Importance of key engineering and technology concepts and skills for all high school students
Comparing perceptions of university engineering educators and high school technology teachers

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Abstract

Objectives: This study compares perceptions of academic engineering educators (AEEs) who prepare future engineers at the university level; and high school classroom technology teachers (CTTs) who provide engineering and technology education (ETE) at the secondary school level.
Theoretical background: the study relates to subjects such as the need for ETE for all students (Barak and Hacker, 2011), U.S. Standards for Technological Literacy (International Technology Education Association, 2000), and prior research on concepts and context in ETE (Rossouw, Hacker, & de Vries, 2010).
Research questions were: 1) Where does the strongest consensus exist among the expert panelists relative to the importance of specific ETE concepts and skills that all high school students should attain? 2) Which ETE concepts and skills are perceived to be most important as part of fundamental education for high school students? 3) Where are there significant differences between AEEs' and CTTs' perceptions of the importance of ETE concepts and skills? 4) What concepts and skills that the study elicits are not presently addressed by the U.S. National Standards for Technological Literacy (STL)?
Methodology: The intent of the study was to solicit and converge expert opinion within the two study groups in order to obtain consensus. The research was carried out using a three-round Delphi survey (RAND, 2011) where feedback from prior rounds enabled panelists to modify and update their positions to achieve consensus. The participants were 18 academic engineering educators and 16 classroom technology teachers – a total of 34 experts.
Examples from results: Strong consensus between AEEs and CTTs was found on 14 of 38 survey items. Among the items that the combined group found to be most important for high school students to attain were to: 1) identify and discuss environmental, health, and safety issues; 2) use representational modeling such as a sketch, drawing, or a simulation to convey the essence of a design; 3) use verbal and/or visual means to explain why a particular engineering design decision was made; and 4) show evidence of considering human factors (ergonomics, safety, matching designs to human and environmental needs) when proposing design solutions.

Keywords

Academic engineering educators, classroom technology teachers

Introduction

Due to the essential roles engineering and technology play in addressing societal and environmental challenges, support for the establishment of PreK-12 engineering and technology education (ETE) programs in the United States has been rapidly growing (NAE, 2009). The idea has been promulgated by many science, technology, engineering and mathematics (STEM) educators and disciplinary leaders, professional associations, and governmental agencies (Katehi, Pearson, & Feder, 2009). As Custer, Daugherty, and Meyer (2010) postulated, there are three factors underlying the growth of PreK-12 ETE: 1) facilitating technological literacy, 2) providing a math and science learning context, and 3) enhancing career pathways.

There is growing recognition that school-based ETE experiences can be pedagogically valuable for all students—not only in providing an effective way to contextualize and reinforce STEM skills, but in mobilizing engineering thinking as a way for young people to approach problems of all kinds (Brophy & Evangelou, 2007; Forlenza, 2010). However, there is no established consensus regarding what constitutes an appropriate K-12 ETE curriculum, primarily because there has been no substantive effort to identify and describe the body of engineering content that such a curriculum might contain (Sanders, Sherman & Watson, 2012).

The objective of this study was to compare the perceptions of two constituencies whose missions focus on preparing students to succeed in our technological world through engineering and technology education. The two groups include academic engineering educators (AEEs) who prepare future engineers at the university level; and high school classroom technology teachers (CTTs) who teach engineering and technology courses at the secondary school level.

Theoretical background

A thorough review of the literature was conducted relative to the need for ETE for all students (Barak &Hacker, 2011); U.S. Standards for Technological Literacy (International Technology Education Association, 2000); prior research on Concepts and Contexts in Engineering and Technology Education (CCETE) (Rossouw, Hacker, & de Vries, 2010); the current state of school-based ETE; and perceptions of engineering design, which according to many scholars is the core process through which engineering endeavors are accomplished (Bloch, 1986; Custer, Daugherty & Meyer, 2009; Rossouw, Hacker, & de Vries 2010; Liao, 2011). Literature related to Delphi survey research methodology was reviewed to establish a rationale for its use to establish consensus about key ETE ideas and skills.

Through the literature review, the most salient ideas that emerged from the ETE literature were synthesized and clustered within a set of unifying themes that emerged through the CCETE study and other major research projects. Clustering concepts and skills within a unifying framework provides learners with a more holistic understanding of engineering and technology and addresses recommendations made by the NSF (G. Salinger, personal communication, March 22, 2001), the National Academy of Engineering (NAE) (NAE, 2010), and the National Research Council (NRC) (NRC, 2011).

The literature review established a basis for identifying concepts and skills that became the starting point (the initial item set) for the survey instrument used in this study. Delphi research methodology was employed because it uses informed judgment of experts to arrive at consensus (RAND, 2011).

This *Comparison of Perceptions* study furthers the work accomplished by the CCETE study (Rossouw, Hacker & de Vries, 2010) to produce a consensus about the underlying ETE concepts and skills within those five broad areas of conceptual understanding. The present research identified concepts and skills that expert AEEs and CTTs (as an entire group) deemed to be of high importance and of lower importance for high school students in the United States to attain as part of their fundamental education. The study then determined where significant differences existed in the perceptions of the two subgroups relative to the importance of these concepts and skills.

Furthermore, this study identified ETE concepts or skills that might be considered important enough for inclusion in the next iteration of the U.S. Standards for Technological Literacy.

Research questions

Four research questions were identified:

RQ1. Where does the strongest consensus exist among the whole group of expert panelists?

RQ2. Which ETE concepts and skills does the expert panel perceive to be most important for HS students to learn?

RQ3. Where are there significant differences between academic engineering educators' and classroom technology teachers' perceptions of the importance of ETE concepts and skills?

RQ4. What concepts and skills are not presently addressed by the national standards for technological literacy that academic engineering educators and classroom technology teachers agree are highly important for students to learn?

Methodology

This study used *Delphi survey research* to solicit and converge expert opinions to obtain consensus (Salancik, Wenger & Helfer, 1971). A convergence of opinion has been observed in the majority of cases in which the Delphi approach has been used (Helmer, 1967). This study employed a three-round modified Delphi survey using the technique designed by Dalkey & Helmer (1963) and revised by Delbecq, Van deVen, & Gustafson (1975).

Several recent important research projects related to this study employed the Delphi survey methodology to identify ETE concepts and skills (Childress & Rhodes, 2007; Dearing & Daugherty, 2004; Harris & Rogers, 2008; Rossouw, Hacker, & de Vries, 2010; Scott, Washer & Wright (2006); and a study conducted by well-respected science researchers established a set of basic and broad concepts related to science education using this methodology (Osborne, Collins, Ratcliffe, Millar, & Dutchl, 2003). Researchers (Delbecq et al, 1975; Ludwig, 1997; Dalkey, Rourke, Lewis & Snyder (1972) suggest that ten to fifteen subjects could be sufficient if the background of the Delphi subjects is homogeneous.

This research was carried out using a three-round Delphi survey (RAND, 2011) where feedback from prior rounds enabled panelists to modify and update their positions to achieve consensus. The participants were 18 academic engineering educators and 16 classroom technology teachers – a total of 34 experts. Three Delphi administrations have been found to be sufficient to arrive at consensus (Brooks, 1979). A literature review found that after three iterations, not enough new information was gained to warrant the cost of more administrations (Altschuld, 1993).

Seven stages characterized the Delphi procedure, in accordance with the method suggested by Fowles (1978).

1. Define the research questions
2. Assemble panel of experts
3. Design and validate an initial set of survey items
4. Conduct the three round survey
5. Analyze survey results
6. Draw tentative conclusions
7. Present tentative conclusions to the validation panel and reach summary conclusions

During the conduct of the three-round survey, Delphi panelists were invited to reconsider their item ratings if these were at variance with prior-round group median ratings. Thus an attempt was made to achieve expert consensus. After the first round when it was evident that scores on all items were quite high, on subsequent rounds panelists were asked to give high scores sparingly. After the third Round, concepts were ordered according to their scores and a final ranking of concepts was determined.

Survey instrument and data analysis methodology

The survey Instrument included 38 survey items comprising concepts and skills in five overarching domains of engineering and technology that are repeatedly referenced in the literature:

1. Design (12 survey items)
2. Modeling (6 survey items)
3. Systems (6 survey items)
4. Resources (7 survey items)
5. Human Values (7 survey items)

The survey was conducted online using Qualtrics survey software and data was exported to SPSS for analysis. In this study, Likert scale data was treated as ordinal data and was reported using descriptive statistics – (medians, frequencies, percentiles, interquartile range (IQR) statistics, and z-scores. A nonparametric test (the Mann-Whitney U) was used to determine statistically significant differences between the two study groups and p-values were reported at the $\alpha = 0.05$ level.

Relative to Research Question 1 (RQ1) – (Where does the strongest consensus exist among the expert panelists relative to the importance of specific ETE concepts and skills that all high school students in the U.S. should attain as part of their fundamental education?), analysis determined the strength of consensus on each item by subgroup and by the whole group. According to Rojewski and Meers (1991), the Delphi technique is used to achieve consensus among participants, and that "consensus is determined using the interquartile range of each concept statement. Interquartile range (see figure 6) refers to the middle 50% of responses for each statement (i.e., distance between first and third quartiles)." Low IQRs are a measure of strong group consensus on a particular item. As suggested by Rayens and Hahn (2000), the IQR may be an insufficient criterion for determination of agreement. An additional measure that contributed to establishing consensus in this study was frequency distribution and the criterion of some percentage of panelists responding to any given response category is used to determine consensus (Loughlin & Moore, 1979, p. 103; Seagle & Iverson, 2002, p. 1; Putnam, Speigel, & Bruininks, 1995; as cited by von der Gracht, 2008).

In this study, factors determining consensus included the whole-group IQR and frequency of responses at the high end of the scale (respondents choosing scale points 6-7) and at the low end of the scale (respondents choosing scale points 1-4). These "consensus factors" were validated by the validation panel and are displayed in table 1.

Table 1. Consensus Factors

Item Importance Level	Determinants of Consensus
Consensus that an Item is of Higher Importance	If IQR ≤ 1.61 and frequency of high scores (6-7) ≥ 80%
Consensus that an Item is of Lower Importance	If IQR ≤ 1.61 and frequency of low scores (1-4) ≥ 25%

Relative to Research Question 2 (RQ2) – (Which ETE concepts and skills does the expert panel perceive to be most important for high school students to attain as part of their fundamental education?), the study examined the median ratings for each item rated by the panelists in the third Round of the Delphi administration. The whole-group median ratings for each survey item and median ratings for each subgroup (AEEs and CTTs) were determined using IBM SPSS V21.0 for Windows software. Median statistics were used because the median is less affected by outlier responses than the mean, and provides a finer level of numerical discrimination than the mode. Once median statistics were obtained for the whole group's rating of each survey item, the medians were ranked using the data ranking function of Microsoft Excel. This ranking indicated which of the survey items the subgroups and the entire panel perceived to be most important.

The validation panel reviewed the final research results and a cutoff point was established. The cutoff point determined which items rose to the level of being considered highly important. In the case of this study, because median ratings for all items were quite high (ranging from a high median rating of 6.71 to a low median rating of 4.60 on a 7-point scale), the validation panel set the item cutoff point at median ratings of ≤ 6.0. Those items that rose above the agreed-upon cutoff level were then deemed to be of "high importance" for HS students to understand. No items were deemed to be unimportant by the validation panel.

Relative to Research Question 3 (RQ3) – (Are there significant differences between academic engineering educators' and classroom technology teachers' perceptions of the importance of ETE concepts and skills?), the Mann-Whitney U statistical test was used to analyze whether the median ratings obtained from the two groups were significantly different. This test is nonparametric and develops statistics based on ordinal data as opposed to interval data. Nonparametric methods are particularly suited to data that are not distributed normally (Pidwirny, 2001). Nonparametric tests compare medians rather than means and, as a result, if the data have one or two outliers, their influence is negated (Hayes, 1997).

Relative to Research Question 4 (RQ4) – (What concepts and skills that the study elicits, do academic engineering educators and classroom technology teachers agree are highly important for high school students to attain as part of their fundamental education and are not presently addressed by *STL*?), the study identified concepts and skills that the study has shown to be highly important for high school students to attain as part of their fundamental education, and did a gap analysis with the existing STL.

The study compared survey items rated "important" by the Delphi panel to existing benchmarks in the high school level Standards for Technological Literacy. If items were similar, rewording based on survey item wording is suggested. If there were gaps, survey items were suggested as additions to the next iteration of STL. During the validation panel meeting to review research results, the validation panel confirmed the researcher's gap analysis and suggested that revisions to STL be addressed in its next iteration based on survey results.

Findings

Based upon an analysis of final (Round 3) data, conclusions related to each research question were drawn.

Related to RQ1, there was strong consensus between the two groups on 14 of 38 survey items. The strongest consensus that items were **highly important** related to students being able to:

1. Identify and discuss environmental, health, and safety issues involved in implementing an engineering project; and
2. Use representational modeling (e.g., a sketch, drawing, or a simulation) to convey the essence of a design.

The strongest consensus that items were of **lower importance** related to:

1. Provide an example and an explanation of how design solutions can integrate universal design principles to help meet the needs and wants of people of all ages and abilities; and
2. Describe, through an example, how the reliability of a system and the risks/consequences associated with its use have or have not been adequately considered prior to its implementation.

Related to RQ2, the ETE concept/skills perceived by the combined group to be most important for high school students to attain were to:

1. Identify and discuss environmental, health, and safety issues involved in implementing an engineering project;
2. Use representational modeling (e.g., a sketch, drawing, or a simulation) to convey the essence of a design;
3. Explain why a particular engineering design decision was made, using verbal and/or visual means (e.g., writing, drawing, making 3D models, using computer simulations); and
4. Show evidence of considering human factors (ergonomics, safety, matching designs to human and environmental needs) when proposing design solutions.

Related to RQ3, significant differences between academic engineering educators' and classroom technology teachers' perceptions were evidenced on four items:

1. Solve engineering design problems by identifying and applying appropriate science concepts;
2. Provide examples of how psychological factors (e.g., bias, overconfidence, human error) can impact the engineering design process;
3. Explain the difference between an open-loop control system and a closed-loop control system and give an example of each; and
4. Develop and conduct empirical tests and analyze system and analyze test data to determine how well actual system results compare with measurable performance criteria.

All of these except the third were rated higher by AEEs than by CTTs.

Related to RQ4, recommendations are made that the next iteration of the STL add, substitute, or reword standards based on 16 survey items that panelists agreed are highly important for HS students in the United States to attain as part of their fundamental education, but are not presently addressed by STL.

An important point worth mentioning is that even though three Delphi rounds were conducted with the objective of reaching consensus between the two groups of experts, there were four items for which a significant difference was found between the two groups at the end of the process. This finding reflects the differences in the educational backgrounds of the two groups. Academic engineering educators are professional engineers who have extensive mathematical and scientific knowledge; classroom technology teachers, on the other hand, study little mathematics and science during their training and are most comfortable teaching about technological tools, materials and processes.

Technology Education in the United States has its roots in crafts teaching and many of today's more experienced technology teachers were educated as Industrial Arts teachers. Therefore, revising technology education curricula with an emphasis on integrating aspects of mathematics and science also implies re-conceptualizing teachers' professional and pedagogical preparation.