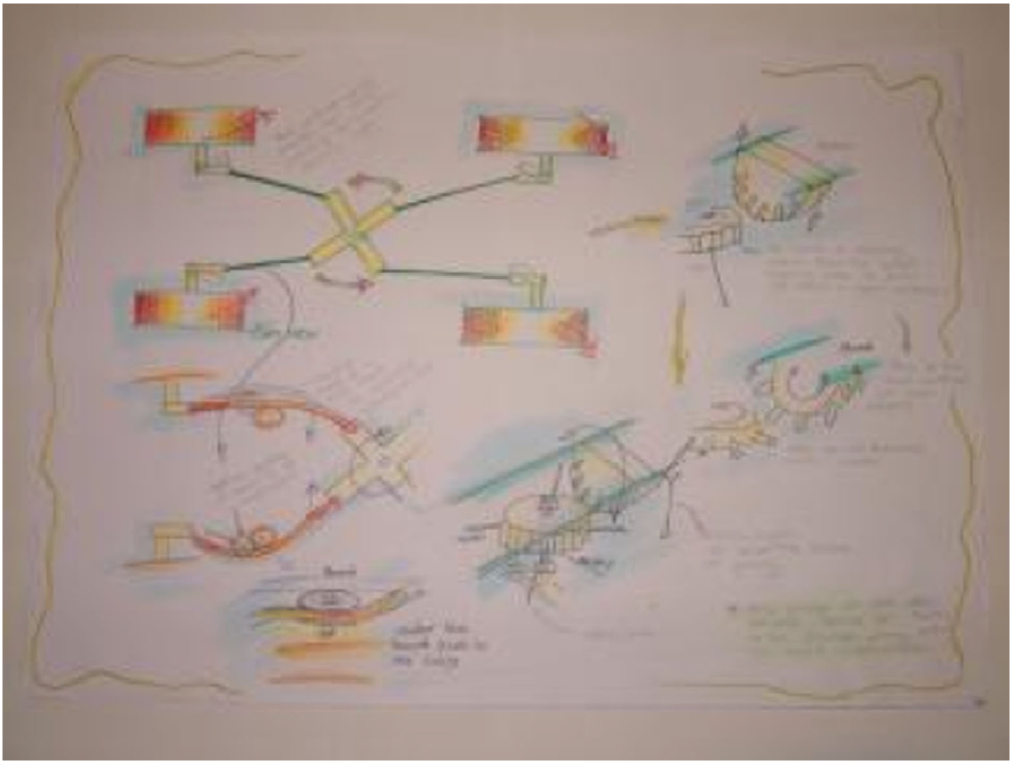

Figure 4. Extract from student's portfolio. [Colour figure can be viewed at wileyonlinelibrary.com]

wheels. The drawings in Figure 4 show how the student is attempting to visualise a concept and represent it to show how the arrangement might work. And the jottings on the side of the drawings further illustrate the thinking that these potential solutions provoke in the student. In the bottom right corner is a note that the rack and pinion solution will be '*... useless when dirt builds up*'. The design drawings are both generative, in the sense of looking forward to new possibilities, and simultaneously reflective, in the sense that emergent ideas are immediately reviewed for practicability and consequence (Kimbell & Stables, 2008). The evidence of iteration throughout the generation of the student portfolio also demonstrates the motivational dispositions that were present in the attempts to find a solution. Commitment and determination, both highly valued dispositions in contemporary education, are clear. It is on portfolios of this kind that assessors typically place great emphasis, since they are so revealing of the quality of learners' design thinking.

It is clear from these few illustrations that there is a good deal of teaching required within a design and technology programme. Students have to become competent with *drawing and modelling* to enable them to represent their thoughts, and they must become competent in *making* to enable them to realise their ultimate solutions. They must have a rich repository of ideas to draw upon—in this case concerning mechanical systems and power transmission. Clearly the teacher has a significant role in all this. But there is a further requirement of this STEM curriculum that bears directly

Figure 5. Image of all-terrain skateboard. [Colour figure can be viewed at wileyonlinelibrary.com]

on the pedagogy/heutagogy debate, for perhaps the most critical thing for students to develop is the capability and the confidence to become autonomous designers; finding out for themselves the knowledge they need for a particular project as they pursue it and making decisions for themselves as they steer themselves through their project.

> When embarking upon a new design, the package of knowledge and skills necessary for the success of the venture will emerge as the design progresses, and so the need to acquire knowledge and skills (and sometimes extend the boundary of knowledge and devise new skills) becomes a clear requirement for the designer. (Council for National Academic Awards/Standing Conference on University Education, 1985)

From the teacher perspective, Hicks identified the profound pedagogic challenge that is entailed in this position:

> Teaching facts is one thing: teaching pupils in such a way that they can apply facts is another; but providing learning opportunities which encourage pupils to use information naturally, when handling uncertainty, in a manner which results in capability, is a challenge of a different kind. (Hicks, 1983)

But from the student perspective, the heutagogic challenge is even greater. To learn to identify a do-able design task; to work through a series of imaging and modelling processes to evolve a solution that might work; to source the special knowledge and/or processes that may be required by the task; to manufacture a prototype with sufficient care and precision that it can be tried out by the designated user; to evaluate its effectiveness in use. And to do all this autonomously.

The England and Wales National Curriculum specification for design and technology (Department of Education and Science and Welsh Office, 1989) was, as with all subjects, divided into two parts. The *Programmes of Study* (*PoS*) specified what should be taught at various ages from 5 to 16, and the *Attainment Targets* (*ATs*) specified what learners would be expected to know and be able to do, and these were the basis on which assessments would be made of learners' ability. In every subject other than design and technology there was a direct correspondence between the PoS and the ATs, so that (e.g. in science) if the PoS specified the teaching of electromagnetism, then the ATs specified that learners would know about electromagnetism. But in design and technology, whilst the PoS specified, for example, the teaching of mechanical systems, the ATs did **not** specify that students should know about them. Rather, the four ATs took a very different form.

> AT1: Pupils should be able to identify and state clearly needs and opportunities for design and technological activities through investigation of the contexts of home, school, recreation, community, business and industry.
>
> AT2: Pupils should be able to generate a design specification and explore ideas to produce a design proposal and develop it into a realistic, appropriate and achievable design.
>
> AT3: Pupils should be able to make artefacts, systems and environments, preparing and working to a plan and identifying, managing and using appropriate resources, including knowledge and processes.
>
> AT4: Pupils should be able to develop, communicate and act upon an evaluation of the processes, products and effects of their design and technological activities.
>
> (Department of Education and Science and Welsh Office, 1989)

In short, the PoS specified the taught content of a technology programme, but the ATs required learners to be able to identify a design task, draw up a design proposal, make it and evaluate it. Whatever 'it' is. The central power of the position staked out here by design and technology is that the taught content in the programmes of study was not to be seen as an end in itself, but rather a resource for action on the part of the learner. And it is that action—design action—that was to be seen as the point of it all. So, it was learners' ability to autonomously undertake that action that was properly seen to be the focus for assessment. Hence the four attainment targets.

The design and technology curriculum emerged in England over the three decades up to 1990, but at that moment the England and Wales National Curriculum for design and technology enshrined in law both the pedagogic challenge for teachers and the centrality of heutagogy for learners. On the face of it there was a contradiction inherent in the formulation. The teachers' side of the bargain requires that they have responsibility for teaching the content of the technology programme, but at the same time the learners' side of the bargain requires that they take responsibility for themselves. In schools' studios and workshops for design and technology what had emerged over that 30 years of evolution was a body of practice that progressively shifted power and control from teachers to learners. In the early years of a programme, teachers would set tasks that demanded limited but significant decision-making by learners. And gradually—whilst still taking responsibility for introducing the core content of the technology programme—teachers would progressively expand the scope and depth of tasks in ways that made the learners themselves more and more responsible for themselves.

The transition from a pedagogically rooted tradition of learning towards a heutogogically informed practice is a subtle and complex one. At its inception, the idea of children thinking things out for themselves was almost heretical and was certainly highly contested territory.

> I once watched a class of infants brought up on free-activity methods, attempting to make paper hats for a Christmas party. One child finally evolved a very inadequate copy of a crown he had previously seen. The rest merely copied him. The argument is that the child should be free to choose what sort of hat he wanted, and that in finding out for himself how to achieve this end, valuable educational experience would be gained. The latter notion pushed to its logical conclusion would demand the recreation by each generation of the whole of human experience: for if the teacher is not allowed to instruct in the making of hats, why should he be allowed to instruct in anything? (Bantock, 1952, p. 67)

Hope's work with infant school learners (Hope, 2004) illustrates just how far the construct of design and technology had moved this thinking in the subsequent 50 years. As if he were writing specifically for the emerging design and technology, Dewey describes the problem of encouraging learner autonomy without the pitfalls that Bantock identifies:

> . . . to think effectively one must have had, or now have, experiences which will furnish him resources for coping with the difficulty in hand. A difficulty is an indispensable stimulus to thinking, but not all difficulties call out thinking. Sometimes they overwhelm and submerge and discourage. The perplexing situation must be sufficiently like situations which have already been dealt with so that pupils will have some control of the means of handling it. A large part of the art of instruction lies in making the difficulty of new problems large enough to challenge thought, and small enough so that in addition to the confusion naturally attending the novel elements, there shall be luminous familiar spots from which helpful suggestions may spring. (Dewey, 1968, p. 157)

In the cases illustrated above, the teacher had ensured that learners were well prepared in exactly the way that Dewey describes. Through a process that might be described as progressive release, they become increasingly familiar with detailing and tackling their own tasks. They become sufficiently familiar with design practices—and sufficiently experienced with material and other technical understanding—to work out for themselves which directions to pursue. Heutagogy and pedagogy are not ideas that are in conflict with each other, but rather they are natural allies. And the balance between them is representative of the progressive shift of responsibility for the conduct of learning from teachers to learners.

An adaptive emergent framework

According to Gurung (cited in Gros, 2016), pedagogies must become 'non-static' and dynamically evolve with the changing circumstances of society, hence requiring constant reflection. In this vein, the current article presents a reflection of the notion of pedagogy with the complex metaphor for learning that is encompassed in the concept of integrated STEM education. The article considers the role of the educator and the learner through a reflection on the dynamics of power as it is conceptualised within pedagogy, andragogy and heutagogy. Of course, it could be argued that neither the teacher nor the learner hold this power under the requirements of national curricula. Teachers often feel pressurised to complete the curriculum requirements in constrictive temporal conditions (e.g. Fitzgerald *et al.,* 2017) and students feel pressurised to perform in high-stakes assessments (e.g. Swain & Prendergast, 2018). While these are of course valid concerns in the debate on learning in STEM, our focus in this article is concerned with analogies used to describe learning and the associated philosophical and epistemological perspectives on the practice of teaching and learning in the STEM classroom. Of particular importance is the role these analogies play in how learning and the learner and teacher are conceptualised in the process itself, and this is where the core contribution of this article lies.

Rather than critically dismissing the importance of pedagogy, this article advocates the adoption of emerging pedagogies. While some authors—such as Blaschke (2012, 2016)—advocate for a pedagogy–andragogy–heutagogy continuum, emphasising a move from directed to autonomous learning, this may not be a realistic conception for practice in the STEM classroom. Depending on the characteristics of a class that a teacher works with, this continuum may not be applicable and heutagogy in such a case will escape any vernacular reality, leaving the student, at the end of their studies, in a scenario where they must be heutagogy capable regardless of their readiness. In contrast, there are also the requirements of national curriculum that must be navigated by the teacher, where interpretation of the specifications can vary depending on the assessment, knowledge types and materials specified (e.g. Males & Setniker, 2019), demanding a differing stance on the pedagogy–andragogy–heutagogy continuum.

As illustrated in the case study, the teacher in STEM must navigate a space where pedagogy and the development of certain skills and knowledge will be necessary on occasion, and where the application of these competencies in new and novel ways to solve a design problem may be necessary at other times. In such a circumstance, where the student is determining their own approaches and learning (heutagogy), and an impasse is reached requiring a supportive prompt from the teacher (principles of andragogy), the teacher is dynamically selecting the pedagogies necessary in an emergent manner to cultivate students' capabilities. This process cannot be captured in a continuum model, and hence we argue for an adaptive emergent space where the teacher aligns with the emerging pedagogic orientation necessary at a given time. This ultimately means that the teacher's role is in itself complex. Constructivist models of pedagogy often speak of the role of the teacher moving from that of the master of knowledge to facilitator (Fox, 2001; Biggs & Tang, 2007), and heutagogy references the role of the teacher as the lead learner (Hase & Kenyon, 2000; Canning, 2010). This article advocates the necessity for the role of the teacher to dynamically change depending on the emergent properties of the situation in the CAS of STEM education. This dynamic space of emergent pedagogies is illustrated in Figure 6.

In this model we propose an adaptive stance that customises the teaching approach to the unique complexity of the goals of the learning scenario, as was naturally

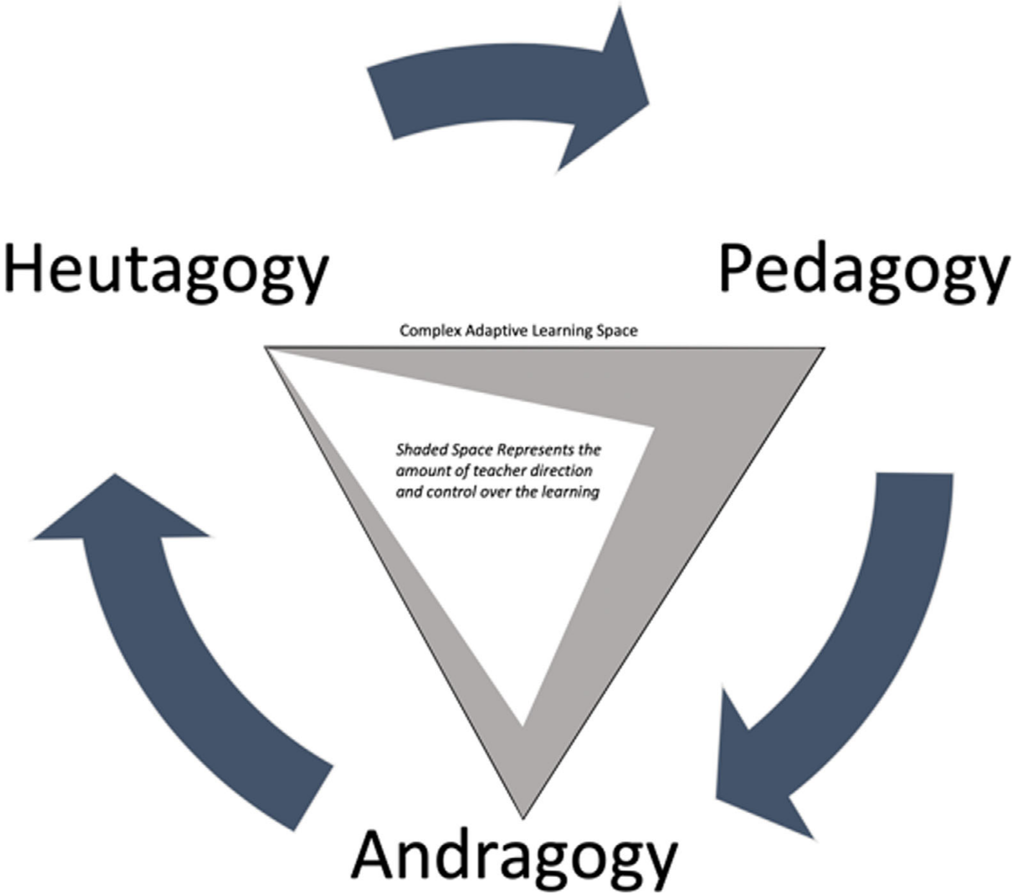

Figure 6. Emergent pedagogical space. [Colour figure can be viewed at wileyonlinelibrary.com]

occurring in the case study. The proposed model of emerging pedagogical space is an attempt to visualise the interaction of different emergent stances for both teaching and research. By suggesting a location in the space, an individual teacher can decide on the most apt teaching approaches required, whether they be fully directed as in the pedagogy apex or fully unguided as in the heutagogy vertex. This model also naturally resonates and fits the learning design framework advocated by Wasson & Kirschner, (2020) by providing a stimulus for reflection on the dynamics of the learning environment. The model allows a learning designer or teacher to conceptualise the balance of power between the educator and the learner, allowing the desired characteristics of the learning environment to be readily visualised. Practitioners within the emerging field of learning design are concerned with making the often tacit procedures undertaken by teachers and trainers visible, thus opening them up to investigation and critique (Mor *et al.,* 2015). The proposed model contributes to this overarching agenda by allowing the tacit dynamics of the learning environment and the teacher–student relationship to become visible. In doing so, it not only provides a catalyst for reflection on these tacit characteristics but also provides a means for methodological alignment of 'tools, ingredients and techniques', as in the Wasson & Kirschner (2020) framework, for the desired educational intervention.

In addition, this may help the researcher to focus on the complexity of their targeted study. Perhaps within the space of the pedagogy apex, the research focus might be a comparative quantitative study to assess the effectiveness of a particular task presentation for optimal learning (e.g. Seery & Delahunty, 2015). Whereas in the heutagogy apex, the focus may be on an ethnographic understanding of equality of educational opportunities in STEM (e.g. Weis *et al.,* 2015). Of critical importance to the research agenda in this space is the study of the networks and social forces that occur and interact within such a CAS. The role of the sociocultural in shaping the processes of teaching and learning is well established in the literature, and this model re-emphasises this by highlighting the dynamically changing role of teacher and learner.

Conclusion

STEM education has struggled with attempts to effectively integrate the four different subdisciplines, but is an area that offers the opportunity for complex self-determined learning practices to emerge. Much previous work on STEM learning has utilised metaphors for learning such as constructivism (Sharma & Yarlagadda, 2018) or information processing theory (Seery *et al.,* 2018). Notwithstanding, the link to formulating practice has been problematic. Raven (2020) discusses these disparities in educational design and provision and warns about the potential dangers of reductionist thinking that has plagued education and often militates against successful integration of differing accounts of learning and practice. This is potentially due to the predominant focus on one particular conception of learning in isolation. By adopting the CAS perspective and forgoing any reductionism of the learning process in STEM, the present article presents a way of conceptualising this learning, without any presumptions as to the appropriate means of conceptualisation. However, rather than leaving the analogy as a failing tautological endeavour, the article has introduced the model of an emergent pedagogical space as both a vernacular and academic lens (McNamara, 1991; Watkins & Mortimore, 1999) to view learning in STEM education.

This article, in analysing the appropriateness of a CAS analogy for learning in STEM contexts, and in subsequently unpacking the need for an emerging pedagogic conception of practice, presents a theoretical frame for investigating the holistic landscape of teaching and learning in STEM. The emerging pedagogical space is intended as a working model in which to conceive of potential teaching practices and potential research investigations. The theoretical model contributes to the scholarship of STEM education by providing a catalyst for practitioners' reflection, particularly relating to the power dynamics, goals and teaching stances of the STEM learning environment. Additionally, the model contributes to research in STEM education by making visible these dynamics and characteristics, thus allowing methodological alignment with the research interest in the context of applied pedagogical research.

Ethical guidelines

No ethical approval was required for the present study as data collection was not conducted.

Conflict of interest

The authors declare no conflict of interest.

Data availability statement

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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