Theorizing the Role of Engineering Education for Society: Technological Activity in Context?

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Abstract

This paper establishes a theoretical position from which to analyse and reason about the difficulties associated with closing the gap between the provision of engineering education in universities and the needs of society. Broadly speaking, the disparity between societal expectations and university graduate profiles highlights that despite achieving success in university; recently graduated engineers are often under-prepared for their initial years in the workplace. Continuing reports of this disparity suggest that current efforts have not succeeded in sufficiently closing this gap.

As an antecedent to reforming engineering education policy or advocating a new pedagogical approach, we first theorise the role of engineering education for society. In adopting lessons from the philosophy of technology and how this has influenced the discourse surrounding K-12 technology education, the relationship between technological activity and technological knowledge is considered as a vessel though which to articulate engineering education. Through situating engineering disciplines as different contexts for technology, the need for engineering students to develop an ontological position towards engineering as technological activity, emerges as important.

In this view, we hold that a fluid epistemological boundary for engineering disciplines necessitates perspectives on how to enact engineering, as *doing* engineering in authentic contexts is advocated to support the well-established practices around learning *about* discipline specific declarative knowledge. The foregrounding of an understanding of engineering as technological activity, founded on (but not limited to) well-established discipline specific knowledge is framed as an ‘ontology-based curriculum’.

We conclude the paper with a discussion of some of the prevailing challenges to operationalising this conception of engineering education for society.

Introduction

Over several decades, there has been an increasing recognition of the difficulties facing engineering education in terms of meeting the needs of a rapidly evolving society. In its broadest sense, this discussion centres on a disparity between society’s need for effective modern engineers, and the knowledge, skills, and attitudes students develop in their engineering education[1]. It has been noted that the provision of engineering education gradually shifted from a practice-based curriculum to an engineering science-based model over the latter half of the 20th century[2]. An unintended consequence of this paradigm shift has been a diminished perception of the value of key skills and attitudes, which were considered integral to engineering education up until this point[3]. Here, we contend that the foregrounding of declarative knowledge, at the expense of higher-cognitive attitudinal and social competencies, appears to be a significant impediment to aligning the engineering education outcomes with societal expectations. It is important to note that there have been a number of commendable efforts to reduce the disparity; the Conceive-Design-Implement-Operate (CDIO)[4] and different variations of problem-based learning (PBL)[5] initiatives stand out as notable examples. However, sustained reports suggest that current efforts, pedagogical and curricular, have not succeeded in sufficiently closing this gap.

The emphasis placed on declarative knowledge over skills and attitudes is further compounded when one considers the dominant assessment model in engineering programs. This model is acknowledged as prioritising the recall of declarative knowledge over the ability to seek new knowledge and apply it to the unique problems that dominate professional practice[6]. In other words, the preponderance of courses, and in turn student activity, dedicated to the internalisation of declarative knowledge in bachelors level engineering education far outweigh the competencies recognised as important for graduates.

Through adopting lessons from the philosophy of technology and the impact this has had on the evolution of K-12 technology education, we first discuss the complicated relationship between technological activity and technological knowledge. Following a brief discussion on the parallels between K-12 technology education and bachelors level engineering education, the importance of developing an ontological position towards engineering as technological activity is considered. Through situating the engineering professions and disciplines as different contexts *for* technological activity, the need for engineering students to develop a disposition towards engineering as technological activity clearly emerges as important.

Offering this perspective as an *ontology-based curriculum*, this paper seeks to foreground an understanding of engineering as technological activity, dependant on existing (though evolving) frameworks of discipline specific declarative knowledge. It is important to note that this line of argument is not intended to disenfranchise engineering education, but rather to empower engineering educators, students and practicing engineers with a means of articulating the intricacies of learning in their profession.

Technology education: epistemological underpinnings

Since the inception of technology education as a school subject in the late 1970's and early 1980's, the subject area has held a precarious place on school curricula internationally[7]. Similar to engineering in many ways, technology education shares a relationship with practical activity, with its roots in craft/liberal arts (technical) education policy of the early 20th century. In efforts to intellectualise the subject area, and to meet the needs of an evolving society[8], policy changes shifted technology education's emphasis beyond the acquisition of predetermined knowledge and skills, consequently then described in terms of a transferability of concepts, principles and skills between different contexts[9]. This paradigm shift in international rhetoric is often considered to have failed to materialise in practice as envisioned, as questions have been raised in respect to the alignment with international rhetoric and the reality of enacted classroom practices[10,11,12].

The difficulties associated with operationalising the reformed technology education have largely been attributed to the epistemological differentiation between this emergent technology education, and the preceding technical subjects, as well as other school subjects. De Vries[13] argues that one of the reasons that establishing an epistemological basis for technology education has been problematic is that the philosophical notion of knowledge as *justified true belief* does not necessarily apply to technological knowledge. Norström[14] suggests that the main reason for this stems from technological knowledge's inherent action orientation, as technologists are less concerned with whether or not knowledge is true, instead being more concerned with whether or not the knowledge is useful in guiding actions towards certain goals. This epistemological fluidity[15] is acknowledged to result in an educational context where ”the domain of knowledge as a separate entity is irrelevant; the relevance of knowledge is determined by its application to the technological issue at hand. So the skill does not lie in the recall and application of knowledge, but in the decisions about, and sourcing of, what knowledge is relevant”[16].

Technological knowledge and activity: disciplinary contentions

Although declarative knowledge is utilised in technological activity, its application is trans-disciplinary in nature and highly context-specific. For example, knowledge from science, agriculture, construction, mathematics amongst countless other areas can be described as technological knowledge dependant on its utility in a particular context. A useful way of conceiving this is to adopt the epistemological differentiation put forward by Morrison-Love[17], where *transformation* is considered as the epistemological basis for technology education, in a similar way to *proof* within mathematics and *interpretation* within science. In alignment with philosophical perspectives on technological knowledge, and its inter-dependency with technological activity, the centrality of action to the nature of activity students engage with within technology education becomes apparent.

In considering the epistemic emancipation of technological knowledge, Houkes depicts a “double demarcation problem”[18]. With regard to articulating a taxonomy of technological knowledge, Houkes acknowledges that one must define the context in which the taxonomy is to be defined before knowledge can be categorised. Making both of these definitions results in an idiosyncratic taxonomy, that is, a taxonomy which cannot be translated to alternative contexts is developed, in essence, nullifying the initial objective. A useful way of conceiving this is to consider technological knowledge independent of a specific context, and ask the question; what now differentiates this knowledge from other disciplines of knowledge?

Assertions of the need to support the development of technological knowledge are therefore problematic, as the differentiation between engagement with authentic technological activity and engagement with predetermined technical knowledge raises questions as to whether or not you can explicate technological knowledge for the purposes of writing a technology curriculum. Moreover, the formulation of technology curricula as bases of declarative knowledge become problematic as it is unclear whether or not this knowledge constitutes technological knowledge. Even in cases where predetermining relevant declarative knowledge may be possible, this introduces the potential to contort understandings of the nature of technology, in that the subject may be reduced to learning *about* technology as opposed to *doing* technology.

Further to this epistemological differentiation between technology and other subject areas in constituting the area of technology as a discipline, contentions also emerge when considering what it is that a technologist does. In adopting the product-centric perspective of disciplines proposed by Turner[19], technology becomes more problematic. Although the term *technology* is prevalent in structures within academia, it is rarely the singular identifying term, in that it is seldom that one claims to educate technologists. Instead, technology, and by association becoming a technologist, is often considered as secondary to vocational traditions. For example, one may identify an industrial designer or a mechanical engineer as a technologist depending on the activity they engage with. Thus, without an emphasis on either *identity* or *exchange* as depicted by Turner[19], technology cannot be considered as a discipline.

Whether an epistemological[20] or market-centric[19] perspective is taken on what constitutes a discipline, technology appears as somewhat problematic. As a result of these contentions, the term *technology*, although clearly identified within a specific remit of K-12 education, will not be used in a disciplinary sense in this discussion. Instead, the perspective adopted elevates technology to a conceptual level, and thus, the discussion may focus on what technology may look like as opposed to exploring what technology is and whether or not it is a discipline. This perspective draws largely on Keirl[21], in his recollection of colleagues at Goldsmiths University in London depiction of technology education as post- or perhaps even anti-disciplinary. Taking this perspective leads to questions of how technology, at this conceptual level, may be related to bachelors level engineering education.

The engineering-technology relationship

The relationship between technology and engineering is not clearly defined. The perspectives on engineering from the K-12 technology education discourse have largely shifted away from the specific term ‘engineering’ as it has certain vocational connotations. In advocating a shift beyond vocational education, towards a broad and balanced curriculum for all, a more holistic interpretation of what technology education strives to achieve has come to the fore[22]. From the bachelors level engineering education perspective, a product focused perspective on what constitutes technology permeates much of the literature, which has rather interestingly, also led to a more holistic interpretation of engineering[23]. However, the critique of technology as product has been contested in the philosophy of technology field for some time[24]. Despite these differences, there are commonalities between engineering and technology that should be discussed as they provide grounds for this perspective put forward herein.

Van de Poel[25] noted that despite the multitude of different perspectives on what constitutes engineering, one common point is that design is commonly agreed as being central to engineering. Within the technology education discourse, design is also seen as central to defining the activity students are to engage with. Beyond this, there appears to be very few similarities in how engineering and technology are conceived and studied[26]. In this paper we will not seek to demarcate a boundary between both areas, and thus will not seek to further the line of discussion in which the tensions between technology and engineering are the major focus[27]. Instead we draw on the design/technological activity centred nature of both areas in theorising how the philosophy of K-12 technology education may be useful in terms of developing a more nuanced conceptualisation of engineering education.

With this, a key differentiation must be made between K-12 technology education and bachelors level engineering. As previously noted, technology education is no longer concerned with the preparation of students for the world of work – at least not directly. Engineering education on the other hand has the focus of preparing graduates for various engineering professions, as well as a broader professional profile recognised as important for and evolving society[28].

‘Doing’ technology

Sharing engineering education’s emphasis on practice over theory[29], the epistemological basis of technology education has only recently been the subject of philosophical investigation. The prevailing position takes the view that technological activity is any intentional change on the man-made world, be that physical, political, sociological or economical, amongst countless others[30]. From this conceptual perspective, engineering activity can thus be classified as technological in nature. As well as this, the nuances between different contexts for engineering, whether they are classified as disciplines or not, can be described as different contexts in which technological activity manifests.

It is here that the nexus of our argument emerges, as outlining the epistemological basis for different engineering contexts (in the design of engineering education programs) has the potential to present challenges. The potential for the declarative knowledge associated with the context for engineering to supplant the knowledge and skills associated with *doing* engineering in the formulation and interpretation of curricula is the point of departure for this discussion. Under the potential for an epistemic boundary to restrict engineering activity in engineering education, fluid epistemological boundaries are advocated instead. It is important to emphasise that this perspective is not anti-knowledge, or areas of expertise, but the point is that the knowledge bases should be framed in such a way that they are not restrictive to the activities that permeate working environments in the engineering professions[6].

From this perspective, two challenges for engineering education emerge; (1) presenting students with an education in which the predetermined declarative knowledge is acknowledged as not being exhaustive, but rather foundational, and requisite to the enaction of activity within a specific context for engineering, and (2) operationalizing an engineering education that balances such a fluid epistemological basis while concomitantly providing sufficient content knowledge grounding and facilitating the pursuit of context specific knowledge.

Engineering as technological activity in context

Whereas technological activity can be taken as any intentional change on the man-made world, engineering activity is necessarily more focused. With the difficulties associated with developing expertise within a specific context for engineering, this narrowing of the remit for technological activity may become problematic if the emphasis of engineering education shifts activity towards an exclusively declarative knowledge-centric approach. In spite of more of a reliance on specialised knowledge, Goldman[31] notes that from a philosophical perspective, engineering remains largely under-defined, and that the way in which knowledge is treated is very different from science. In engineering activity, the application of scientific knowledge is not the sole agenda - Goldman views engineering activity as an action-oriented application of relevant knowledge from a variety of disciplines in solving a problem. From this depiction, the perspective taken on engineering as technological activity becomes apparent.

Unlike more liberal technological activity where speculation can afford to play a major part, engineering activity is recognised as being more high-stakes. As a result of this, defined processes have been put in place to ensure consistency of application. One of the more prominent examples of such a process is the engineering method presented by Koen[32]. Koen noted the deficiencies associated with defining a singular method of *doing* engineering in calling for more acknowledgements of engineering heuristics – heuristics are taken to anything that provides a plausible aid or direction in the solution of a problem. Through the engineering method, Koen sought to optimise the use of heuristics to cause the best change in a poorly understood situation within the available resources.

Although significant advancements have been made since the inception of Goldman's philosophy and Koen's method, discussions on student preparedness for the engineering profession largely point to under-prepared graduates. We hold that the reasons behind this may lie in the *why* behind engineering activity. A way of articulating this deficiency stems from the fourfold classification of technology (Figure 1) put forward by Mitcham[24]. Technological knowledge, activity, and objects are well represented in policy and curricula and are thus, likely understood by engineering educators and communicated to engineering students. However, the place of volition, the decision-making behind implementation of engineering activity, in the space of human activity, has not been studied to the same degree.

How can one concomitantly develop students' knowledge of engineering, proficiency in *doing* engineering, and decision making around the *why* of engineering activity in a context that is, by definition, evolving?

A context for epistemic autonomy: Authenticity in engineering education

As noted in the introduction, with engineering education's shift from a practice-based curriculum to the engineering science-based model of the latter half of the 20th century, the role of key skills and attitudes within engineering education was diminished. In this section we consider how authenticity in engineering education may be used as a vehicle to shift thinking and practices to a more authentic engineering education with a focus on *doing* engineering.

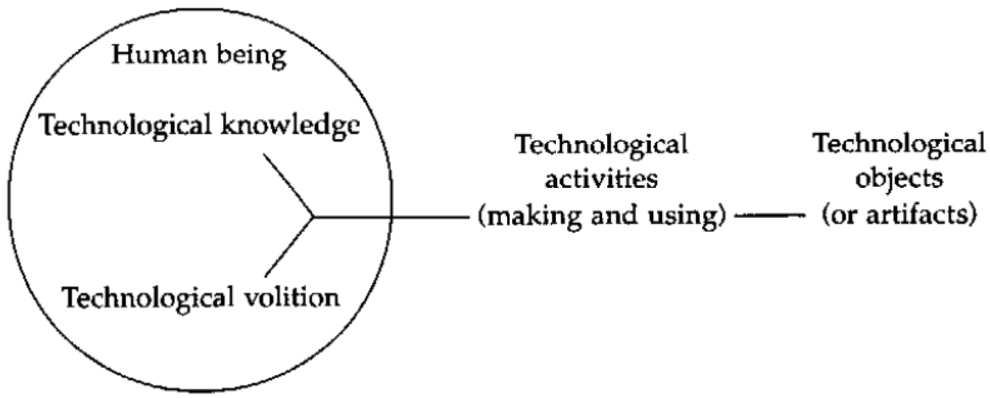

Figure 1: Modes of the manifestation of technology from Mitcham[24]

The incorporation of "authentic" contexts into engineering education practices has been attempted for some time, but it is common that these attempts are not appreciated by the students for whom they are intended[33]. These difficulties can be explored from a variety of perspectives[34], but central to the analysis is the ability of students to discern and appreciate the "authentic" in the context of their engineering education, as well as develop a nuanced understanding of the value they bring to their future employers. The perspective taken here is in alignment with Trevelyan and Williams[35] in their exploration of how engineering education can add value in an industrial or vocational context, in particular the importance of student's reaching the insight that their value lies not purely in their technical knowledge and skills, but also in how they are applied to ameliorate risk in the development of engineering solutions in complex environments.

Without navigation with regard to the nature of engineering (as technology) and the role of volition in activity, it is not surprising that students are quite often perplexed when confronted by these innovations. The practices and values to which they are exposed are most often than not drawn from a diverse gamut of potential future career pathways and associated professions with their various value systems, ways of performing their profession, and not least understandings of what knowledge and skills are of value and to be valued. Students face the unenviable task of trying to assemble these fragments of 'imitative authenticity' into a coherent whole.

The significance of this struggle has been illuminated from the staff and student perspectives previously[33], where the difficulties associated with apparent rejections of staff attempts at authenticity in both tasks and assessment on the part of the students. From such findings, questions arise of student perceptions of their future careers, and the nature of their future working environments and perceptions of the role of engineering education would be well served by more detailed analysis. As it currently stands, evidence suggests that student's conceptions of the nature of their future professions, as well as the values respected by industry leaders are not well aligned with those of the academic staff who attempt to introduce what they perceive to be authentic situations and performance criteria.This process of learner/instructor attunement deserves further consideration in the Engineering Philosophy and Education communities.

An ontology-based curriculum

In shifting towards more authentic contexts in engineering education, with the intent of facilitating students working in a fluid epistemological space, how degree programs are conceived and perceived is of critical importance. The main reason for this stems from the potential for malleable knowledge boundaries to be misrepresented and misinterpreted, thus teacher and learner activity may diverge, departing from the conceptual basis and intent of the curriculum.

In an attempt to consolidate this potential variance, an *ontology-based curriculum* is proposed as such a curriculum foregrounds a conceptual understanding as the ultimate goal of a degree program. In framing engineering as technological activity, the need for students to develop an understanding of the role of knowledge and volition within activity and critical perspectives on technological objects or artefacts can be framed. Acknowledging engineering disciplines (or perhaps more accurately professions) as different contexts for technology serves an important purpose here, as within this perspective, the contexts and methods by which an understanding of technology is achieved is to a degree, at the discretion of the teacher and the learner.

Over the past number of years, variations of this approach have been implemented in programming education at a module level[36]. Within this context however, governing concepts are (relatively) well defined, and the range of possible routes for the learner is regulated by the nature of the computer programme(s) and associated capabilities. In other words the context is bound. Applying an ontology-based approach to the trans-disciplinary activity advocated previously is of concern as the quantity of variables introduced by a relatively boundless context may become too difficult for learners to navigate and for teachers to guide. Particularly when one considers the additional variance of authentic problem-solving contexts observed in the engineering workplace[6]. As a result of this, ensuring continuity of understanding, or ontological position, between teachers should be of concern as the potential for learners to diverge beyond the remit of concepts is likely. As a consequence, educators must be constantly aware of this and be equipped to redirect learning to the conceptual understanding(s) at hand.

In considering a shift towards an ontology-based curriculum, traditional pedagogical and assessment approaches to engineering education should also be discussed as they still hold place in contemporary practice. In considering Biggs' constructive alignment[37], a shift in policy does not necessarily mean a shift in thinking about the nature of activity in a subject area, and thus pedagogical and assessment practices may not evolve. An interesting example of this was observed the K-12 technology education context in New Zealand. Here it was noted that teachers' tended to contort emergent curricular perspectives on what constitutes capability to fit existing pedagogical and assessment practices[38]. Similar in many ways to the notion of imitative authenticity previously discussed, it is important that an ontology-based approach to formulating a curriculum for engineering education acknowledge both the ontological and epistemological considerations for practice, where practice pertains to both pedagogical and assessment norms.

One final point that is of particular relevance when considering an ontology-based approach to engineering is the sustainability of curriculum. Although there is foundational knowledge and skills that will always be of relevance to engineering contexts, the fluidity of context facilitated through a holistic understanding of technological activity lends itself to the adaption of new and emerging content with relative ease. In this sense, educators and learners may adapt contexts for engineering education based on recent developments in the field and emerging technologies with relative ease, as the basis of the curriculum remains the same. In fact, one could argue that this approach requires engineering educators to take ownership of the contexts for learning and in the cases where teachers actively engage with these decisions – the potential future-proofing of engineering curricula. There is no formula for identifying which contexts are appropriate for learning, other than the potential for learners to engage with the ontological position outlined in the curriculum, and perhaps, a prediction of future societal needs.

In acknowledgement that the perspective of an ontology based curriculum for engineering education is a largely utopian aspiration, the following section considers some issues, both contemporary and more long-standing, which may serve to perpetuate the disparity between the perspective put forward herein and the actuality of everyday practices.

Challenges

In many ways the structure of this paper may appear backwards in that a proposal for a curriculum as a whole is considered before the view of knowledge and knowing and the view of learning in engineering. The primary rationale behind this holistic proposal for engineering as technological activity is to instigate discussion on the views of knowledge within engineering, and in turn, the views of learning engineering. Predicating engineering education on the intellectual processes embedded within technological activity and an understanding of what constitutes engineering is quite a departure from the nature of most education programs. There are a number of perspectives which must therefore be considered when contemplating the introduction of an ontology-based curriculum for engineering education.

Firstly, perspectives on the performative climate of many educational contexts identified that a neo-managerialist culture has resulted in the commoditisation and marketisation of education across all levels of provision[39]. Characterised by strides for accountability, systems now purport to measure quantifiable outcomes, most often through the lens of educational assessment. Within this system, efficiency of schooling has come to the fore as both the amount of time ‘spent’ learning and the quantity of learning per unit of time are sought to be optimised. As the focus of the approach proposed herein lies in the learners ability to select and apply appropriate knowledge rather than to recall explicit knowledge, the degree to which they can be compared to conventional subjects pedagogical and assessment practices is not known. Although it would not be surprising if the nature of education proposed would not be as efficient as the dominant practices in today’s education systems.

With this, perspectives on assessment within such a system are also of importance. With the emphasis on activity, in a variety of contexts, the difficulties associated with balancing criteria as is the case with traditional assessment methods has led to assertions of the need to consider a more holistic approach to assessment[40]. Despite the significant efforts in reforming policy and pedagogical practice in engineering education[2], assessment systems have remained largely unchanged. It is unclear how appropriate existing assessment systems are to assessing student learning within and ontology-based curriculum.

Finally, in combining the epistemological perspective with learning theory, the learning sciences agenda should also be considered. Despite having gained significant traction over the past number of decades, the appropriateness of the adoption and application of findings from disciplines with different epistemological and ontological basis as the perspective outlined herein is yet to be determined. A useful way of conceiving this is to consider the perspective put forward by Kirschner[41] in highlighting the difference between *learning* science (in school) and *doing* science (as a scientist does). In remaining true to engineering as technological activity, the interdependence between knowledge and activity that learners engage with engineering activity, and that they must ‘do’ technology. This position is not intended to question potential contributions of the learning sciences but rather a caution against the acceptance of validated findings between disciplines with different epistemological basis. In other words, the need for ecologically situated approaches to studying teaching and learning in the context of engineering education becomes apparent.

Conclusion

Defining engineering education through the variability necessitated by technological activity highlights the need for a common ontological position on how the area is conceived. Upholding the ambition to remain true to philosophical perspectives on the systemic nature of technological knowledge, in the face of education systems that increasingly value atomised aspects of learning internationally is perhaps the most significant challenge to engineering education. It is important to note the engineering education is not bereft of an epistemology, but rather its epistemological basis is complex when compared to conventional, declarative knowledge-centric disciplines. In defining engineering education through its epistemological fluidity regarding the treatment content knowledge, we propose that the conceptual principles of Goldman’s contingency philosophy and the volition component of Mitcham’s classification of technology must remain central to how activity is represented in the different contexts for engineering education.

Although it may appear sufficient to establish relevant declarative knowledge for the various disciplines of engineering education and build degree programs around these, we advocate that doing so may only serve to further the disparity between policy and practice in engineering education[3]. Instead, proposing that stakeholders embrace a fluid epistemology in an ontology-based curriculum retains true philosophical depictions of the nature of technology. In doing so the question of “authenticity” and “authentic” experience is central to establishing the relevance of a more activity-centric approach to engineering education. The question which arises from this perspective, is whether or not, such a conception of engineering education may be facilitated in 21st century engineering education.

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