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Engineering Education in Schools*

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Challenges that attend attempts to introduce engineering education into schools are explored and claims by the technology education community as credible purveyors of this knowledge examined. The article contends that the primary challenge besetting the establishment of engineering knowledge in the schools is absence of a comprehensive knowledge base. This is complicated by the fact that the teachers are typically not engineers, and accordingly are handicapped. Just who should teach the content is also an area of tension. Technology education has made strong claims regarding the teaching of engineering design. Here the article argues that this tradition has an empirical and creative focus that makes its claims credible. It concludes that ultimately all claimants to the subject, under the guidance of engineers, must collaborate around provision of the knowledge base, as well as instruction.

Keywords: schools; knowledge base; pre-university education; engineering pathway

INTRODUCTION

ENGINEERING EDUCATION—when should it begin? This article contends that it should do so in elementary and secondary school years, for reasons that include but extend well beyond the creation of a pipeline to engineering careers. Engineering education in schools could be in service of the grander goal of technological literacy for all citizens. There is evidence that as the new field of engineering education crystallizes, advocates are coming to view schools as an important ally in their cause, and some countries are seeking ways to represent engineering knowledge in school curricula. Modern engineering relies heavily on science and mathematics, thus it could be argued that it is superfluous to make the case for separate treatment of engineering knowledge in schools since these foundational disciplines already hold well-established places in the curriculum. This argument cannot be lightly dismissed. But science and mathematics as school subjects may not be able to capture the applied nature of engineering, nor its ill-defined, creative aspects. Engineering has an empirical, hands-on dimension in addition to its abstract aspects, and would probably be better represented in schools if curricula activities that are meant to depict it are authentic representations of the work of engineers, rooted in practice. This raises interesting questions about the location of engineering within the curriculum, and what kind of teacher is best suited to teach it.

This article explores the challenges inherent in the inclusion of engineering knowledge in school curricula. Such challenges accompany any new subject area making a claim for space in already crowded curricula. There are questions relating to the nature and scope of the subject matter, the instructional conditions needed for authentically representing the methods and processes, the kind of preparation needed by those who would teach it, the relationship of the subject to others existing in the curriculum, the kinds of learning that should accrue from its teaching and how that learning should be assessed. Goodson [1] has documented the metamorphosis of subjects such as geography, biology, rural studies, and environmental education as they strove to become accepted in the curriculum as knowledge, and has found support for hypotheses he set forth regarding how new kinds of knowledge become consolidated in the schools. According to Goodson [1], school subjects differ in the degree of status accorded them within schools and beyond. Some subjects are high status, e.g. math and science, while others, such as art and music, are low status. Status affects their rate of acceptance. Subjects also differ in the extent to which they have inherent conceptual structure and progression of ideas that afford articulation across the grades. Subjects are not monolithic entities but are often federations of sub-groups and traditions. For example, in addition to the engineering community, engineering education has other claimants in the schools, in science and in technology (or design & technology) education.

Goodson [1] contends that there are three traditions noticeable among school subjects, namely, utilitarian, pedagogic and academic, and that the process of establishing a subject involves movement from utilitarian and pedagogic traditions to academic ones. The utilitarian tradition is associated with low status subjects that deal with practical knowledge. The pedagogic tradition refers to subjects that draw on personal or commonsense knowledge and are organized around the way children learn. This is seen in the

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development of social studies. The academic tradition is content focused, stressing the abstract and theoretical. Here we would find mathematics, science or foreign languages. When subjects have progressed from utilitarian and pedagogic to academic stages, it is usually because they have specialist scholars in the universities as champions. Goodson's observations are not accepted uncritically here, but they provide an interesting lens through which we can view the challenge that engineering education faces in seeking to establish a presence in school curricula. One tension underpinning the establishment of engineering knowledge is that claimants to it in the schools can be found in both utilitarian (technology education) and academic (science) camps. It could be argued that the claims of the subject technology education (known in some countries as design and technology) as a purveyor of engineering knowledge is consistent with the historical tendency of advocates of utilitarian subjects to improve their status along academic lines [2]. Later in this article the claims of the technology education community with respect to engineering education are examined more closely.

The establishment of school knowledge is in large measure politically determined. Further, school subjects are social constructions the content being determined by the push and pull of advocates with their varying agendas. For example, one agenda of the engineering education movement is to attract more students to engineering careers. Those subjects that are supported by powerful constituencies have much more chance of becoming established than those with less support. Here Grossman and Stodolosky, [3] speak of the connection that some school subjects have with parent disciplines, these disciplines exerting influence on the curriculum and on instruction, in some cases forming strong boundaries around the subject matter, boundaries being weaker and blurred in other cases. On this general point of the relative standing of constituencies, and the influence of parent disciplines, one would expect engineering education to have much credibility as a claimant for space in the schools. But within schools, those expected to purvey engineering education are typically not engineers. The scientific community has science teachers in the schools as their allies in the purveyance of science. The engineering community does not have a comparable cadre of allies since typically there is a dearth of engineers among the teaching force in schools. Absence of engineers in the schools results in the engineering field having to rely on proxies to advance their cause. This is a problem of consequence, since it requires significant professional development of the teachers who must teach engineering content. Without significant orientation, these teachers cannot be expected to teach subject matter in which they do not possess content expertise. Nor can they be expected to devote the kind of professional energy it takes to keep subjects vital. The reorientation of teachers who are non-engineers to teach engineering content is a challenge that faces all countries wishing such content to become the possession of all citizens.

Despite its strong political base, what with powerful constituencies such as the ASEE (in the US) speaking for the subject to schools, engineering education holds a precarious existence still, because no constituency of teachers in the schools owns it. Subjects do not become established by external heralding alone. They need internal champions, communities of advocates who would continually re-examine content, and who would conduct the research needed as the basis of such examination. There may be need for rapprochement here—for the engineering community to devote greater energy toward the forging of alliances with those in the schools who share the philosophy that engineering knowledge is to be made widely reachable. Evidence of the nature of the challenge is the finding by Yasar *et al.* [4] that while K-12 teachers are very supportive of the idea of infusing design and technology into the curriculum, they tend to hold negative stereotypes about engineers. This speaks of a gap between a profession and the schools that would have to be closed as a prelude to collaboration among the communities who have claims to the subject.

An important distinction to be made here is that between attempts of the engineering community to introduce engineering education into schools, and the ongoing attempts of the technology education (or design and technology) community in employing design and problem solving as the primary vehicle for inculcating technological literacy in schools. Welch [5] observes convergence of the goals of these two communities, contending that existing school-based design activities in Canadian schools align with the goals of engineering education, and that such activities arguably can provide students intending to pursue engineering with important foundational preparation. Welch describes a range of school-based initiatives focused on design and technology that feature problem solving, and that encourage children to draw upon tacit knowledge and to employ divergent thinking. Ultimately these curriculum efforts are felt to promote designerly thinking.

INITIATIVES ORIGINATING IN ENGINEERING OR SCIENCE

In the United States, there has in recent times been a major thrust within the engineering and science communities towards the introduction of engineering ideas into schools. In science this can be seen in the inclusion of design as a topic among content standards that must be taught to students. *Benchmarks for Science Literacy* features 'the designed world' [6] as a standard. The *National Science Education Standards* include 'abilities of technological design" as a primary focus across grade levels [7]

Cunningham *et al.* [8] describe a project originating within the science community and funded by the National Science Foundation that was aimed at demonstrating how an integration model based on the collaborative efforts of science, mathematics and technology education teachers could be utilized to introduce engineering education into the middle school curriculum of Massachusetts. Teachers from these three subject areas participated in professional development activities that focused on the design process. They developed lesson plans that focused upon design challenges which integrated maths and science. Evaluation data showed that the teachers felt more capable of introducing the subject into the classes because of their participation.

Also seeking to enhance students' appreciation of science and engineering, in the elementary grades, Kimmel [9] described a project in which such children were exposed to hands-on applications of science (and mathematics), on the assumption that students learn these subjects best through active methods. The approach taken in this project was that science was made a priority subject in the elementary curriculum. In particular, the programme targeted minority students. It included an outreach component in which engineering science undergraduates from economically disadvantaged backgrounds worked with graduate students and in partnership with elementary teachers, to help transform the curriculum to make science more appealing to students. Reporting on a collaborative initiative in Columbia, Carulla *et al.* [10] describe how engineering was used in that country as a vehicle for inculcating scientific and technological literacy. Engineering faculty combined with industry, museums and schools to reform the science curriculum, such that it could deliver on the broad national goal of technological literacy for all. Beyond engineering education, this model was informed by the larger philosophy of a technologically literate citizenry.

Many initiatives originate within the engineering community. In the United States, within recent years the American Society for Engineering Education (ASEE) has launched a large K-12 effort aimed at making engineering ideas more accessible to students. The website of this organization reveals the many fronts upon which it reaches out to schools (see http://www.asee.org/k12/index.cfm). Douglas, Iversen and Kalyandurg [11] describe ASEE efforts to popularize engineering education in schools. They explain that the organization created a guidebook as well as an e-newsletter designed for consumption in the schools. Some 350,000 teachers have received the guidebook, and the newsletter reaches 10,000 schools. They describe six ASEE guidelines for improving engineering education in the schools, framed by (a) hands-on learning (b) interdisciplinarity (c) connection with state mathematics and science standards (d) efforts to attract the best teachers (e) making engineering fun, and (f) fostering partnerships, especially between higher education and industry. The efforts of the ASEE are clearly noteworthy, especially in helping children to become more familiar with the work of engineers. Such career orientation is important. But more important, arguably, is the learning of engineering concepts and processes, and for this to occur, there would be need for curricular intervention. Important bodies such as the ASEE must come to terms with the practical challenges of curriculum change, including messy components such as the retraining of teachers, and the provision of curriculum materials that are of tested and proven quality.

Another major initiative in the US is *Project Lead The Way* (see http://www.pltw.org/curriculum/curriculum.html) [12]. This may well be the programme that engages the broadest number of children in a curriculum deliberately seeking to advance engineering. In the middle school the curriculum is framed by the overarching concept 'Gateway to Technology' which is comprised of five units, namely (a) Design and modelling (b) Magic of electrons (c) Science of technology (d) Automation and robotics and (e) Flight and space. In the high school, students are offered 'Foundation' courses, such as principles of Engineering and Digital electronics, 'Elective' courses such as Computer integrated manufacturing and Aerospace, and a 'Capstone' course on Engineering design and development. This programme is tightly controlled. The teachers receive professional development aimed at readying them to teach the courses. The spread of *Project Lead The Way* across many states is evidence of the need in school systems not just for curricula that directly address engineering. *Project Lead The Way* is a successful venture, but there are no published accounts on the workings of this project, especially on the extent to which it is achieving its aims.

There are several descriptions in the engineering literature in which engineering faculty report on initiatives aimed at spreading the subject to schools [13, 14, 15]. These initiatives tend to be of short duration, intending to entice students toward consideration of engineering as an eventual career. Caroll [13] described a unit on bridge building for elementary children in which engineering seniors were involved. Elements of the bridge were transported to the classroom where design and assembly took place. Such a project has incalculable demonstration value, not just in terms of the authenticity with which engineering can be taught to small children, but the way in which practical challenges such as absence of a school workshop can be overcome. Working with elementary and middle school children, Poole, De Grazia and Sullivan [15] developed weeklong interdisciplinary units of pre-engineering. The project involved holding professional development for teachers during summer. DeGrazia, Sullivan, and Carlson [16] described a funded project that used engineering to help students integrate math and science. This project employed engineering graduate students in the professional development of K-12 teachers, helping to expand their engineering knowledge. Projects such as this are valuable because they bring engineering faculty and programmes in direct connection with schools. Crawford, Wood, Fowler & Norrell [17] described a program called DTEACH (Design Technology and Engineering for America's Children) in which engineering design was infused into the K-6 curriculum. The program introduced children to engineering concepts and devices (such as pulleys, levers and cams, and forms of energy). The approach was interdisciplinary. Students used their new knowledge to design and build models illustrating what they learned in other subjects. They worked in teams and engaged in a variety learning experiences in science and mathematics, and in technology. One outstanding feature of DTEACH was the emphasis placed on identifying and codifying fundamental concepts and processes that students were expected to learn. The content identification scheme they reported is one of the more detailed that has appeared in the literature. As will be discussed later in this article, one of the problems plaguing the introduction of engineering education is the absence of content schemas setting forth what is to be learned by children.

The initiatives reflected upon here provide evidence of engagement between the engineering and science communities and the schools. In the case of *Project Lead The Way* we see an initiative that is widely adopted and has had many years of trial in the field. There is a need now for studies that can provide important findings on the extent to which this approach yields outcomes that are consistent with desired ends of engineering education. We see in ASEE efforts how a major engineering organization can work innovatively with schools to enhance the teaching of a subject. The scale of the efforts here is large. But here again there has not been data showing whether such efforts yield desired results in schools.

On an intuitive level, we can see that all initiatives, whether short term or long, systemic or highly localized, can help in some way in advancing the goals of engineering education. But in the long run, engineering education will continue to be a subject at the margins of schools until demand for it issues naturally from schools and the communities that support them and not from bodies with special interests. To become more entrenched in schools, engineering education will have to take on the features of a school subject and argued in terms of what is good for children. An alternative to becoming established as an autonomous subject, could be a collaborative model as discussed by Cunningham *et al* [8] in which engineering education becomes the joint claim of interested parties in the schools.

EPISTEMOLOGICAL PROBLEMS

To become established as knowledge in school curricula, subjects must be able to carve out uniquely distinct space, and must have advocates who are willing to advance their claims. Engineering education should not have great difficulty being accommodated in schools, because the field of engineering is prestigious and has high standing. But while status is an important part of a subject's eventual acceptance, it is only one part of it. As Goodson points out, a subject must be able to point to a codified body of knowledge that can be ordered and articulated across the grades [1]. Here engineering education suffers, since despite the many efforts to date to infuse such knowledge into schools no focused attempt has been made to try to systematize the state of the art in engineering in a way that is translatable in schools. Much of the efforts tend to be short term and focused on a particular topic or unit. In short, what is needed within engineering education is the dismantling of its known knowledge base of theory and practice to reveal its essential elements, and the distilling of that which is enduring—processes and concepts—in a way that can be reached by children. Inherent in this line of thinking is that there is need for the discipline of engineering education to be articulated. As an adjunct to this, there is need for approaches to content derivation that have high demonstration power in illustrating how content can be found.

From the literature some approaches stand out in the extent to which they are suggestive of how engineering content can be derived [18, 19, 20, 21]. Holt [18] offers an excellent conceptual schema that can form the backdrop for content derivation in engineering. He speaks of the nature of mechanical engineering, contending that a key aspect of this is practice. This could be a place to start. What constitutes the elements of an engineer's practice? What is the content of the storehouse of knowledge of practice that engineers have in their repertoire that they draw upon when they do their work? Petroski [19] suggests that part of this storehouse is knowledge of errors—of what not to do. Engineers also rely on heuristics, rules of thumb that help guide design decision making. Heuristics can be a type of knowledge that can be laid bare, and that could be introduced into school curricula. Koen's [20] taxonomy of heuristics is useful as a place to begin. Included are (a) simple rules of thumb, (b) factors of safety, (c) attitudes, (d) risk heuristics and (e) resource allocation heuristics. There is need for identification of a body of heuristics that can become knowledge in the schools.

A very interesting curriculum approach is that taken by Sandler [21] in which the case is made for paying more attention to the empirical dimension of engineering. Students should be taught design grammar, he contends, based upon knowledge collected from engineering experience. One example he provides is that of a conical plug in a housing that must provide sealing between the surfaces. Six possible solutions are provided, and the suitability of each is evaluated until the correct design is finally chosen and the reason given. This is an exciting way in which engineering education can be approached in schools. One can imagine a curriculum that is supported by a large number of such engineering cases, each introducing a critical engineering concept, and demonstrating the ways engineers think. Sandler [21] writes that every topic in the engineering education curriculum can be treated in this manner—as a case. He contends that the intellectual effort expended on such technical concepts is on a par with that required for solving computational problems, and that there already exists a vast storehouse of engineering know-how that can be retrieved as exhibits of proven practice in the curriculum.

The approach taken by Eberhardt [22] is also noteworthy in terms of applicability in schools. He describes the teaching of engineering to non-engineering majors, with the focus on aeronautics. Students studied related history, airplane design, lift, drag, wing design, wind tunnels, stability and control, aircraft structures, aircraft propulsion. Hands on activities were included. Labs included flying Microsoft Flight Simulator. Important here is the approach. This unit of the curriculum is encompassing enough to provide students with a view of engineering that includes both theoretical and empirical dimensions. This is a prototype. There is need for the engineering community to provide a large number of such units, on engineering artifacts and processes (bridges, roads, tunnels, lifts, rockets) supportive of coherent curriculum. These units could issue from common everyday experience. Pudlowski [23] described a curriculum process in which the content was arrayed around engineering themes, such as robotics, mechatronics, systems engineering and manufacturing technology. This is not unlike *Project Lead The Way*. This approach too has promise as curriculum logic, but the themes would need to be converted into actual units that teachers can comfortably utilize in their classrooms. Gorman *et al.* [24] described an approach in which the starting point of learning was a basic telephone the design of which students had to improve upon. This too was imaginative, but in the schools, much background technical content will have to be taught to students if they are to get to the point where they can improve upon proven designs in particular engineering disciplines.

Engineering Pathway, an engineering-based curriculum project led by Alice Agogino as Principal Investigator, and funded by the National Science Foundation, (see http://www.engineeringpathway.com/ep/) is a major repository of resources for the teaching of engineering ideas K-12 [25]. This project provides a large number of curriculum units, spanning several domains of engineering, accompanied by lessons and hands-on activities. The assumption is that the teachers would not necessarily be engineers. The lessons are particularly appealing, many of the topics (e.g. 'Animals and engineering') providing a down to earth view of the work of engineers, filled with surprising turns. In this particular cited lesson, students learn that engineers can model the world of animals, to develop design technologies useful to other animals and to humans. Throughout, lessons and units are connected either with particular state science standards, or national science standards. Engineering Pathway also provides resources for teachers intending to use the curriculum materials. In my view, this project will in time become widespread, mainly because of the detail into which the units, lessons and activities go. This kind of detailed curricular support is an incentive for even reluctant teachers to try to use the materials. While the curriculum includes a large number of engineering situations, the approach falls short of what would be required for codifying and representing the discipline of engineering. The approach of the project is not to codify engineering knowledge necessarily, but rather to provide interesting samples of it for use in schools, and it may be that this is a practical curriculum compromise given the daunting practical scope of the disciplinary challenge.

A very promising approach to the introduction of engineering design in the schools is that seen in Massachusetts, which has gone further than any other state in the US in seeking to infuse engineering design into the curriculum, and in providing guidance in how to do so [26]. Massachusetts deliberately connects science, technology and engineering in its curricular scheme, and particular for the subject that the state (uniquely so) calls 'Technology/Engineering', where it sets forth learning standards for the grade bands pre -2; 3–5; 6–8; and 9–12. There are times in these standards when the state curriculum provisions address engineering elements directly in a way not ordinarily seen (e.g. by treatment of simple and complex machines in grades 3–5; and material identification, types of bridges and adaptive and assistive bioengineered products in grades 6–8). But standards are a long way from teacher content knowledge, and they are also a long way from a needed content taxonomy that makes engineering content reachable by the non-engineers who must teach this content in the schools.

ENGINEERING EDUCATION AS A DISCIPLINE

Curricula are more than mere representations of the content of fields. Rather, they must take into account the nature of students, and their learning needs. Gardner and Boix-Mansilla [27] make a case for disciplines in schools, contending that disciplines can be the basis of teaching for understanding. They define disciplines as follows:

> Disciplines consist of approaches devised by scholars over the centuries in order to address essential questions, issues, and phenomena drawn from the natural and human worlds; they include methods of inquiry, networks of concepts, theoretical frameworks, techniques for acquiring and verifying findings, appropriate images, symbol systems, vocabularies, and mental models.

Accordingly, since disciplines are dynamic and evolve in time, it is necessary to socialize students in what obtains at this point in history. Students can be made to engage the curriculum through exploration of a set of essential or generative questions. A critical point made by these authors is that, more than mere compilations of content, disciplines must be connected with the processes that yielded content knowledge. Resonating with this latter point, Rogers [28] observed that common translation of disciplinary knowledge into school subjects lacks the processes (such as inquiry or design) that characterize the field. The result is that subjects are associated with facts and students cannot connect with the processes that yielded them.

Engineering education in schools remains out of reach because what is to be taught and what is to be learned by students is not set out coherently anywhere. One possible approach here might be for the creation of content standards for the subject area, in line with science [27], and technology education [29]. Although content standards are not quite the same as spelling out the structure and essential content of a subject, it would be a vast improvement on what now exists.

ENGINEERING DESIGN AS CONTENT

It is interesting that one of the major features of the approach to engineering education in schools is the focus on design. This aspect of the subject puts it ahead of many other school subjects, many of which do not emphasize the modes that yield their content. The disciplinary approach to the curriculum that has been explored above has its strengths, but also its limitations. One limitation is that teachers have too difficult a time trying to determine what choices they should make from all that is before them as content. A second limitation is that a disciplinary approach may better suit subjects that are essentially passive, not requiring enactment in their teaching. Literature is probably best learned by performance in plays, music by playing instruments and art by drawing or sculpting. Accordingly there is support in the curriculum literature for non-disciplinary approaches to content. In a critique of discipline-based curricula, Rogers [28] offered problem-solving as an alternative approach which would include design as well as inquiry.

Within science, there is now a strong focus upon inquiry rather than knowledge of facts. Inquiry features in American science curriculum standards and in the science discourse. The intent is to have students enact science—to start with a question, set forth hypotheses and use empiricism to try to arrive at answers. The basic difficulty here and in any subject that takes this approach, is that processes such as inquiry or design or problem solving, are not content-independent. This is a lesson that recent research on learning has shown. In *How People Learn* authors reported that content knowledge was important to inquiry. They found that:

> To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understands facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application [30].

Thus, a student cannot successfully conduct a heat experiment without understanding basic laws of heat transfer. Likewise, students who are asked to improve upon the design of a basic telephone cannot do so without knowledge of basic current flow. There is evidence that some science teachers have difficulty with the inquiry approach. Crawford [31] finds that beginning teachers differed in their understanding and commitment to the inquiry approach, based on held beliefs about the nature of science. Waight and Abd-El-Khalick [32] found that technology restricted rather than aided attempts by science teachers to take an inquiry approach.

Design is viewed as the heart of engineering, and is an aspect of the curriculum of engineering programs. Variations of a basic model of design, including steps such as problem definition, problem evaluation, synthesis, analysis, and communicate and manufacture, are seen in the engineering literature [33, 34, 35]. Despite the centrality of design to the work of engineers, there is not an accord on its standing within the engineering discipline. A reason is that different from the rest of engineering, where the requirement is for convergent thinking, design requires divergent thinking, and ability to work within ill-defined parameters. Dym, Agogino, Eris, Frey, & Leifer [35] point out that the state of design in the education of engineers remains unsettled, with even design faculty being unable to articulate what it is.

While design remains an unsettled aspect of engineering education, it is receiving an increasing amount of attention as the way to represent engineering in the school curriculum [8]. Design serves a similar purpose to engineering as inquiry serves to science [36] and it invites the same caution raised above, namely, that design is not a content-independent activity.

DESIGN: CLAIMS OF TECHNOLOGY EDUCATION COMMUNITY

Earlier in this article the observations of Welch [5] regarding the apparent convergence of aims between teachers of design and technology and the advocates of engineering education in Canadian schools were set forth. The counterpart to design and technology in the United States is technology education, a subject whose content standards [29] received the endorsement of the engineering community, the foreword being written by William Wulf, in his capacity as President of the National Academy of Engineering. Technology education, as its counterparts in other countries, seeks to introduce students to the human made world and to do so in authentic active ways. The overarching goal of the subject is to inculcate technological literacy, an important aspect of that being engineering literacy.

Recently, design has emerged as the primary vehicle through which advocates believe this grander goal can be achieved. Accordingly design is directly addressed in four of the subject's 20 standards [29]. In a recent article, Yasar *et al.* [4] captured some of the ways in which the subject addresses the question of design. The ferment that is occurring among advocates on the merits of design, and issues inherent in its introduction in schools can be seen in recent literature (see [37, 38, 39]). Wicklein [37] contends that design is the ideal framework for the field, for reasons that include the contention that engineering naturally organizes maths, science and technology, and that the study of engineering raises academic levels within technology education.

Technology education has a strong empirical component. Design and making have been part of its tradition, in domains such as construction, manufacturing, power and energy and construction. Instructional approaches include super-mileage vehicles, robotics contests, bridge building and rocketry. There is a long tradition here of students working in three dimensions, solving open-ended, ill-structured problems. The new engineering thrust has caused some to believe that technology education should move away from its tacit knowledge tradition towards more rational approaches to design including predictive analysis, and that mathematics and science should feature more in the subject's teaching.

How valid are the claims of technology educators with respect to engineering? This is not straightforward, since, employing Goodson's schema, the subject falls within the utilitarian tradition of school subjects, thus tending to be low status. Science, on the other hand, another claimant, falls in the academic tradition, and has probably an easier affinity with the field of engineering than technology education, whose heritage is craft. There is evidence though that traditional class differences between subjects are being eroded. As well as the support given by the engineering community to the creation of technology education, standards have been referenced. This support continues and can be seen in the ongoing work of the National Academy of Engineering in support of the goal of technological literacy for all, the primary objective of the technology education field [40].

But perhaps most tellingly, there is now the existence of the National Centre for Engineering and Technology Education (NCETE) an NSF-funded project aimed at bringing the two communities together toward the goal of infusing engineering content into the high school curriculum [41]. Status differences between the engineering and technology education communities will not disappear because of a funded project, but all the signs now point to the understanding that a collaborative model on the question of engineering is superior to a competitive one.

Technology education has the advantage of having been an established presence in the American curriculum since the 1870s. From its inception the subject has sought to promote ingenuity by exposing children to the world of tools and machines and materials. The pedagogy has always had a situated, active component. Students have the opportunity to be inventive, to think divergently, to test, estimate and to make. It is the case that the approach to design and problem solving has tended to follow trial and error methods. Even so, there is much about learning in technology education classrooms and laboratories that amounts to a rehearsal of aspects of the work of engineers. There are compelling accounts in the literature that technology education indeed fosters creativity, and designerly thinking in children, in ways that conceivably suggest to them that engineering might be a career to which they can aspire [42, 43, 44, 46].

An argument can be made that conceptual design may constitute a practical limit for the subject's teaching, the teachers not having had formal preparation sufficient for them to move students into the realm of analytic design. But here a solution can be collaboration, technology education teachers teaming with engineers, and with science and mathematics teachers, to make design instruction more rigorous.

The strongest case that the field makes as a purveyor of engineering education is that its teachers are so functioning in any case. Come Monday morning in a high percentage of technology education classrooms and laboratories in the United States and elsewhere in the world, children can anticipate opportunities to work on ill-structured problems in realms of energy, construction, manufacturing, communication or transportation. They will learn how to estimate, to make trade-offs, to consider safety factors, to understand customer needs, to arrive at the right tooling and to make decisions about appropriate processes. In these classrooms, many will in fact be rehearsing in outline, what it means to be an engineer. This is a point that Welch makes in his compelling argument that there are complementarities between the goals of the engineering profession and technology education, where the teaching of engineering education in the schools is concerned.

CONCLUSIONS AND IMPLICATIONS

This article has been addressing challenges in the way of establishing engineering education more firmly in schools. Insights about the metamorphosis of subjects as set forth by Goodson [1] were drawn upon to provide the backdrop for analysis. This approach reveals that engineering education has in its favour the prestige of the engineering community. But also revealed is that engineering education faces epistemological challenges in that engineering content suitable for schools has not been comprehensively set forth anywhere. The state of Massachusetts has taken the lead in the United States in setting forth content standards for technology/engineering. But standards assume teacher content knowledge, or that there will be need for necessary professional development as seen in efforts described by Cunningham *et al.* [8] among teachers in that state. Engineering Pathway [25] also provides a large array of engineering challenges that are connected to (science) standards, but it will be difficult for teachers to stray from the provided content, since their base of engineering knowledge will be confined by the project's curriculum.

There is still need for knowledge transfer from the engineering profession to education, first to teacher education programmes, whether in science or technology education, then into classrooms. Such knowledge transfer would have to make plain just what engineers do, and such knowledge will have to be systematized. The art of engineering of which Quinn [47] speaks needs to be unravelled. Much of what constitutes engineering content remains accessible mainly by engineers. Engineering efforts in the schools have tended to be of short-term nature, where particular units or topics have been the focus. Also discussed here has been the fact that two existing school subjects, science and technology education, lay their own claims to the subject, each having design included among its content standards. Given epistemological challenges, and claims from two different subjects as purveyors of engineering content, what options then are there that can lead to the desired result of establishment in the schools? The following sets of ideas are prompted in response to this including:

(a) There is great need for advocates of the subject, whatever their disciplinary orientation, to agree upon and articulate a set of engineering education content standards that can guide teaching in the grades.
(b) There is need for the engineering community to concentrate on documenting engineering practice in a comprehensive way that gets to essential concepts and practices, such that these could be tailored for schools.
(c) There is need for piloted and field-tested content modules on a large array of engineering concepts and practices—materials that can then be commercialized and made available for schools.
(d) Engineering education probably should opt for an approach in the schools that is inclusive of claimants from different traditions. Claimants such as the science and technology education communities are better off working collaboratively than competitively on this question.
(e) There is need for a host of model or demonstration curriculum projects in which engineers are directly involved in the schools, projects that have an inquiry component the results of which can aid in curriculum and instruction refinement.
(f) Where there are programmes that have some history of offering engineering education, there is now need for research aimed at examining their workings and effects.

Generally there is need for goal clarity in engineering education where schools are concerned. The need for filling the engineering pipeline to arrest shortages in young people entering engineering careers should not be conflated with the teaching and learning of engineering concepts or processes in the schools. Too much of the efforts in the service of engineering education sometimes seem to place the profession first, the goal often being little more than changing the career perspectives of students. Instead, the focus should be on converting the vast store of knowledge and practice of the profession into cultural knowledge that can be possessed by all children. If engineering can thus be made accessible, the subject will thus become democratized as many are able to get closer to its mysteries. It is this democratizing process that might lead ultimately to more children believing that they can become engineers.

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