Laying down the "T" and "E" in STEM education: Design as the basis of an integrated STEM philosophy

Abstract

STEM – science, technology, engineering, and mathematics – has become ubiquitous in education. How STEM and STEM education are to be defined is still a matter of debate, however, and it is only just recently that STEM education has been probed from a philosophical point of view. The need for a philosophical basis for STEM education is therefore fundamental. The aim of this study is thus to investigate specifically the role of the "T" and "E" in STEM, and how they not only may be fruitfully integrated with the "S" and "M", as part of a philosophy of STEM education, but also potentially form a methodological backbone of such a philosophy when it comes to design. The research question that underpinned the study is: What are the affordances of Mitcham's (1994) fourfold philosophical framework of technology for unifying the STEM subjects, with particular consideration of the "T" and "E"? The research methodology consisted of a qualitative meta-synthesis of the literature regarding the philosophy of technology and engineering, technology education, and the current issues of integrating the various STEM subjects. We conclude that from a methodological point of view – Mitcham's "activity" – the design in technology ("T") and engineering ("E") holds the most promising affordances for unifying the four STEM subjects. Design as part of particular design projects may require the "design" of applicable scientific experiments as well as the design of applicable mathematics expressions and formulae specifically when modelling in "E" (and "T").

Keywords: technology education; engineering education; STEM education; design; philosophy

Introduction

In the last decade the acronym STEM – science, technology, engineering, and mathematics – has become a buzzword, typically invoked when discussing educational policy, curricula and economic competitiveness. The acronym has also become ubiquitous in education, in particular in relation to educational initiatives in science and engineering education broadly defined. STEM as an educational enterprise has been growing in importance, particularly in the USA, UK, and other Anglo-Saxon countries (e.g. Banks & Barlex, 2014). How STEM education is to be defined is still a matter of debate, however. It is only just recently that STEM education has been probed from a philosophical point of view, with the aim of investigating what it is and what underpins it theoretically, although it is often from the point of view of one of the subjects such as science or mathematics (see e.g. Chesky & Wolfmeyer, 2015).

The need for a philosophical basis for *all* of STEM education is therefore fundamental, so that educational initiatives can rest on a solid philosophical foundation. Arguments have been put forward for a completely subject-based STEM education, that is, an S.T.E.M. education (e.g. Henderson et al., 2017), but various integrated approaches seem to dominate (e.g. Kelley & Knowles, 2016; Peterman et al., 2017). Criticism against various cooperative STEM approaches has also been put forward and includes, for example, that they may lead to a conflation of science and technology, or that the “T” and the “E” often tend to be downplayed in favour of the “S” and the “M” (e.g. Bers et al., 2013; Sanders, 2009). There is thus a philosophical vagueness surrounding the concept of STEM education. Pitt (2009) summarises it in the following way:

> Some people define any activity that involves any of science, technology, engineering or mathematics as a STEM activity; others argue that intrinsic to the concept is some linking of two or more of the component areas of learning, and that real STEM must be more than the sum of its parts (Pitt, 2009, p. 41).

The root of this ambiguity arises from the fact that science, technology, engineering and mathematics as subjects are not necessarily connected in neither content nor pedagogy. Tang and Williams (2018) tested the concept of an integrated STEM literacy empirically, and concluded that:

> Based on the similarities found in several language and thought processes of the disciplines, we conclude that there is presently a research basis for postulating a unitary STEM literacy that reflects the shared general capabilities required in all the STEM disciplines. At the same time, there are also substantial differences that support the retention of the existing literacy constructs (i.e., S.T.E.M. literacies) to reflect the specific linguistic, cognitive and epistemic requirements found in each disciplinary area. This distinction from the singular STEM literacy is necessary to highlight the skills and practices that are unique to each particular discipline, and therefore not applicable in all the other disciplines (p. 1).

Therefore, a great challenge for teachers in STEM subjects is to design classroom activities and lessons that integrate two or more of the subjects in their teaching in both a meaningful and relevant way (Bell, 2016; De Vries, 2017a; Margot & Kettler, 2019; Radloff & Guzey, 2016). Thus, it may be possible to balance the intrinsic, epistemic qualities of each subject with cooperation concerning the common general capabilities, that is, S.T.E.M. literacies with STEM literacy.

If STEM education is to remain philosophically solid and powerful as an educational endeavour it is clear that it should revolve around some kind of integration of two or more of the four subjects, at the same time as the core of each subject has to be respected. The aim of this study is thus to investigate specifically the role of the “T” and “E” in STEM, and how they not only may be fruitfully integrated with the “S” and “M”, as part of a philosophy of STEM education, but also potentially form a methodological backbone of such a philosophy when it comes to *design*. Design is here defined as an activity aimed at achieving the goals of people, companies or society more broadly, by describing objects or systems that are able to fulfil technical functions efficiently (Vermaas et al., 2011). The research question that underpinned the study is: What are the affordances of Mitcham’s (1994) fourfold philosophical framework of technology for unifying the STEM subjects, with particular consideration of the “T” and “E”? The research methodology for this philosophical paper consisted of a qualitative meta-synthesis of the literature regarding the philosophy of technology and engineering, technology education, and the current issues of integrating the various STEM subjects.

A philosophical framework for technology, technology education – and STEM education

According to Mitcham's (1994) fourfold philosophical framework, technology is manifested as object, knowledge, activity and volition. Technological knowledge and volition, with their origin within human beings, give rise to technological activities expressed as concrete technological objects. These four modes of manifestation of technology have been linked to the four components of general philosophy, as well as to the analytical tradition within the philosophy of technology, namely ontology, epistemology, methodology and volition respectively (Ankiewicz, 2016, 2019; Ankiewicz et al., 2006; De Vries, 2017b), as illustrated in Fig. 1. On the one hand, technological knowledge and volition, with their origin within human beings, give rise to technological activities expressed as concrete technological objects (indicated by the black arrows). On the other hand, objects can also influence peoples' activities, knowledge and their will (indicated by the grey arrows).

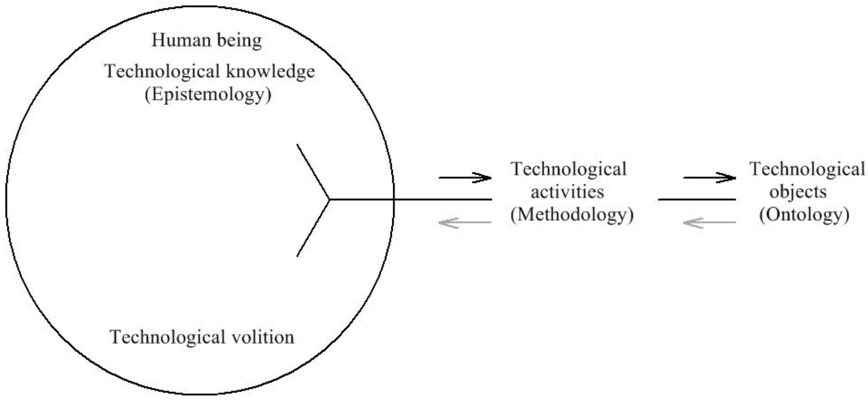

Figure 1: Modes in which technology is manifested
(Mitcham, 1994, pp. 160 and 209, as adapted by Ankiewicz, 2019 and Ankiewicz, De Swardt and De Vries, 2006).

It follows that all of these four components of philosophy could be applied also to the "S", "E" and "M" in a STEM education philosophy, although it remains to be seen whether they can be cogently unified philosophically. Evidence from other studies suggests that the STEM subjects are too dissimilar concerning ontology and epistemology for a successful integration on these grounds (e.g. Tang & Williams, 2018), so we suggest *methodology* as an area to explore philosophically across the STEM subjects, with special regard to the primary methodology of technology education – design. We thus need to find common ground for a transdisciplinary STEM philosophy built on interaction and cooperation – looking sideways, whilst respecting the integrity of each subject – in precisely the methodological dimension.

Design methodology as a way of philosophically unifying the STEM subjects

Design processes are the object studied in the discipline of design methodology (De Vries, 2001). Two radically different paradigms form the basis of the discipline of design methodology, i.e. the rational problem-solving and the reflective practice paradigm. The rational problem-solving approach is a more structured approach generally associated with engineers while the reflective practice paradigm is a less structured approach usually associated with architects (Ammon, 2017; Ankiewicz et al., 2006; Dorst, 1997). A combination of the two approaches into the conceptual, information and embodiment stages of design activity results in a dual model of design methodology (Dorst, 1997).

Design is the primary methodology of technology which is more intuitive (De Vries, 2018) as it has an element of trial and error to it (Williams, 2011) and is in itself "an independent epistemic praxis" (Ammon, 2017, p. 495); thus, it is largely associated with the reflective practice paradigm. Design also features in engineering which is part of the broader field technology (De Vries, 2018). Engineering is actually a sub-set of the broad area of technology (Williams, 2011). However, design as a characteristic of engineering is different from design in technology. It is infused with the more structured elements of modelling, quantification and the use of concepts (De Vries, 2018); thus it is generally associated with the rational problem-solving paradigm.

Based on Dorst's (1997) dual model the combination of "T" and "E" could provide a clue for the problem on how to exploit the affordances of STEM (De Vries, 2018). Like other scholars (e.g. Williams, 2011) we do not support an integrative approach to STEM for the mere sake of integrating the STEM subjects. We acknowledge the dangers of integration for the integrity of the various STEM subjects; there must be a relevant, authentic connection between the STEM subjects (De Vries, 2018).

There are particular knowledge aspects in science and mathematics (as well as other subjects) supporting technology that do not belong to technology. Hence the – perhaps somewhat arrogant – statement: "Technology […] is a field of study that has its own intellectual domain; yet, it can make maths, science, and other fields tangible and relevant to bring them to life" (ITEA, 1997, p. ii). Therefore, it is not really such a novel idea that technology ("T") can be the "integrator" of "S", "E" and "M" (Ankiewicz, 2003; Bybee, 2013; Ritz & Fan, 2015). Bishop (1988) also concedes the primacy of technology, and mathematics, in this sense, as a cultural product or tool.

From the literature on STEM education there seems to be mainly two ways of interaction, i.e. the application of existing knowledge from the STEM subjects (e.g. Barlex, 2007) and an approach where there is knowledge development in all STEM subjects simultaneously, as well as the application of knowledge from the various STEM subjects (De Vries, 2018). Focusing on design – as a characteristic of both technology and engineering – may be conducive to the application of existing knowledge from the STEM subjects as well as knowledge development in all STEM subjects simultaneously.

Barlex (2007) mentions a more incidental type of interaction between the STEM subjects which occurs in design projects when technology students apply knowledge from the other STEM subjects (Williams, 2011). As opposed to incidental interaction between the STEM subjects – and in order to establish a real connection between them – De Vries (2018) suggests the use of particular design challenges in which engineering principles, scientific concepts and mathematical ways of thinking are essential for finding solutions to the challenge. Thus, he advocates an approach where there is knowledge development in all STEM subjects simultaneously, and not merely the application of existing knowledge related to them – similar to how it happens in practice. In such design challenges students will "design" and do experiments to understand scientific phenomena. Design in science may also be more experimentally oriented – such as, for example, in synthetic chemistry – whereas design in technology and engineering are not really experiments in the scientific sense but rather an epistemic practice of its own that is open ended, iterative and produces its own knowledge (Ammon, 2017). Design in technology, engineering – and even sometimes in mathematics, according to Bishop (1988) – will typically lead to the making of an object, or system (cf. Vermaas, 2011). The students will also "design" mathematical expressions or functions and do calculations to optimise their design by modelling to test their optimisations. The steps of mathematical modelling resemble, to a large extent, the stages of technological design within the rational problem solving paradigm. Such challenges will fit the nature of design as a process, and in the philosophical sense a methodology, in which both new knowledge is developed (about designing itself, but also science and engineering), and existing knowledge (previously learnt in science, technology and/or mathematics) is applied (De Vries, 2018; Vossen et al., 2019).

Concluding discussion

Philosophy – more specifically Mitcham's (1994) fourfold philosophical framework of technology – holds affordances for cogently unifying the STEM subjects. From an "S" and "M" perspective there is philosophically – specifically ontologically and epistemologically – little substantially in common with "T" and "E" that could unify the four STEM subjects, although, for instance, Bishop (1988) argues that mathematics is basically to be seen as a technology, and specifically expounds on a conception of design similar to in technology and engineering. Nevertheless, "S" and "M" can actually advance independently of "T" and "E". However, from a methodological point of view the "design" in "T" and "E" holds the most promising affordances for unifying the four STEM subjects, especially when considering that design in mathematics in certain conceptions also aligns with this. Design as part of particular design projects may require the "design" of applicable scientific experiments as well as the design of applicable mathematics expressions and formulae specifically when modelling in "E" (and "T"). As "T" and "E" are indispensable for STEM, we would not have had STEM if it was not for the "T" and "E". We will expand this study in the near future indicating that the fourth component of philosophy, i.e. volition, may hold additional affordances for coherently unifying the four STEM subjects.

Finally, we call for more research about design in STEM classrooms. It is imperative that interventions are carried out which integrate the STEM subjects in authentic design projects in a similar manner to those described by De Vries (2018), in which technological and engineering principles, scientific concepts and mathematical ways of thinking are essential for finding solutions to the challenges in the projects. Furthermore, such research should consider the ways the separate STEM subjects interact around a design challenge, and how students could benefit by engaging in design as a methodology in all four subjects. Models and modelling could, for example, be one way of methodologically creating bridges between the STEM subjects in such authentic design projects (cf. Hallström & Schönborn, 2019).

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