AC 2010-53: TOWARDS DEVELOPING AN ONTOLOGY FOR K-12 ENGINEERING TECHNOLOGY EDUCATION

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Toward Developing an Ontology for K-12 Engineering Technology Education

Abstract

Hofstra University's Center for Technological Literacy and the University of Technology, Delft, conducted an international research study in the summer of 2009 to identify the most important unifying concepts and disciplinary contexts in K-12 engineering and technology education (ETE). The purpose of the study, titled *Concepts and Contexts in Engineering and Technology Education* (CCETE), was to provide a framework for developing contemporary ETE curricula. The study drew upon the expertise of 30 individuals from nine countries with a broad range of experience in ETE-related domains. These experts included philosophers and historians of technology, journalists, technology teacher educators, and engineering educators.

A set of core unifying themes, applicable to all technological fields, emerged from this study and gave insight into the nature of engineering as a holistic endeavor. The themes are design (e.g., optimization, trade-offs, specifications), modeling (e.g., representation and prediction), systems (e.g., function, structure), resources (e.g., materials, energy, information), and human values (e.g., sustainability, innovation, risk, failure, social interaction).

In addition, a set of technological contexts emerged. Situated in the belief that K-12 ETE should address issues that support a sustainable world, these contexts include food (e.g., agriculture, biotechnology), shelter (e.g., construction), water (e.g., supply and quality), energy, mobility (e.g., transportation), production, health (e.g., medical technologies), security, and communication. Further refinement indicated that when developing a curriculum, the contexts should be elaborated in two directions: a "personal concern" or "daily life practice" direction and a "global concern" direction.

Introduction

One of the main issues in the development of ETE is the search for a sound conceptual basis for the curriculum in the U.S. and other countries worldwide. This search has become relevant as the nature of technology education has changed: it has gradually evolved from focusing on skills to focusing on technological literacy. Additionally, the National Academy of Engineering's report, *Engineering in K-12 Education*[1], examines the current status of engineering education and raises a number of issues about ETE. The lack of conceptual framework for ETE is one of those issues. It is important for students to develop an understanding of technological literacy, and this understanding implies that they have developed a realistic image of engineering and technology.

We need to be explicit about what we mean by engineering and technology. Engineering is about creating the human-made world, the artifacts and processes that never existed before. This is in contrast to science, the study of the natural world. Most often engineers do not literally construct the artifacts; instead they provide plans and directions for how the artifacts are to be constructed. Both small artifacts (like a hand calculator) and large ones (like a bridge) are part of the realm of engineering. Engineers also design processes. The processes may be those used to create chemicals and drugs, to direct how components are put together on an assembly line, or to indicate how checks are to be processed in banking. Technology encompasses the way humans develop, realize, and use (and evaluate) all sorts of artifacts, systems, and processes to improve the quality of life. Technological literacy is what people need to live in, and control, the technological environment that surrounds them. This literacy comprises practical knowledge, reasoning skills, and attitudes. According to the National Academy of Engineering, technological literacy requires that children have a knowledge base not only about technology but also about the math and science that underlie it[2].

Engineering and technology education has long been delivered in two ways: through general education and through vocational education. In general education, the focus historically has been on practical (craft) skills. However, this emphasis has changed in most countries, including the U.S.; traditional school subjects have been replaced with what is generally called "technology education." The main purpose of technology education is developing technological literacy, but in some cases a vocational element remains. In vocational education the focus has been on preparing for a career in the trades or in technical areas. This kind of teaching has focused on specific knowledge and skills. The latest development is that engineering has been accorded a more substantial place in general (technology) education. This shift is combined with the integration of science and math and leads to what is known as science, technology, engineering, and mathematics (STEM) education. Our use of the term *engineering and technology education* (ETE) relates to these contemporary developments and characterizes ETE as important and valuable for all students. Traditionally, curricula for engineering and technology education are structured according to either engineering disciplines (e.g., mechanical engineering, electrical engineering, construction engineering) or application fields (e.g., transportation, communication). These structures do not offer much insight into the nature of engineering and technology. A better approach for developing insights is to search for basic concepts that are broadly applicable in engineering and technology and cut through different engineering domains and application fields.

The various efforts to develop a sound conceptual basis for teaching engineering and technology have led to the development of important insights and ideas. A major accomplishment was the development of the *Standards for Technological Literacy*[3] in the U.S. In these standards there are many concepts related to engineering and technology; however, the focus in developing them was on technology education, not engineering technology education situated in a STEM setting. Although useful as focal points for learning, standards typically define what students should know and be able to do in specific content or programmatic areas. In some cases, competencies defined by the standards are quite broad; in other cases, the competencies are atomistic.

To enhance standards-driven curriculum by helping learners understand relationships between technological domains, this study has identified a set of overarching, unifying themes that cut across context domains and thus give insight into the holistic nature of engineering and technology. These broad, unifying themes can be used to develop curriculum and learning experiences in engineering and technology education.

Methodology for the Ontological Study

CCETE consulted experts from a variety of disciplines concerned with basic concepts related to engineering and technology. The disciplines are technology education (as a component of general education at the secondary level, technology teacher education, and educational research); engineering education (at the tertiary level) and engineering organizations; philosophy and history of technology; design methodology; and science and technology communication. This last discipline is concerned with communicating about science, engineering, and technology, and those who are involved with it are faced with the need to work with clear and broadly applicable concepts related to engineering and technology.

CCETE consulted experts from nine countries (Australia, England, Germany, India, Israel, Netherlands, New Zealand, Scotland, U.S.). The *Standards for Technological Literacy*[4] were developed primarily by experts in the U.S., and one of their goals was to create a study whose results could inform K-12 engineering technology education globally.

CCETE identified not only unifying themes but also technological contexts in which the themes can be taught. This effort should be seen against the background of recent developments in educational research. Such research has led to the insight that themes are not learned easily in a top-down approach (i.e., learning the themes at a general, abstract level first and then applying them to different contexts). Even an approach in which themes are first learned in a specific context and then transferred to a different context has proved unfruitful. Recent insights developed reveal that themes should be learned in a variety of contexts so that generic insights can grow gradually[5, 6]. This growth leads to the ability to apply the themes in new contexts. In this approach, it is important to identify the themes that should be learned as well as the contexts that are suitable for learning those themes.

Modified Delphi Study

One way to ascertain the opinion of a group of experts is to conduct a Delphi study. This research method, aimed at establishing a consensus of experts' opinions, has both strengths and weaknesses. The main strength is that one can use statistical means to establish whether or not a consensus exists, and this lends a certain objectivity to the study (even though the choice for the criteria and the criterion values remains a matter of preference). The main weakness is that one depends totally on opinions rather than facts (albeit expert opinions). This makes the quality of the study dependent on the choice of experts for the Delphi panel. An advantage of a Delphi study over a panel meeting is that no single expert can dominate the consensus.

The disadvantage is that it is not possible to discuss the results of previous rounds with the experts. Although the number of Delphi studies is still not high, the method has once again been accepted as a serious research design. A Delphi study was conducted by Osborne[7] and published in the *Journal of Research in Science Teaching*. This study was relevant not only because it justified our choice of the Delphi method, but also because it had a goal that was very similar to our own: to establish a list of basic and broad concepts related to science for use in the development of science education curricula.

In our case we have combined the Delphi study and the panel meeting. This paper presents the outcomes of the Delphi study and was used as input for a panel discussion on August 5–6, 2009, at Hofstra University. Thus we hoped to combine the advantages of the Delphi study and the expert panel meeting.

Research Design

Our research design, similar to the one Osborne[8] used, is typical for Delphi studies. A group of experts were invited by e-mail to participate in the study. In a first round, the 33 experts who agreed to participate were asked to generate themes and contexts and rate each one for importance. The number of experts involved is well over the 20–25 usually involved in a Delphi study. In our research we have adapted this first round: we provided the experts with a draft list of themes and contexts to rate on a 1–5 Likert scale. We did this because we wanted to clarify the level of generality we were looking for. In other words, by suggesting such themes as "systems" and "optimization," we wanted to prevent experts from suggesting themes that were substantially less transferable.

Area of ETE Expertise	Number of Participants
Philosophy/History and Communication of Technology	5
Engineering Educators	8
Technology Educators	20

Table 1. Disciplinary Breakdown of Delphi Participants

Another adaptation is that we added draft definitions to the unifying themes and contexts and asked the experts to comment on these and to indicate whether or not they found the defined themes and contexts suitable. The following rounds were more standard. In the second round the experts were presented with the broad themes and contexts, their amended definitions, and their scores resulting from the first round. They were asked to give scores of importance again, based on their own opinion as well as on the information related to the total average score of the whole group. No more themes or contexts could be added. We emphasized that our aim was not to reach exact definitions of the themes and contexts. Instead, we hoped to convey the essence of each theme and context, so that the experts would not need to respond again to the definitions but only rate them. Also, we asked the experts to be sparing with high scores so that only the most important concepts would stand out. We pointed out that aiming for a short list was also the reason why we did not include each theme and context that the experts had suggested in the first round.

The outcomes of the Delphi study have been used as the input for a meeting of a panel of experts, with the purpose of turning these outcomes into a framework for curriculum development. The panel consisted of six participants in the Delphi study plus two other experts who had not been involved in the Delphi study (four engineering educators, four technology educators). Also, two of the researchers were present whose backgrounds were in the philosophy of technology and technology education. The process was as follows: first, the group reflected on the contexts that came out of the Delphi study, and second, it reflected on the overarching themes. Both of the lists were found to lack structure and hierarchy, an omission that is understandable from the methodology of the Delphi study. An analysis was made of the nature of the consecutively ranked themes and contexts to provide the necessary structure for use as a curriculum framework.

The technological contexts that ranked high on the list that resulted from the Delphi study appeared to consist of two subgroups of contexts. In the first group, the panel recognized the contexts that traditionally had been used in the U.S. as curriculum organizers: construction, production, transportation, communication, and biotechnology. The remaining contexts, the second group, all seemed to reflect major global concerns. Some examples of these are energy, food, water, and medical technologies. This impression was confirmed by the motivations given by some of the experts in the Delphi, one of whom phrased this as “making the world a better place.” In the discussion, the panel realized that both the traditional and the global concern contexts were related to basic human needs that are addressed by engineering and technology.

Thus, the panel developed a single list of technological contexts that reflected engineering and technological endeavors in the context of addressing personal, societal, and global concerns. The contexts included food (e.g., agriculture, biotechnology), shelter (e.g., construction), water (e.g., supply and quality), energy (e.g., production, distribution), mobility (e.g., transportation), production (e.g., manufacturing), health (e.g., medical technologies), security (e.g., firewalls), and communications (e.g., Internet, satellite).

This list both does justice to the outcomes of the Delphi study (it covers the top nine of the contexts listed) and has a logic to support it (the contexts are all basic human concerns). It was important that some contexts were put forward by the Delphi experts from a “global concern” point of view, while other contexts were put forward because of their “daily life” character. So the panel decided to add the recommendation that when developing a curriculum, the contexts should be elaborated in two directions: a “personal concern” (or “daily life practice”) direction and a “global concern” direction.

The next step was to reflect on the unifying theme list. It was evident that this list contained themes of different levels of abstraction. Therefore it was decided to identify those themes with the highest level of abstraction and to put the remaining themes under these “main” themes. The panel identified the following themes as the most abstract: design (as a verb), systems, modeling, resources, and values. The last theme was not listed as such but was introduced by the panel as a heading for several themes in the list that were value-related. It also reflected the concern of a number of Delphi experts to make the normative dimension of technology and engineering visible in the list of unifying themes. The remaining themes that scored high could then be put under these five main headings.

The unifying themes are design (e.g., optimization, trade-offs, specifications), modeling (e.g., representation and prediction), systems (e.g., function, structure), resources (e.g., materials, energy, information), and human values (e.g., sustainability, innovation, risk, failure, social interaction).

Figure 1 illustrates how the unifying themes and technological contexts might be visualized. This draws upon the NCTM’s *Principles and Standards for School Mathematics*[9], where there are content standards (e.g., algebra, geometry) and process standards (e.g., problem solving, reasoning, and proof) that highlight ways of acquiring and using content knowledge. We are proposing an analogous model. The unifying themes are analogous to the process standards in mathematics, reflecting in some ways the habits of mind that a technologically literate person could use in understanding technological contexts, the content analog in mathematics.

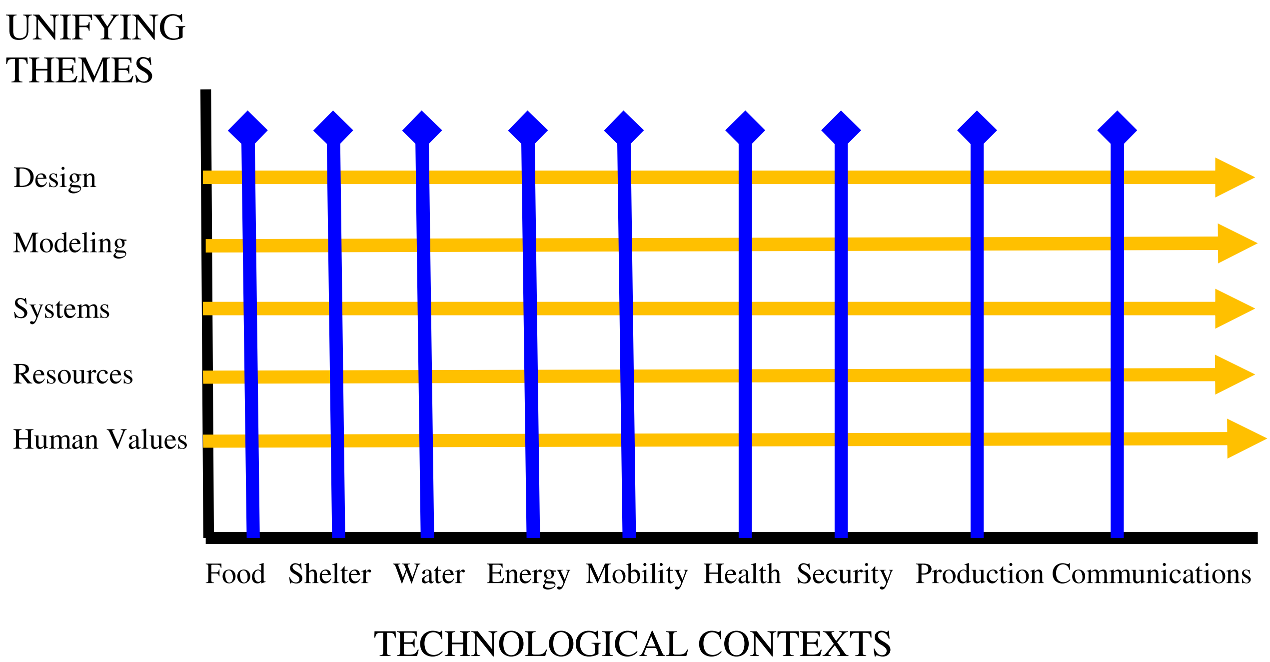

Figure 1. Matrix Illustrating Unifying Themes and Technological Contexts

Conclusions

The modified Delphi study enabled us to work with experts representing nine countries and a variety of technological disciplines, all concerned with K-12 engineering technology education. The study further allowed us to glean from the process an orthogonal set of standards—unifying themes and technological contexts for K-12 ETE. It is both interesting and important, we believe, that this international group conceived of K-12 ETE as being fundamentally involved with sustainability on the personal and the global level. This is a new image of engineering and the technological world, both of which are often cast in terms of disaster and tragedy.

While evolving a framework, and contributing to its development with this paper, there is much to do in terms of deciding what is needed at different grade levels. How does one discuss systems, in the context of water, with a 7-year-old? What is the discussion like with a 15-year-old? At all grade levels there is competition for time; adding another discipline may not be possible, except as an elective option. However, some of the unifying themes can bring pedagogical advantages to the teacher; for example, the use of design can increase student engagement. Current research[10, 11] indicates that the use of design challenges, with informed design teaching strategies, improves student mathematics content knowledge and positively affects student attitudes.

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