Contemporary Issues in Technology Education

Wendy Fox-Turnbull
P. John Williams *Editors*

Locating Technology Education in STEM Teaching and Learning

What Does the 'T' Mean in STEM?

Springer

Contemporary Issues in Technology Education

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This book is dedicated to all the hard-working technology teachers who have embraced technology education as a student-centred, inquiry-based academic and practical learning area, set within authentic and meaningful contexts. The current STEM movement has the potential to enrich design and technology, placing it at the centre of an interdisciplinary curriculum, assisting the students to learn science and maths in a purposeful context. It also has the potential to relegate it to the use of technical tools and skills—digital or otherwise.

We hope this book will assist and motivate teachers in the former.

Acknoweldgements

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Chapter 1
Locating Technology Education in STEM Teaching and Learning: So, What Does the T Mean in STEM?

Wendy Fox-Turnbull

Abstract The vision for this book is to explore and clearly define technology (T) when embedded in Science, Technology, Engineering and Mathematics (STEM). It grew from a concern that prevailing perceptions of technology when embedded in STEM is merely the use of technological tools to serve the learning needs of science and mathematics. Those who have a clear and deep understanding of technology education know that this is not the case. Interdisciplinary integration is key to this understanding. Burke (Technol Teacher 73:14, 2014) states that an integrative STEM approach recognizes that technology and engineering provide opportunities for students to develop deeper knowledge about science. We would argue that an integrative STEM approach recognizes that technology and engineering provide opportunities for students to develop deeper knowledge about the world and how to intervene in it, drawing on design, science and mathematics knowledge to assist this process.

The vision for this book is to explore and clearly define technology (T) when embedded in Science, Technology, Engineering and Mathematics (STEM). It grew from a concern that prevailing perceptions of technology when embedded in STEM is merely the use of technological tools to serve the learning needs of science and mathematics. Those who have a clear and deep understanding of technology education know that this is not the case. Interdisciplinary integration is key to this understanding. Burke (2014) states that an integrative STEM approach recognizes that technology and engineering provide opportunities for students to develop deeper knowledge about science. We would argue that an integrative STEM approach recognizes that technology and engineering provide opportunities for students to develop deeper knowledge about the world and how to intervene in it, drawing on design, science and mathematics knowledge to assist this process.

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The diversity of approaches to STEM complicates its discussion. Not only does the definition of the T in STEM differ according to practitioner perceptions, but the approach to integration within STEM differs between schools and could be multi-disciplinary (concepts and skills separately in each discipline but in reference to a common theme), interdisciplinary integrating knowledge and methods from different disciplines, using a real synthesis of approaches) or transdisciplinary (creating a unity of intellectual frameworks beyond the disciplinary perspectives) and single or multi-teacher-led. The relationship of a STEM activity to the curriculum is also diverse and could be extra-curricular (out of school timetable and outside the school curriculum), intra-curricular (a STEM project delivered within a single subject over a few lessons of weeks, such as Science) or inter-curricular (timetabled as STEM and focused on the pedagogy of fostering the capacity for applied synthesis). Within this diversity, a number of themes emerge in the authors' discussions of STEM within the book, a summary of which follows.

Technological Applications in STEM: This theme highlights the application of technology in STEM education. It covers technology and engineering as disciplinary domains, design pedagogy and the role of food (Reinsfield), textiles (von Mengersen) and makerspaces (de Vries) in the STEM context. The themes emphasize the significance of technology in addressing real-world challenges and fostering innovation (Hallström and Norström). Authors advocate for technology education as a central pillar in STEM, enabling students to apply their knowledge and skills to create practical solutions and technological artifacts (Ankiewicz, Fox-Turnbull, Hacker, Reinsfield, Svärd and von Mengersen).

Philosophy, Theoretical and Historical Perspective of Technology in STEM: This theme explores the philosophical aspects of technology's role in STEM education and includes the development of products or artifacts (van Keulen) and identifies its constructivist theoretical underpinning (Ankiewicz). The historical roots of technology are discussed, and parallels are drawn with the Greek concept of 'techne,' which had a profound influence on European educational practice. By examining the meaning of technology as an artifact and as artful practice, this theme highlights the importance of traditional, tacit practices that cannot solely be taught through theory. The human aspect of technology is emphasized, as it aims to solve problems from a human perspective. This philosophical reflection encourages educators to view technology as an essential component of STEM and recognize its cultural and historical significance, noting that technology can be disruptive whether it be through outcomes or actions (Lee, van Keulen).

Technology in STEM with Integrity: Maintaining the integrity of technology, technological knowledge and technological practice is central to this book. It advocates the avoidance of 'Mucky Brown Paint' syndrome (all learning areas mixed together in busy activity rather than specific learning) (Fox-Turnbull, Lee). Doyle makes a clear distinction between technology and technology tools used for digital learning in education and explores the impact of technology and digital educational tools, especially during the COVID-19 pandemic, on STEM education. He also examines the adoption of digital technology in STEM classrooms and its implications for future STEM activities. The book also advocates for the purposeful addressing of curriculum knowledge in STEM Projects (Banks, Fox-Turnbull, Hacker, Lee, Reinsfield, van Keulen, von Mengersen) to advocate for a focus on the importance of technology teachers having a wide curriculum knowledge to support the 'T' in STEM school projects. In addition, it emphasizes cross-curriculum approaches, collaboration and the integration of science and mathematics in technology-focused STEM projects (Hallström and Norström and Lin and Sie) and situates textiles (von Mengersen) and foods (Reinsfield) within the STEM family and acknowledges the importance of play worlds advocating for the bringing together of play and imagination in design to amplify technological learning (Fleer). Learning is not restricted to the classroom but also occurs outside of the curriculum (Lin and Sie) and in community makerspaces (de Vries). Hallström and Norström position the need for experts in the field within technology and engineering practice. Hacker examines the relationship between technology and engineering and the impacts both have on the wider world.

Integration and Curriculum Development: This theme focuses on the integration of STEM education, emphasizing the need to bring together science, technology, engineering and mathematics to create a holistic learning experience drawing on notions of social constructivism (Lee). Various approaches to integration are explored, including conceptual frameworks and models that facilitate the blending of these disciplines (Lee, Fox-Turnbull). The theme highlights the benefits of integrated STEM projects for both teachers and learners while discussing the challenges in implementing such approaches. By addressing curriculum knowledge and cross-curriculum collaboration, this theme advocates for a more comprehensive and interconnected STEM education. The book delves into different approaches and models to integrating STEM education (Banks, Beaumont, Fox-Turnbull, Hacker, Lee,) and explores the role and notions of integration (Lee) and the importance of keeping the academic integrity of distinct knowledge disciplines and the challenges and benefits of implementing integrated STEM projects within authentic learning contexts. (Beaumont, de Vries Lee, Banks, Fox-Turnbull). Jones and Roberts discuss the concept of STEM literacy and its relation to disciplinary literacies. They emphasize technological literacy as a necessary foundation for achieving STEM literacy.

Assessment and Evaluation in STEM: This theme discusses the importance of assessing technology in STEM education. It acknowledges the fluid and non-deterministic nature of technological activities, making assessment a complex task. Seery and Canty explore the role of assessment in informing teaching and learning, aiming to strike a balance between evaluating students' performance and fostering a student-centered approach. It emphasizes the need for holistic assessment and teachers' professional judgment to capture the multidimensional aspects of technology in STEM. Fully embedded assessment is for learning rather than of learning (Banks, Seery and Canty). Assessment is a significant component of any technology program, especially in the senior secondary context. Svärd identifies a number of challenges for the senior secondary sector including teacher knowledge, especially across the STEM disciplines, lack of time and teacher preparation and different ways of working technology requires.

Gender and Equity in STEM: Niiranen et al. delved into the issues of gender representation and equity in STEM education and explored gender segregation and unconscious bias in technology-oriented fields. The chapters within this theme discussed the importance of gender-aware approaches to promote equitable participation and representation of genders in STEM (Niiranen et al. Reinsfield). By shedding light on the experiences and perceptions of female students and educators, this theme advocated for creating inclusive and supportive environments for all learners.

Senior Secondary Education in STEM: Svärd focuses on the implementation of STEM education in senior secondary schools. It highlights the significance of interdisciplinary education to prepare students for real-world challenges and encourage them to engage with complex problems. The theme emphasizes the role of technology education in integrating and contextualizing learning, bridging the gap between different STEM subjects.

Overall, the book covers a wide range of themes that collectively contribute to a comprehensive understanding of technology's place in STEM education. It highlights the theoretical, practical and societal aspects of integrating technology within STEM and advocates for a more inclusive, equitable and interdisciplinary approach to teaching and learning (Hacker, Lee, Fox-Turnbull). The exploration of technology's historical and philosophical roots adds depth to the understanding of its significance in shaping human development and problem-solving approaches. Furthermore, the book recognizes the importance of addressing gender disparities and fostering a supportive learning environment for all students. By examining the implementation of STEM at different educational levels, the book offers valuable insights into curriculum development and pedagogical practices. It provides a rich resource for educators, researchers and policymakers interested in advancing STEM education and technology integration in the modern educational landscape.

*ChatGPT was used in the identification of some of the initial themes.

Reference

Burke, B. N. (2014). The ITEEA 6E learning byDeSIGN[TM] model: maximizing informed design and inquiry in the integrative STEM classroom. *Technol Teacher, 73*(6), 14.

Wendy Fox-Turnbull is an Associate Professor at the University of Waikato and Associate Dean-Academic in the Division of Education. Wendy is the editor of Australasian Journal of Technology Education and on Editorial Board of International Journal of Work Integrated Learning and co- editor European Journal of STEM Education. In 2019 she was guest editor for Design and Technology: An International Journal Primary Edition. In 2018 she was the invited section editor for the International Handbook in Teacher Education, Section Technology Teacher Education. Wendy was chair of the Technology Education New Zealand (TENZ Council) from 2006 to 2018 and has convened three TENZ conferencesTENZ 2005, TENZ2015 and TENZ/ICTE2017 and one International Technology Research conference (PATT) in 2013. Research special interests include authentic learning in technology education, the place of women in technology related

STEM careers, the role and nature of effective conversations in learning and teaching and learning approaches for the 21st Century. Wendy is a registered and certified teacher.

Chapter 2
A Philosophy for the Place of Technology in STEM

Hanno van Keulen

Abstract This philosophical reflection focuses on the 'T' of technology in STEM as it appears to stand out as the product or artefact resulting from the practices of science, engineering, and mathematics. This interpretation is enriched by a historical and cultural comparison of technology to 'techne', the Greek word for craft that had a deep influence on European educational practice and draws attention to the value of traditional, tacit practices that are not taught through theory alone. The meaning of technology, as artefact and artful practice, is further analysed from viewpoints of linguistics, cognitive psychology, anthropology, and ethics. Technology is thoroughly human in the sense that it solves problems from a human point of view, and therefore we all should, in principle, be able to understand the technology and recognize its affordances. Technology has shaped us as much as we shape technology: the development of our cognitive system goes hand in hand with making and using technology, both in the development from birth to adult as in the evolution from our prehistoric ancestors to the creative and responsible Homo sapiens we may one day become.

Keywords Philosophy of STEM · Tacit knowledge · Embodied cognition · Craft · STEM education

2.1 Introduction

Do we need to think from a philosophical point of view about STEM? We already have well-established philosophies of science, of technology, and of mathematics. This book focuses on the 'T' of technology in STEM. Does technology change in nature when it becomes a constituent of STEM, requiring additional philosophical reflections? Will the combination reveal new or emerging properties of technology,

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like gelatine can reveal its ability to turn juice and sugar into a tasty dessert, or molecules of H_2O, which are not liquid or wet themselves, can form a drop of water?

A reflection on the origin of STEM shows that STEM was not proposed from a theoretical, let alone a philosophical point of view. The first mention of STEM was in the USA in the last decade of the twentieth century, in the context of workforce shortages related to technical professions. Reportedly, the juggling with nouns towards STEM started with Science, Mathematics, and Technology (SMT), after which Engineering was inserted to make the acronym easier to pronounce (SMET). Apparently, this did not resonate well enough, so the order was changed, and STEM was born. Clearly, STEM is not a natural phenomenon, out there, waiting to be observed, analysed, and defined. It is a social construct, which implies that its meaning is 'in the eye of the beholder' and to be found in the social and cultural practices where STEM is discussed, taught, learned, and applied.

Adding 'engineering' to the mixture of science, technology, and mathematics is an act that potentially changes meaning and opens a venue. It suggests that technology and engineering are different enough to justify the inclusion of both. What could be this difference? Science, engineering, and mathematics can be regarded as practices and not as material things. You cannot pick up science and let it fall on your feet. The word technology, though, is often used for material things, artefacts (Mitcham, 1994), the products of a practice that may be informed by engineering and the application of mathematics and science. So, thinking about the 'T' in STEM is thinking about the special position of human-made artefacts resulting from practices that are informed by the bodies of knowledge and skills of science, mathematics, and engineering.

But perhaps this is true only when and if we speak English. English is the language of academia, but native speakers of other languages will recognize difficulties when translating STEM. For example, in Germany, the acronym most widely used for STEM is 'MINT', which stands for Mathematik (Mathematics), Informatik (Computer Science), Naturwissenschaft (Natural Sciences), and Technik. 'Technik' may be translated into 'technology' but not in the sense that it refers to artefacts. Its meaning is much closer to practice. 'Technik' has an ancient origin in the Greek word 'τέχνη' (techne), which refers to the artful making of useful things. For Germans, 'Technik' and 'Ingenieurwissenchaften' (engineering) are therefore too similar to be used both in a combination like STEM. This is also true for several other related languages that use 'techne', more or less, in its original Greek meaning, like Dutch and Swedish.

2.2 Historical and Cultural Aspects

What this means is that philosophical reflection on STEM and on the 'T' in STEM has historical and cultural connotations. Are we reflecting on technology-as-artefacts that result from scientifically and mathematically informed engineering practices (American style) or on technology-as-artful practice with roots in craftsmanship, rather than in academic science (Greek-German style)? For the ancient Greeks, making things and working with their hands out of necessity was not held in high regard. Craftsmen were respected when their work had quality, but they were artists rather than scientists. They may have had a certain knowledge base, but this was often unarticulated, implicit, tacit, personal, and not the explicit and undeniable, 'scientific', theorems the philosophers sought, to learn about and understand the eternal truths. 'Science', from the Latin 'scientia', means 'knowing' or 'understanding'. Knowing and using your mind was for the Greeks not related to making and using your hands. The school of Aristotle, although he himself a keen of observer of nature and a proto biologist, became known as 'Peripatetic', which means so much as philosophizing by walking around, with hands behind the back. Aristotle's ideas and theories were brilliant, and his influence lasted for centuries, but they were eventually questioned when experimenting became the companion of theorizing and observing. Experimenting implies using your hands; bare hands and the naked eye can be reinforced with tools; and tools and instruments require making. Science and technology, understanding and making, became fundamentally entangled in the age of the scientific revolution with its front runners Galileo, Huygens, and Hooke. But 'Technik', as the practice of non-academic craftsmen, retained a parallel position, still creating artefacts based on tacit approaches that were mastered through imitation, rather than through theory. In 'The Craftsman' (Sennett, 2009), a wonderful book on how craft is taught and learned through the ages, Richard Sennett gives the example of Stradivari, who build violins like never before and after, because he was unable (or unwilling) to articulate his secrets to his pupils. Artefacts made through tradition do not necessarily lack quality; on the contrary, they come into being through pathways that are alien to academia and tend to be ignored or even refuted, precisely for their lack of theoretical transparency and rationale.

Combining academic science, mathematics, and engineering for the sake of producing technology could easily become self-evident and dominant in the US education system since this only came into being well after the seventeenth century. Europeans, however, inherited their school system from classical and mediaeval times. The oldest universities (Bologna, Paris, Oxford) were established around 1200 and were utterly impractical. Just like it was in Greece, the gymnasium (secondary education) and the university were for the elite, who did not need to work for a living but sought intellectual challenge, like reading Plato, writing poetry, excavating Egyptian treasures, or collecting exotic butterflies. Greek, Latin, and History were the important subjects. Medicine was studied through the works of Hippocrates and Galamus, with the result that for the sake of your health, you'd better go to a midwife or herb collector than to a medical doctor.

The Industrial Revolution with its increasing need for workers with advanced knowledge of mechanics, chemistry, transportation, steel production, et cetera, initiated radical changes in the school system. For example, in 1863 the Dutch Government created a new secondary school, the 'Hogere Burger School', with an emphasis on mathematics, physics, and chemistry. Translating the name of the school into American English nicely illustrates the cultural stance towards the 'techne' of Europe. It seems obvious to translate 'Hogere Burger School' into 'high school' or 'higher education for citizens' ('burger' means 'citizen'). But in 1863 'higher' did not refer to the next step in a sequence from primary to tertiary education. Rather, this school was meant for 'higher citizens' as opposed to 'lower citizens': the new elites that made their money through trade and industry and, like the old elites, did not work with their hands. The difference was perhaps that they preferred reading Von Humbold above reading Plato. Theory, and not making, fleshed out the curriculum, and teachers in these schools nowadays still perform experiments mainly to illustrate the theory, not to develop practical skills. The children of the real labourers and craftsmen, on the other hand, did not go to secondary school until well into the twentieth century, and they still are underrepresented in the schools that prepare for academic learning. Many European countries with a Greco-Roman heritage maintain a two-tiered educational system, with a theoretical and a vocational column, with approaches to the material world that are often incompatible.

So, a philosophy for STEM emphasizes a historical and cultural reflection on the place of artefacts, theory, making, and the appreciation of tacit craft in educational settings. If this analysis is adequate, curriculum developers on both sides of the Atlantic may draw different lessons on how to elaborate STEM into their school systems: interest in non-theoretical traditions on the one side and equity for craft on the other. This also has repercussions for the cultures with native craft traditions in Asia, Africa, Oceania, or the Americas. They are exposed to the powerful self-evident views concerning the STEM curriculum from Europe and North America, and the world may lose valuable ways of making artefacts when a one-size-fits-all STEM approach is thoughtlessly implemented. History can inspire reflection on the role of technology in STEM, and there are more points of view that can enrich our understanding of the T in STEM. In the next sections, we will explore viewpoints from linguistics, cognitive psychology, anthropology, and ethics.

2.3 Linguistic Aspects

The reflections above already show how important language is. Greek techne is not identical to American technology. Therefore, what 'STEM' can mean to an American is not what it can mean to a German, a Dutchman, or a Nigerian. The fact that the meaning of a word depends upon historical and cultural contingencies, however, does not imply that we cannot cross the boundaries and understand other viewpoints. The laws and constants of physics require precision up to five decimals and apply everywhere in the world, but cultural and social concepts typically are fuzzier. 'Play', for example, has no definition that includes all instances that everybody agrees on are play; compare tennis to patience. Such constructs are called 'categories': they have instances but no all-encompassing definition.

Words, like STEM, have origins. Words occur in a context. The meaning of words is not a matter of definition from scratch, and teaching is not forcing learners to reproduce these definitions. Rather, students should be taught how to derive meaning from the context. This is a personal act (Polanyi, 1962), not something that is produced by an AI algorithm. This is the domain of hermeneutics, an approach to understanding texts that are not self-evident. The meaning of an unknown word, for example, can be derived from its place and apparent role in a sentence, a paragraph, or a book. Likewise, the meaning of an artefact can be derived from the interaction of the artefact with its material and immaterial context. Interpretation is a key activity: a correct interpretation leads to a fruitful application. The ability to apply correctly implies understanding. This is the hermeneutic circle. For the German hermeneutic philosopher Hans-Georg Gadamer (Gadamer, 1960, 1972), this is how we should also approach technology (in its meaning of artefact): the technology will impose its affordances on me, that is, how it should be used if I encounter it in its proper context, and if I apply all my knowledge of the context to find out what it can do for me.

Technologies that are too new or disruptive, however, cannot exist or come into being in a context that cannot interpret them. That is why the first motorized cars looked like horse-drawn chariots. Imagining a Corvette was beyond imagination. Typically, technology is a solution to a problem, and we cannot understand solutions to problems that have not (yet) been articulated. Currently, e-books have page numbers like printed books, but who knows how we will find our way into texts in the future? Gadamer compares the assessment of technology to the experience we have when we are confronted with a piece of art. Conveniently, the German language uses the same word for a piece of art as for a technological artefact: 'Kunstwerk'. We can recognize what is a true work of art, and the same experience of truth can be obtained when we are confronted with technology. Good technology fits a solution to a problem in a specific context, in our life, experienced as the flow of things and events that makes sense to us. We intuitively appreciate buildings, structures, tools, and utensils when we recognize an applicability that is consistent with the surroundings and our needs, whether they have been created by theoretically informed engineers or by illiterate craftsmen.

To many people, STEM should make room for the 'A' of Arts and evolve into STEAM. What do proponents mean by the A? Does it express the interest of the STEM community in craft and traditional ways of making? Or is meant that painters, sculptors, musicians, dancers, et cetera, are also creative problem solvers whose approaches can inspire STEM professionals? Both interpretations have merit, and linguistic analysis can help to prevent misunderstandings. For a set of articles that are mutually inconsistent in this respect, see the special issue 'STEM and Arts Education' of the European Journal of STEM Education (2021).

Linguistics is also important to understand where the words we use within STEM come from. Living and surviving in the material world means correctly understanding the affordances of this world and effectively applying this understanding to our daily life. To some extent, this can be tacit. But there is a gap from daily life to the highly abstract theoretical language of scientists and engineers, to be bridged by education (Collins, 2010; Sullivan, 2017). A starting point is needed. A new and unknown phenomenon has to be named: deictic pointing and using words like 'this' and 'that' may work on the spot but do not transfer to an audience that does not participate in the practice. Lakoff and Johnson (Lakoff & Johnson, 1980) elaborated the role of metaphor in STEM. Typically, we start with improvising on a concept we know and map its characteristics to the unknown, to develop an initial understanding (Nersessian, 2008). 'Electrical current' is a good example: we recognize the similarities between a river flowing from high to low altitude while transporting useful stuff. We conveniently forget about the differences: electrical current does not evaporate or make you wet. 'Current' has received a new meaning. In this way, well-known phenomena with an explicit vocabulary keep on inspiring scientists to explain the not-yet-well-known (Abrahamson et al., 2012; Browne, 2003). Reflecting on technology in STEM thus is reflecting on language.

2.4 Cognitive Psychology

Technology is material, and so are we. Understanding technology is for a part embodied, in the sense that artefacts like we are subject to similar forces and influences, and artefacts typically are solutions to human problems and challenges to cope with the material world (Niebert et al., 2012). A cup can contain water much better than our hand. Present-day technology is not an incomprehensible black box but a set of babushka dolls: it uses other technology which again uses other technology (Arthur, 2009), but after some peeling-off in the end you reach your body. A cell phone at the bottom is your voice but with the ability to reach others over a greater distance. We may lack the mental and physical facilities to 'really' understand string theory, quantum coupling, or four dimensions that are perpendicular to each other. But we are fundamentally related to artefacts and every child, student and citizen should in principle be able to understand the devices we are confronted with, however complicated they may seem at first sight. A challenge for education!

We experience the world through our senses, and we interact with the world with our hands. We feel gravity pulling us down from the moment we are born, and the struggle to stand on our feet is a yearlong intense effort, so when we feel 'down', we can notice that we also keep a low body posture. Therapists know this and advise you to actively keep your head up and lift the corners of your mouth to automatically feel better. More important people sit in a higher place, suggesting that they were stronger than others in the struggle to move up against gravity. Our understanding of this metaphorical use of such words is embodied (Lakoff & Johnson, 1999). In contrast to feeling high or low, we never feel 'left', because there is no force acting on the horizontal as there is a force like gravity acting on the vertical, and consequently moving left or right is emotionally irrelevant.

For many psychologists, cognition and language, therefore, are embodied (Abrahamson et al., 2012; Gibson & Pick, 2000; Glenberg & Kaschak, 2002; Zwaan & Kaschak, 2009; Marechal et al., 2013). We develop our concepts through perceiving affordances and acting on these. What fits our bodily experiences is easier to understand. Technology is meant to solve our material problems, and therefore we should always be able to connect with it. It should fit like a glove. Surely, a dolphin won't understand this metaphor: dolphins concentrate on other affordances. For children, is far easier to understand the meaning of 'up' and 'down' and apply this knowledge when opening a drawer than to understand the meaning of 'left' and 'right'.

When we learn to walk, we become aware of the meaning of shades, recognizing what we have to do with our feet to prevent stumbling. When the sun is behind you and the shade is behind the obstacle, you must lift your feet because it is an elevation. When the shade is before the obstacle, there is a hole to step over. Through learning, our brain and our cognition become adapted to this specific material world (Dehaene, 2020). We are accustomed to a world in which the sun is above us and not below us, otherwise, our automatic interpretation of shades would have led to the opposite behaviour. Also, we do not experience a change in our clothes when we move from the dark into the light: we assume that these are the same clothes and thus must retain their colour. Computer scientists have only recently mastered the animation of shades in such a way that the animation appears somewhat realistic to the human observer because our brain has learned to create an awareness of what makes sense to us, not what is objectively visible (Ware, 2013; Wolfe et al., 2009). So, in a sense, reflecting on technology in STEM is reflecting on early childhood education and cognitive psychology.

2.5 Anthropological Aspects

Our body allows us to work with technology, especially with artefacts that elaborate on our body. A hammer is like a fist, but heavier and less vulnerable. A file is like nails but harder and, again, less vulnerable. The brain we are born with allows us to understand and operate these tools. The first learning takes place at a very early age before we can speak or think with words. We shape technology, or so we think. Developmentally, however, there is a case for technology shaping us and thinking as preceded by making. Anthropologists have studied how we learn to make stone tools (Malafouris, 2013). It was two million years ago that the first stone tools were made, by ancestors that were not yet evolved into Homo sapiens ('wise', 'understanding', 'thinking'). Was the tool designed and developed from the imagination of a prehistoric mastermind? Anthropologists think not. With *f*MRI techniques, they studied how expert tool makers use their brains when tool-making and compared this to novices learning to make stone tools. Experts use the brain regions associated with conscious thinking, especially the prefrontal cortex. They have learned what to do and what to observe, and they act on purpose, doing what they want to do. Novices, however, when trying to make stone tools, primarily use the motor regions of the brain. They act randomly at first, and they are unable to repeat a lucky strike at will. Eventually, when the body tacitly understands what to do, the prefrontal cortex enters the stage, and novices slowly start to become conscious about what they are doing and what they see, feel, and hear. It is through this sustained doing that stable connections between neurons in the brain will be made, and these will connect the motor region with perception, emotion, and language, allowing us to remember, describe, explain, rejoice in success, and repeat and improve the action till perfection (Hurford, 2007). Learning is a permanent change in the brain, and the development of the prefrontal cortex is correlated with the advent of the 'maker movement' (Feinberg & Mallat, 2016). Between the first primitive stone tools and conscious technological advancements lies a vast amount of time, enough to evolve a brain suitable for tool-making, speech, and thinking. Within our lifetime we will not notice how technology shapes us, but our successors will. Reflecting on technology is reflecting on human development (Bickerton, 2014; McGinn, 2015).

2.6 Ethical Aspects

Tool making and tool using shaped us. Tools and technology shaped the world. This process has accelerated enormously, especially since the nineteenth century. And not just for the good. Kevin Kelly advocates the view that if technology is 51% beneficial, in the long run, humanity will benefit (Kelly, 2011), but who pays for the collateral damage? Maybe these trade-offs remain inevitable when thinking about the impact of technology on society is restricted to scientists, engineers, and mathematicians and predominantly plays a role in the introductory and closing paragraphs of grant proposals. Scientists and engineers nowadays know they can use help from ethics, various religions, and other sources of wisdom (Goorden, 2017). Jacques Ellul, both a philosopher of technology and a Christian theologist, pointed out that it all started in a Garden but, at least for those willing to believe the Book of Revelations, it will end with a City, requiring architects, constructors, and craftsmen (Ellul, 1970). Perhaps, optimists like Kelly are right and technology, used wisely, will help create the sustainable and safe society we all hope for. What attracted and seduced Eve and Adam in the Garden may not have been an apple but a stone tool, perhaps with a warning tag 'to be used creatively but responsibly'. Thinking about the consequences is, yet, not hard-wired in our DNA, unfortunately. There is a resemblance with the problem of obesity: our body can handle scarcity much better than abundance. Likewise, we are well-equipped to recognize the affordances of new technologies, but we fail to recognize the trade-offs. Will this capacity ever evolve? Reflecting on the 'T' of technology in STEM thus is reflecting on how we should live.

2.7 Conclusion

Technology is the central concept of STEM. Technology-as-artefact complements science, engineering, and mathematics, as the product of practices. Technology-as-techne reminds us that not all practices that create valuable products have a rational foundation in evidence-based academic theories. Technology-as-art has the double connotation of valuing traditional craftsmanship and present-day Art School creativity. Technology-as-embodiedness reminds us that technology is not a black box but reflects our material selves. Situating technology in both a developmental and an ethical context appeals to us to apply our creativity and problem-solving capacities freely to design technology as a solution to a problem, but always in a responsible way.

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Chapter 3
STEM as Integration-Maximising Learning Opportunities

Kerry Lee

Abstract This chapter will outline the history, theories and approaches pertaining to the notion of integrated learning, before providing an overview of different types of integrated STEM education. Comparisons and connections will be made between various notions of integration including Kelley and Knowles' four-pulley conceptual framework, Bybee's nine perspectives of STEM, Nadelson and Seifert's STEM Continuum and Vasquez's four forms of STEM integration. This will provide the reader with a deep understanding of the levels and approaches to STEM integration. The role and confusion relating to the inclusion of the T (technology) in the STEM acronym will be provided. The benefits of STEM integration for teachers and learners will be outlined, followed by the key challenges of implementation. Prior to the conclusion is recommendations for future research.

Keywords Integration · Interdisciplinary · Multidisciplinary · Transdisciplinary · Models

3.1 Introduction

This chapter builds on the notions of the philosophy of STEM introduced in the previous chapter. It outlines the many facets of STEM integration. The chapter will begin with a brief overview of integration of learning before narrowing down and delving into STEM integration; the foundations; and the approaches before finally reflecting on the implications for teachers and learners.

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3.2 History Behind the Notion of Integrated Learning

The origins of the term integration in the field of education have been recorded by a number of authors including Barber (2012, 2014), Huber (2005) and Perez and Barber (2018). For a detailed account of the progression of the notion of integration see Klein (1990). Klein stated the earliest notable uses of the term integration appeared in a book by Herbert Spencer in 1855 but it was not until 50 years later, in 1898, that Alexis Bertrand wrote about the history of integrated instruction. It was at this time that integration was first recognised as a pedagogy (Goldberg, 2012). Initially the term referred to natural relations among the disciplines (Ciccorico, 1970). By the 1920s the term was linked with a project approach to learning, with an emphasis on the students' personal and social concerns. It was associated with the core curriculum movement in the 1930s and problem-solving in the 1940s. Since this time the focus has been on content integration and process integration (Klein, 2005).

Integration of learning has increased in popularity and has now become a buzzword (Leadbeatter, 2021). With many believing that the "integration of learning is a central goal for all professions" (Clapton et al., 2008, p. 334), including that of education (Jamison et al., 2014), and is a superior and ideal type of learning (Leadbeatter, 2021). The increase in popularity of integrated learning is also evidenced by the increase of research in the field, with approximately 1,470,000 research articles written between 2005 and 2010 and an impressive 2,030,000 between 2010 and 2015 (using a Google Scholar Search). Initially the general focus during these times was on approaches and knowledge drawn together from more than one discipline in an integrated unit, thematic study or a social-problem approach to science. However latterly the focus has been more on interdisciplinary study using communities of learning and collaborative approaches.

Although integration of learning is now routinely part of a teachers' lexicon it is rarely explained, with many incorrectly presuming a common and shared understanding of the term. However integration of learning can imply an outcome (Booth, 2011; Huber & Hutchings, 2004) or an action (Gill, 2007; Goldman & Schroth, 2012). Or it can focus on learner dispositions (Welsh & Dehler, 2013; Wolff & Luckett, 2013). It is also referred to as a process of learning, where the learner pulls together experience, knowledge and skills, gained from a range of contexts. This enables the learner to see similarities and *connect* the knowledge, *apply* the knowledge to a new context or *synthesise* existing knowledge to create new knowledge (Barber, 2014). Others refer to the integration of learning as a curriculum process (Goldman & Schroth, 2012); a goal of education (Clapton et al., 2008; Jamison et al., 2014); or any combination of these. Unfortunately these many interpretations of the term have proven to be problematic (Leadbeatter, 2021; Saito et al., 2016). The notion of STEM integration is also problematic, with commonly used terms including: STEM integration, integrated STEM, integrative STEM and interdisciplinary STEM (Moore et al., 2020).

3.3 Theories and Approaches Pertaining to Integration of Learning and STEM Learning

In order to understand the foundation of STEM integration it is important to first understand the foundation of all integrated learning; as one is a subset of the other. These will only be discussed briefly in order to provide a reference point, as they are expanded upon in Section B of this book. The conceptualisation of integration of learning has been founded on many theories. These include the famous works by Lao Tzu, Buddha, Heraclitus, Kant and Vico (Prince & Felder, 2006), followed by constructivist theorists such as Dewey, Piaget and Vigostsky, as well as Rogers, Montessori and Maslow (Ültanir, 2012).

The works by these theorists underpin well-known approaches used in STEM teaching and learning, which include: discovery methods (Bruner, 1960); inquiry-based learning (Schwab, 1960); project methods (Wingert et al., 2011); problem-based learning (Barrows, 1996); Bloom's taxonomy (Boom, 1956); Fischer's skill theory (Fischer, 1980); SOLO taxonomy (Biggs & Collis, 1982); planned behaviour, (Ajzen, 1985); just-in-time teaching (Novak et al., 1999); multicultural pedagogies (Jamison et al., 2014); transfer of learning (Barber, 2012); constructive developmental perspectives (Barber, 2014; Perez & Barber, 2018); as well as the use of tools as inquiry, discussion methods and peer-teaching. Because STEM learning has a practical nature it is often associated with cross-curricular learning (Barnes, 2011), theme-based learning (Mumford, 2000), generative learning (Wittrock, 1989) and real-life learning (Steele & Ashworth, 2013).

The majority of the above theories and approaches are underpinned by the notions of social constructivism. Learning is expected to be driven by the learner, and the teacher is the facilitator or supporter alongside. The traditional transmission teacher with the teacher standing in front of the classroom is incompatible with these approaches. Learning is strongly influenced by prior knowledge. Motivation is derived from authentic real-world professionally relevant situations and problems (Moore et al., 2020) which provide context for learning content and skills (Prince & Felder, 2006). Teaching is expected to move from a teacher-centred pedagogy to a learner-centred teaching and learning approach: a content-based paradigm, to an outcomes-based paradigm.

3.4 STEM Integration

Initially teachers used STEM to holistically refer to the four separate and distinct fields of science, mathematics, engineering and technology (Kelley & Knowles, 2016; Sanders, 2009; Wang et al., 2011); subjects which had historically been taught in isolation (Banks & Barlex, 2014b). However, the teaching of siloed subjects seemed to show a disconnection to real-world situations and problems where multi-disciplinary teams are needed (Wang et al., 2011). In this way disciplines are seen as interdependent (Bybee, 2013a; Kelley & Knowles, 2016; Wang et al., 2011). Until the late 2000s, researchers and practitioners emphasised the connections between subjects and advocated new *integrative* approaches to design and STEM (Honey et al., 2014; Kennedy & Odell, 2014).

Although disciplinary crossing is one of the most significant features of integrative STEM, the approaches of integration and the extent of crossing vary considerably (English, 2016). For example, some researchers (e.g. Honey et al., 2014; Wang et al., 2011) emphasise that the context or the problem should be complex enough to require students to apply more than one subject's knowledge. Honey et al. (2014) defined integration as "working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines". Other researchers propose merging the content of one or more given subject(s) into other subjects' courses (e.g. Kennedy & Odell, 2014; Sanders, 2009), such as when students gain science learning outcomes in a technology class (Kelley & Knowles, 2016). Due to the diverse interpretations of integration, more comprehensive perspectives and systems have been proposed, in which different types of integrated STEM are organised by certain rules. Most agree that STEM education integration requires at least two disciplines, with many requiring more (Moore et al., 2020).

This chapter provides an overview of a number of categorizations that define different types of integrated STEM education, including Kelley and Knowles (2016)'s four-pulley conceptual framework, Bybee (2013b)'s nine perspectives of STEM, Nadelson and Seifert (2013)'s STEM Continuum and Vasquez (2014)'s four forms of integration. The four notions of STEM integration presented by Vasquez (2014) are now commonly used, and for this reason they will be overlayed on the models developed by Kelley and Knowles, Bybee and Nadelson and Seifert to show the cohesion and commonality between the various interpretations.

3.4.1 Levels of Integration

Vasquez (2014) provided four labelled and clearly differentiated forms of integration: disciplinary, multidisciplinary, interdisciplinary and transdisciplinary. In this model the extent of integration and the interconnection amongst the subjects increases along the continuum (as shown in Fig. 3.1). The initial STEM acronym highlighted the importance of each of the respective subjects, however, a preference quickly developed for interdisciplinary and transdisciplinary approaches (English, 2016; Vasquez, 2014). Fox-Turnbull in her chapter identifies a number of issues and innovations with each approach as it relates to the primary and lower secondary classroom.

As the teachers increase the level of integration the distinction between disciplines becomes more blurred (Vasquez, 2014). In a multidisciplinary approach to STEM the topic is the only thing that ties the learning together. For example with the topic "Change", the children could: learn about states of matter and heating and cooling in science; look at how various cultures preserve food using dehydration, before making their own dehydrated snack in technology; investigate the how the wind and