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# Advancing Diagnostic Skills for Technology and Engineering Undergraduates: A Summary of the Validation Data


## Abstract

Facilitating student growth and development in diagnosing and solving technical problems remains a challenge for technology and engineering educators. With funding from the National Science Foundation, this team of researchers developed a self-guided, computer-based instructional program to experiment with conceptual mapping as a treatment to improve undergraduate technology and engineering students' abilities to develop a plan of action when presented with real technical problems developed in collaboration with industrial partners. The pilot-testing and experimental portions of the project confirmed that the subjects found the training interesting and useful. However, the experimental data did not support the conclusion that the treatment caused an increase in diagnostic performance. Analysis of individual data demonstrated that for a portion of the sample, significant gains occurred. Qualitative analysis demonstrated that the majority of the students treated the experience as a trivial academic exercise, which seriously limited their efforts. A major step forward occurred in the ability to automatically compare student maps with the expert's reference map using a modified version of the similarity flooding algorithm. Student feedback was based on this automatic comparison. In all, the experience has encouraged the team to continue and expand the use of conceptual mapping as a tool for improving diagnostic and problem-solving skills.


***Keywords:*** diagnostic skills; conceptual mapping; self-guided instructional design; similarity flooding

## Introduction

For some time, technology and engineering educators have focused on improving students' cognitive and metacognitive abilities, especially in the areas of design and problem solving. It is clear that these abilities are essential for personal and professional success. However, an argument can be made that more work is needed. This study was an attempt, supported by funding from the National Science Foundation, to develop and pilot test computer-based, self-

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paced diagnostic skills training using conceptual mapping techniques developed by Novak (1977). Cognitive abilities are highly successful predictors of job performance, and the development of advanced cognition skills is critical to perform any diagnostic assignment. According to Gabbert, Johnson, and Johnson (2001), one of the ways to address cognitive development is "by examining the strategies students use to complete learning tasks" (p. 267). Causal-model theory argues "that, in principle, people are sensitive to causal directionality during learning"; our learning does not involve only "acquiring associations between cues and outcomes irrespective of their causal role" (Waldmann, 2000, p. 53). It is predicted by associative theories that in some learning conditions, our representations are fundamentally flawed. There is

> evidence that learning from experience seems more of a process of negotiation in which thinking, reflecting, experiencing and action are different aspects of the same process. It is negotiation with oneself and in collaboration with others that one may actually form the basis of learning. (Brockman, 2004, p. 141)

Interestingly, this applies as well to the informal learning that occurs in such technical situations as help desk support for information systems. Haggerty (2004) noted that the support and implementation of structured and systematic problem-solving processes and detailed verbal modeling of explanations about the problem are critical to the development of advanced cognition and effective outcomes because they will also increase self-efficacy and satisfaction.

Diagnostic learning (i.e., analyzing causes based on information about the effects) needs to be differentiated from predictive learning (i.e., determining effects based on specific causes). "An important feature of diagnostic inference is the necessity of taking into account alternative causes of the observed effect" (Waldmann, 2000, p. 55). Given that the effects (symptoms) have already occurred and are not necessarily actively recognized by the learner, "diagnostic learning is a test case for humans' competency to form and update mental representation in the absence of direct stimulation" (Waldmann, 2000, p. 73).

Some technical problems are well defined with a clear goal: There is a definite cause and outcome and a proven algorithm to ensure that the problem is solvable. However, many technical problems are ill-defined: The cause or causes, what constitutes relevant data, and the steps to be taken are unclear. Consequently, there is a need for advanced cognitive skills such as analytical, creative, and practical thinking when diagnosing technical problems. Writing from an organizational perspective, Okes (2010) states that a "problem is often not a single problem but many different problems" (p. 38). In such cases, the diagnosis will be difficult since there are likely to be multiple causes. The ability to diagnose multiple causes of a common effect versus a common cause for multi[ple] effects requires the technician to learn about these fundamental causal relationships correctly. And this ability is improved through practical experience and the ability to evaluate the causes and solutions of problems. Waldmann (2000) believes that a combination of technical expertise and logical and creative thought processes are essential for diagnosing a problem. Okes (2010) makes a distinction between creative problems and analytical problems: With creative problems, multiple solutions are necessary; however, analytical problems require "the right solutions [that] will not be known until a proper diagnosis is done. [For analytical problems,] it is the [utilization of a] diagnostic process, known as root cause analysis, which finds the causes" (p. 37).

**Technical Diagnostic Work**

"Most people never receive training in root cause analysis, and those who are experts have often learned it through years of experience diagnosing a wide range of problem situations" (Okes, 2010, p. 36–37). One of the ways in which diagnostics skills are developed is through the understanding of cause and effect relationships when performing diagnostics. Typically, technical workers learn "cause and effect relationships resembling symptom–cause troubleshooting charts which they held in memory for use in subsequent troubleshooting" (Green, 2006, Abstract, p. 2).

Troubleshooting requires the technician to utilize problem-solving skills. According to Sharit and Czaja (2000), this is one of the most complex cognitive processes. Haggerty (2004) writes that providing "technical support [is] . . . one mechanism by which [information system] users can gain the necessary knowledge, skills and abilities to use their technology [the system] effectively" (p. iii). As Haggerty (2004) states, "effective support is characterized by a timely and well structured problem solving process where a knowledgeable, sympathetic and patient analyst provides thorough and specific information and explanations, matched to the user's demonstrated level of ability, according to the needs of the specific technical problem" (p. iii). Technical workers, however, often encounter complex, ill-structured problems in their professional efforts to solve technical problems and do not have access to any form of technical support. Three major issues relative to organizational culture's impact on problem solving are identified by Okes (2010), including: how people view problems (e.g., someone to blame), who will be called upon to diagnose and solve the problem, and the ratio of the number of problems to the available personnel to solve them.

**Instructional Techniques**

Most would agree with Stoyanov and Kirschner (2007) that "solving problems is considered an important competence of students in higher education" (p. 49) and that higher education institutions must take on this important task. What seems to be at issue is how to go about the task effectively. Historically, problem-solving instruction has focused mostly on well-defined problems and a rather simple, step-by-step approach. However, most situations that are viewed as problems are typically not well defined, nor do people tend to be successful in solving them using a simplistic problem solving heuristic. What seems to be needed is practice with ill-defined problems within a supportive and instructional environment (Stoyanov & Kirschner, 2007).

To develop diagnostic skills, “the knowledge that one should analyze the problem situation, generate ideas, select the most appropriate, and then implement and evaluate is necessary, but not sufficient” (Stoyanov & Kirschner, 2007, p. 50). It is also important to know how to process information, form and test hypotheses, and make choices based on the data (Johnson, 1994). “The selection and application of these procedures, techniques, and tools depends to a large extent on the desired outcomes of problem-solving determined by the nature of ill-structured problems and the cognitive structures and processes involved in solving them” (Stoyanov & Kirschner, 2007, p. 50). “Instructional design should determine the most effective and efficient conditions of providing both process and operational support to solving ill-structured problems” (p. 50).

Writing on the topic of professional development, Mayer (2002) defines problem-based training as providing “realistic problems and the solutions of these problems in a variety of situations” (p. 263). He lists the four types of problem-based approaches enumerated by Lohman (2002) that “can be presented in computer-based environments, book-based environments, or live environments” (Mayer, 2002, pp. 263–264): (1) *case study*, (2) *goal-based scenario*, (3) *problem-based learning*, and (4) *action learning* (p. 264). He theorizes that

> “there are three cognitive steps in problem solving by analogy: (1) *recognizing* that a target problem is like a source problem you already learned to solve, (2) *abstracting* a general solution method, and (3) *mapping* the solution method back onto the target problem” (p. 267).

More research is needed “to understand how each of the problem-based training methods [in Lohman’s (2002) article] supports the processes described [the three cognitive steps]” (Mayer, 2002, p. 267). The use of graphical structures to help make sense of information is important to problem solving and systems thinking.

Novak, the person credited with the development of conceptual mapping, argues “that *the central purpose of education is to empower learners to take charge of their own meaning making*” (Novak, 2010, p. 13). His work in conceptual mapping is based on the theoretical work of Ausubel, Piaget, and Vygotsky. Initially developed as a means to collect data about children’s knowledge, his research quickly led to the conclusion that concept mapping was useful in helping students learn and helping teachers to organize instruction. It has also been demonstrated to be a useful tool for evaluating what has been learned. Recently, he has applied mapping as planning and problem solving in corporate settings.

Siau and Tan (2006) identify "three popular cognitive mapping techniques—causal mapping, semantic mapping, and concept mapping" (p. 96). The term *cognitive map* is developed in psychology as a means of describing an individual's internal mental representation of the concepts and relations among concepts. Cognitive mapping techniques are used in identifying subjective beliefs and to represent these beliefs externally. "The general approach is to extract subjective statements from individuals, within specific problem domains, about meaningful concepts and relations among these concepts and then to describe these concepts and relations in some kind of diagrammatical layout [Swan, 1997]" (Siau & Tan, 2008, p. 100). This internal mental representation is used to understand the environment and make decisions accordingly. "*Causal mapping* [emphasis added] is the most commonly used cognitive mapping technique by researchers when investigating the cognition of decision-makers in organizations [Swan, 1997]" (Siau & Tran, 2006, p. 100) because it allows an individual to interpret the environment with salient constructs. The theory argues that individuals, with their own personal system of constructs, use it to understand and interpret events. "*Semantic mapping* [emphasis added], also known as idea mapping, is used to explore an idea without the constraints of a superimposed structure [Buzan, 1993]" (Siau & Tran, 2006, p. 101). With semantic maps, an individual will begin at the center of the paper with the principal idea and work outwards in all directions. This produces an expanding and organized structure consisting of key words and key images. *Concept mapping* is another cognitive mapping technique, which "is a graphical representation where nodes represent concepts, and links represent the relationships between concepts" (Siau & Tan, 2006, p. 101). Concept mapping is an integral part of systems thinking.

**Systems Thinking**

Batra, Kaushik, & Kalia (2010) define systems thinking as

> a holistic way of thinking, fundamentally different from that of traditional forms of analysis in which the observer considers himself the part of reality as a whole system. System[s] thinking resists the breaking down of problems into its component parts for detailed examination and focuses on how the thing being studied interacts with the other constituents of the system. . . . This means that instead of taking smaller and smaller parts or view[s] of the system taken for study, it actually works by expanding its view by taking into account larger and larger numbers of views or parts of the system. (p. 6)

"Systems thinking is increasingly being regarded as a 'new way of thinking' to understand and manage the 'natural' and 'human' systems associated with complex problems . . . (Bosch et al., 2007a)" (Nguyen, Bosch, & Maani, 2011). When employing systems thinking to deal with real problems, it is necessary for the trainer to classify real-world problems by system language because the classification can help students or trainees find an appropriate method and methodology to deal with specific problematic situations. According to Batra et al. (2010),

> The character / nature / approach of systems thinking makes it extremely effective on the most difficult types of problems to solve. . . . Some of the examples in which system thinking has proven its value include: complex problems that involve helping many actors [learners] see the "big picture" and not just their part; recurring problems or those that have been made worse by past attempts to fix them; issues where an action affects (or is affected by) the environment surrounding the issue, either the natural environment or the competitive environment; and problems whose solutions are not obvious. (p. 6)

Batra et al. (2010) discovered that systems thinking leads to: "in-depth search of problem contributors by finding out further reasons for those problems and lead to actual reasons of the same," "solution[s] to all kinds of problems by considering them as a whole system" (p. 10), finding the root-cause of a problem by exploring not just analyzing the problem and making assumptions, and "permanent solutions of problems by acting on all possible reasons simultaneously [instead of just making] plans to solve the problem by removing the reasons one by one as per the plan formation" (p. 11).

**Evaluation of Diagnostic Skills**

In order to acquire skills, learning has to take place. According to Kontogiannis and Maoustakis (2002), "most research in artificial intelligence and machine learning has . . . underplayed issues of problem formulation, data collection and inspection of the derived knowledge structures (Langley and Simon 1995)" (p. 117). They further state that the stages of inspection and evaluation of knowledge structures are significant because "by making knowledge structures easier to understand or comprehend, we are in a better position to meet criteria of validation, generalization and discovery." (p. 133). Basically, the issue of comprehensibility must be part of the evaluation process for technical applications. The learner has to be able to input and output knowledge. Comprehensibility should address transferability to a new context in the future. With the increased use of computer-based diagnostic skills, evaluation is not done separately from the ability of humans to interact with the computer to perform problem-solving tasks.

Kontogiannis' and Maoustakis' (2002) "informal approach for refining and elaborating knowledge structures" (p. 120, Figure 1) provides some insight on what to consider when performing evaluations of diagnostic skills. The model illustrates the significance of the individual to become an expert in the field to effectively perform diagnostics. It is imperative that the expert is able to employ several diagnostic strategies. This entails "fault-finding strategies and knowledge structures [, which] are dependent upon the amount and kind of data that are available—for example, data regarding equipment reliability data, direction and rate of change of process variables, sequences of change, etc." (p. 120). Their model demonstrates the significance of identifying any weakness in the process at the analytical stage. The role of the expert is to determine if the process for solving the problem was justifiable in terms of the principles of operation. At the modification stage, the ability of the learner "to impose a hierarchical structure upon the" (p. 123) process is crucial to problem solving. This would entail "providing descriptions of groups of faults that relate functionally to each other" (p. 123). Moreover, the creation of subordinate goals and plans are important as they are "high-level objectives or concepts . . . . By progressively breaking up all goals into plans or sequences of checks, the overall task becomes easier to achieve" (Kontogiannis & Maoustakis, 2002, p. 123). Kontogiannis and Maoustakis further explain that "the distance or gap between the top goal and the available responses [, verbal statements of the problem made at a high or detailed level,] becomes smaller" (p. 123). The subjects of their study were required to participate in fault-finding activities. This demonstrated the level to which they were able to transfer what was learned. In order to study subjects' diagnostic skills, the authors created three modules: "Module 1—Training," "Module 2—Fault finding test in the manual mode" (p. 128), and "Module 3—Transfer to diagnosis in the automatics mode" (p. 129). Their findings indicated "that deep goal structures facilitate both the acquisition and the transfer of knowledge" (p. 132).

**Problem and Purpose of the Study**

Research to date supports the assertion that domain-specific problem-solving skills can be developed by educational and training programs. The more experience an individual has with a system and with solving problems that occur in the system, the more proficient a problem solver that individual becomes. What is less certain is the extent to which general problem-solving instruction can result in improvements in near and far transfer of knowledge to novel problem situations. There is strong evidence that the application of conceptual mapping improves learning, memory, and application of knowledge. It is also clear that conceptual mapping enhances systemic understandings.

This project was designed to test the premise that the use of conceptual mapping techniques to force in-depth analysis of technical problems and the creation of a process map of the student's intentions during the diagnosis phase of problem solving would increase the student's level of accuracy when compared to the process used by experts in the particular system. It was argued that developing this expertise in mapping would help the students become more agile in their thinking regarding ill-defined problems.

A quasi-experimental model was used to test the null hypothesis $H_0$: $\mu_{\Delta 1} = \mu_{\Delta 2} = \mu_{\Delta 3} = \mu_{\Delta 4}$. In other words, there would be no statistically significant difference between the four groups in terms of the mean difference in percentage accuracy for the two trials.

## Method

The project staff developed a 2-hour, computer-based training program using the Lectora authoring software. The first hour of this training was designed to introduce students to systems and troubleshooting problems. During this phase of the training, the subjects were taught to use the Visual Understanding Environment (VUE) open-source software to develop conceptual and process maps. Also during this phase, the subjects were given a "simple" technical problem and asked to map out a plan of action. Using a similarity flooding algorithm, the students' maps was then electronically compared to an expert's map that was already encoded. The information developed by the algorithm was returned to the subjects as feedback so that they would know how well they did.

The second phase of the training took the form of two technical problems developed in collaboration with industrial partners. The first problem involved an electrical grid distribution system, and the second problem focused on a malfunctioning heat exchanger system. In both cases, the subjects were provided with a description of the system and tables containing operational information. From the information presented, the subjects were asked to analyze the system and develop a process map for addressing the apparent malfunction.

The evaluation of this project included pilot-testing the training program after the completion of the first hour, after the completion of the electrical grid problem, and after completion of the full training program. The subjects were provided the program and all necessary software on a memory stick and typically completed the training on a laptop.

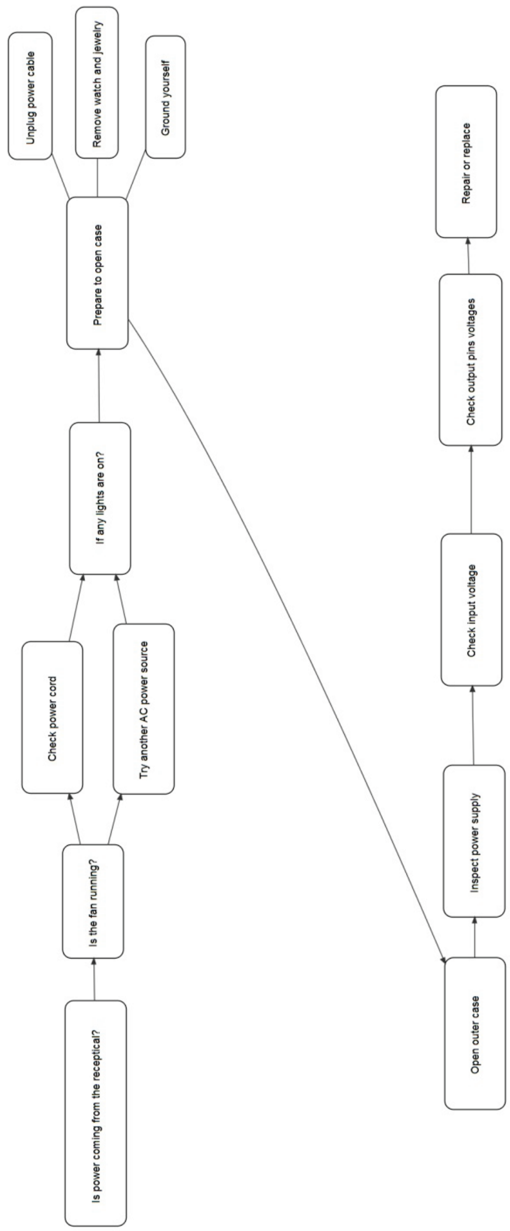


*Figure 1.* Sample expert process map (practice problem).

**Instrumentation**

A feedback questionnaire was developed to provide subjects the opportunity to express their reactions to the training. The Likert-type questions were similar to end-of-course student evaluations of instruction. In this case, the focus was on the "look and feel" of the program and the extent to which the students perceived the training to be interesting, relevant, and helpful. Subjects were also encouraged to provide open-ended comments.

**Population and Sample**

The population for this study was junior and senior undergraduates enrolled in engineering, engineering technology, and closely related majors. The sample was drawn from students enrolled in the College of Technology at Indiana State University (the Principle Investigators' home institution) and four other universities. Faculty members involved with Indiana State University's PhD in Technology Management Consortium and faculty members at the four other institutions accepted invitations to participate. The sample consisted of the classes of those faculty members.

There were four treatments, and the groups were randomized and assigned to the groups of students in the order in which the faculty of these groups agreed to participate. Typically, faculty members would volunteer a particular class that they taught because the training was perceived to be relevant to the focus of the particular course. Subject participation was voluntary, confidential, and anonymous.

**Data Collection**

Experimental data was collected automatically as the subjects completed the training. The primary dependent variable for the experiment was the difference in percent accuracy for the two attempts for each problem. Upon completion and submission of the subject's map, the map was compared to the expert's map, and percentage accuracy was reported. The subject received this percentage as feedback. One group only received its scores (control condition). The other three groups were given a secondary form of additional feedback: metacognitive cues, review of the expert map, and both. All subjects then were given the opportunity to revise and resubmit their maps. The resubmission was also evaluated for accuracy, and the percentage was reported to the students and recorded.

After completing the training program, the subjects were given a "satisfaction" questionnaire to provide feedback regarding their reactions to the training. There was a range of 1–4 for each of the eight questions asked. Consequently, the overall range for the satisfaction score was 8 to 32 points.

**Data Analysis**

Student satisfaction data was analyzed using only descriptive statistics that resulted in a mean and standard deviation for each question and the total for all eight questions (i.e., overall satisfaction). Experimental data analysis included testing the differences in percentage accuracy between the first draft and second draft of the subject's process maps. In addition, one-way analysis of variance was used to determine if there were any differences in mean percentage accuracy based on treatment type, university where the subject was studying, and major.

## Results

### Sample

A total of 130 subjects participated in the experimental portion of this project. Table 1 provides a summary of the demographic data collected.

**Table 1**
*Demographic Data*

| Gender | | Major | | University | |
|---|---|---|---|---|---|
| Female | 9 (7%) | Mech. Eng. Tech. | 58 (44.6%) | ISU | 72 (55.4%) |
| Male | 106 (81.5%) | Const. Mgmt. | 35 (26.9) | BGSU | 35 (26.9%) |
| NR | 15 (11.5%) | Info. Tech. | 15 (11.5%) | IUPUI | 11 (8.5%) |
| | | Mech. Eng. | 11 (8.5%) | PU | 8 (6.1%) |
| | | Pack. Tech. | 10 (7.7%) | RHIT | 4 (3.1) |
| | | Elec. & Comp. Tech | 1 (.8%) | | |

The home institution for this project was Indiana State University. As a result, the majority (55.4%) of the subjects were from that university. Subjects enrolled in mechanical engineering (8.5%) and mechanical engineering technology (44.6%) comprised 53.1% of the total. The majority (81.5%) of the subjects were male.

**Satisfaction**

Overall, on a scale of 8–32 points, the mean score for subject satisfaction with the training was 25.62 ($S_{n-1} = 3.25$). Each subject's ratings were averaged across the eight questions. The overall mean for all subjects was 3.2. Table 2 provides a summary for each of the eight questions.

**Table 2**
*Mean and Standard Deviation for the Eight Satisfaction Questions*

| Item | *M* | *SD* |
|---|---|---|
| 1. The computer based training was interesting | 3.09 | 0.67 |
| 2. The screen design was reasonably attractive | 3.15 | 0.55 |
| 3. The screen layout was logical (i.e., made sense) | 3.27 | 0.57 |
| 4. All of the program buttons worked as expected | 3.21 | 0.70 |
| 5. It was easy to navigate my way through the program | 3.29 | 0.66 |
| 6. The content of the training program was meaningful | 3.12 | 0.64 |
| 7. This training would be useful to anyone in a technical career | 3.27 | 0.67 |
| 8. Overall, this was a high quality, professional experience | 3.22 | 0.63 |

Of the 126 subjects to complete the satisfaction inventory, only 28 (22%) had an overall mean satisfaction rating below 3.0. The mean satisfaction scores ranged from a low of 1.75 (one subject) to a high of 4.0 (four subject).

The majority of the subjects chose not to provide any written comments. Of the 26 subjects who did comment, 11 (42%) made positive comments, and 15 (58%) made negative comments. The negative comments focused on parts of the program that did not work as expected and on needing more time to complete the training. One participant thought that the training would be stronger if it were more challenging.

**Experimental Validation**

Subjects were offered the opportunity to provide a process map for three problems during the training. The first problem was used as an orientation to the process that they would be using for the two main problems. For the first problem, the subjects were only given the opportunity to provide one map. Based on a comparison with the expert's map for that problem, the overall mean was 18% accuracy ($S_{n-1} = .16$). In other words, the subjects found the task somewhat challenging.

Taken as a whole, the subjects who completed the second problem (i.e., electrical power grid problem) scored an average of 18.8% ($S_{n-1} = .042$) on their first submission and 15.4% ($S_{n-1} = .043$) on their second attempt. A paired samples *t*-test revealed that the difference was statistically significant ($t_{(129)} = 2.919$, $p < .01$), although the reverse of expectations. Subjects who completed the third problem (i.e., heat exchanger problem) scored on average 11.7% ($S_{n-1} = .021$) for their first submission and 12.6% ($S_{n-1} = .03$) for their second submission. This was not found to be a statistically significant difference ($t_{(128)} = -1.17$, $p > .05$). In all cases, percent accuracy was based on 100% (i.e., perfect match).

**Table 3**
*Mean Differences for the Control Group and Three Treatments for Both Problems*

| | | **Diff_1** | | **Diff_2** | |
|---|---|---|---|---|---|
| **Group** | ***n*** | ***M*** | ***SD*** | ***M*** | ***SD*** |
| 1 | 35 | -.06214 | .176141 | -.00243 | .014368 |
| 2 | 32 | -.00813 | .123798 | .04019 | .129542 |
| 3 | 35 | -.02497 | .088989 | -.01091 | .101700 |
| 4 | 28 | -.03775 | .117151 | .00764 | .026403 |
| Total | 130 | -.03358 | .131248 | .00795 | .085689 |

The null hypothesis was that the mean difference for the three treatments would be equal to one another and the control group. Based on a one-way analysis of variance, the null hypothesis could not be rejected for the electrical grid problem ($F_{(3, 126)} = 1.014$, $p = .389$) nor for the heat exchanger problem ($F_{(3, 126)} = 2.315$, $p = .079$). As can be seen, the mean difference for the two submissions for the heat exchanger problem was most pronounced. In addition, no statistically significant differences were found based on gender, major, or the university at which the students were studying.

Although group data confirmed that by and large the subjects did not perform well on the three problems included in this training, analysis of the top performing subjects demonstrated that some students did in fact understand the problem and the process mapping technique reasonably well, as shown in Table 4.

**Table 4**
*Individual Subject Performance for Each Problem*

| Electric Grid Problem | | Heat Exchanger Problem | |
|---|---|---|---|
| First Attempt | Second Attempt | First Attempt | Second Attempt |
| 0.560 | 0.734 | 0.651 | 0.535 |
| 0.461 | 0.526 | 0.497 | 0.692 |
| 0.423 | 0.652 | 0.491 | 0.554 |
| 0.515 | 0.751 | 0.419 | 0.537 |
| 0.493 | 0.741 | 0.475 | 0.648 |
| | | 0.342 | 0.829 |

## Discussion

As stated earlier, the purpose of this project was to experiment with the development of a self-paced, computer-based program (using the Lectora authoring software) to introduce engineering and technology undergraduates to conceptual mapping techniques to help enhance their diagnostic skills for technical problems. The first hour of this training was designed to introduce students to systems and diagnosing problems. This phase covered the use of the Visual Understanding Environment software to develop conceptual and process maps. Also during this phase, the subjects were given a "simple" technical problem and asked to map a plan of action. Using a similarity flooding algorithm, the students' maps were then electronically compared to an expert's map that was already encoded. The information developed by the algorithm was returned to the subjects as feedback. The second phase of the program included two technical problems developed in collaboration with industrial partners. The first problem involved an electrical grid distribution system, and the second problem focused on a malfunctioning heat exchanger system. In both cases, the subjects were provided with a description of the system and tables containing operational information. From the information presented, the subjects were asked to analyze the system and develop a process map for addressing the apparent malfunction.

The computer program was pilot-tested after completion of the first hour, after completion of the electrical grid problem, and after completion of the full training program. During the quasi-experimental phase, the subjects were asked to complete a satisfaction survey of the finished product and the overall experience. The quasi-experiment involved subjects from five universities and six majors in engineering or technology. The subjects were provided the program and all necessary software on a memory stick and typically completed the training on a laptop.

In short, the subjects during pilot testing and during experimentation found the training to be interesting ($\overline{X}$ = 3.09 on a 4-point scale) and useful ($\overline{X}$ = 3.22 on a 4-point scale). However, on average, the subjects' level of performance was much lower than expected. It was clear that about 20% of the subjects clearly understood and found the mapping technique and the feedback provided to help them improve their diagnostic skills. In general, this was not the case. That is, performance on the two main tasks was low and remained low, regardless of the type of feedback given.

There were several indications that provide some explanation (i.e., limitations of the work to date). Qualitatively, all of the staff noted that during testing, the majority of the subjects (a) did not have enough time to complete both of the major problem-solving tasks and (b) were treating the exercise as any other academic exercise. A good number of the subjects did nothing more than complete a single map for the problem and simply resubmitted it after reading the feedback.

The data, feedback from the subjects, and researcher observations revealed that the electric grid problem was difficult for students to process. In other words, the heat exchanger problem was much more compatible with the simulation capabilities of the training program. Students tended to get lost in the screens provided as a static simulation of the electric grid.

Finally, it was clear that at least 2 hours were needed to complete the training as designed. In most cases, the exercise was fitted into a regular class period (75–90 minutes), typically without the professor in attendance. For most, it was not enough time to complete the training and the two problems.

A major contribution of this work was the development of automatic student feedback by programming the software using a similarity flooding algorithm (Melnik, Garcia-Molina, & Rahm, 2002). This algorithm provides a means of comparing two graphic items such as conceptual maps. The project team modified the original algorithm to include an automatic thesaurus for synonyms, the use of relative similarity versus full similarity, weighting the nodes, and setting threshold values. Each modification significantly improved the algorithm's accuracy, so that it was possible to compare various expert maps with themselves and get a 100% matching indication. The team validated the algorithm using multiple tests (see Shahhosseini, Ye, Maughan, & Foster, 2014, for a complete report of this work).

Technology and engineering educators at all levels are seeking additional ways to help students improve their cognitive and metacognitive reasoning skills. This project was an attempt to determine the extent to which a self-paced, computer-based program would help novice troubleshooters (i.e., students) learn important principles about mapping and diagnostics. The students found the training interesting and useful, but additional work is needed to ensure that the instruction is taken seriously by students. Further, the researchers will work to expand the work to all stages in the process from problem identification to solution and follow-up assessment.

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# Use of Dynamic Visualizations for Engineering Technology, Industrial Technology, and Science Education Students: Implications on Ability to Correctly Create a Sectional View Sketch

**Abstract**

Spatial abilities, specifically visualization, play a significant role in the achievement in a wide array of professions including, but not limited to, engineering, technical, mathematical, and scientific professions. However, there is little correlation between the advantages of spatial ability as measured through the creation of a sectional-view sketch between engineering technology, industrial technology, and science education students.

A causal-comparative study was selected as a means to perform the comparative analysis of spatial visualization ability. This study was done to determine the existence of statistically significant difference between engineering technology, industrial technology, and science education students' ability to correctly create a sectional-view sketch of the presented object. No difference was found among the sketching abilities of students who had an engineering technology, industrial technology, or science education background. The results of the study have revealed some interesting results.

***Keywords***: dynamic visualizations; engineering technology; science education; spatial ability; spatial visualization; technology education.

A substantial amount of research has already been published on visualizations and the implications on spatial abilities. Spatial reasoning allows people to use the concepts of shape, features, and relationships in both concrete and abstract ways to make and use things in the world, to navigate, and to communicate (Cohen, Hegarty, Keehner & Montello, 2003; Newcombe & Huttenlocher, 2000; Turos & Ervin, 2000). Over the last decade, lengthy debates have occurred regarding the opportunities for using animation in learning and instruction. One of the main reasons for this emphasis is recognizing the importance of these abilities in fields such as the natural sciences, geometry,

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engineering, and architecture (McGee, 1979). Multiple scientific works reference the demand for good spatial abilities in engineering, architecture, and almost every science career (Martín-Gutiérrez, Gil, Contero, & Saorín, 2013). Research suggests that spatial abilities are fundamental, not only in engineering and technical fields but in an estimated 80% of jobs overall. This includes but is not limited to those in medical professions, pilots, mechanics, builders, and trades people (Bannatyne, 2003). Educators dispute whether spatial abilities can improve performance in science and math even though science and other subjects depend on spatial thinking as a fundamental skill for achievement (LeClair, 2003; Schultz, Huebner, Main, & Porhownik, 2003).

Improving spatial abilities has been shown to also improve academic achievements in mathematics and science (Keller, Washburn-Moses, & Hart, 2002; Mohler, 2001; Olkun, 2003; Robichaux, 2003; Shea, Lubinski, & Benbow, 1992). Research has shown that spatial ability is significantly correlated with achievement or retention in chemistry (Coleman & Gotch, 1998), physics, (Pallrand & Seeber, 1984), and the life sciences (Lord, 1990). In addition to the sciences, a strong correlation has also been observed between spatial and mathematical ability, and some indicators suggest that spatial ability is important for achievement in science and problem solving (Grandin, Peterson, & Shaw, 1998; Keller, Wasburn-Moses, & Hart, 2002).

However, there is little correlation between advantages of spatial ability as measured through the creation of a sectional-view sketch between engineering technology, industrial technology, and science education students.

For this study, the following was the primary research question:

- Is there a difference between engineering technology, industrial technology, and science education students' ability to correctly create a sectional-view sketch of the presented object?

The following hypotheses will be analyzed in an attempt to find a solution to the research question:

- $H_0$: There is no difference between engineering technology, industrial technology, and science education students' ability to correctly create a sectional-view sketch of the presented object.

- $H_A$: There is an identifiable difference between engineering technology, industrial technology, and science education students' ability to correctly create a sectional-view sketch of the presented object.

## Review of Literature

### Spatial Ability

Spatial ability is the ability to form and retain mental representations of a given stimulus (Carroll, 1993; Höffler, 2010). "Spatial vision, or acquisition of a developed sense of spatial reasoning, is clearly seen as the most [fundamental and] rewarding part of engineering graphics instruction" (Contero, Naya, Company, & Saorín, 2006, p. 472). Spatial abilities and rotation abilities are essential components for success in technical and engineering professions, as well as science, mathematics, and medical professions. Spatial ability is known as the act of "searching the visual field, apprehending the forms, shapes, and positions of objects as visually perceived, forming mental representations of those forms, shapes, and positions, and manipulating such representations 'mentally'" (Carroll, 1993, p. 304). A learner's spatial skills are a significant predictor for success in manipulating objects and interacting with computer-aided design (Norman, 1994). In recognizing the importance of spatial abilities for engineering and technology fields and the instructional tools used, it is also important that students with poor spatial skills improve through appropriate instructional techniques (Rafaelli, Sorby, & Hungwe, 2006). Research by Sorby (2012) suggests that "students who have the opportunity to improve their spatial visualization skills demonstrate greater self-efficacy, improved math and science grades and are more likely to persist in engineering" (p. 1).

### Spatial Ability Used in Engineering and Technology Education

Spatial abilities, specifically visualization, play a significant role in the achievement in a wide array of professions including but not limited to engineering, technical, mathematical, and scientific professions. In engineering education, spatial ability has been recognized as having a positive correlation with learning achievements and with retention (Mayer & Sims, 1994; Mayer, Mautone, & Prothero, 2002). The use of physical object manipulations, freehand sketching on paper, and computer-aided sketching can improve the spatial ability of freshmen engineering students (Martín-Gutiérrez et al., 2010). Spatial ability in engineering courses has also engaged the use of descriptive geometry, orthographic views, and three-dimensional modeling as a means to improve learners' spatial abilities (Martín-Gutiérrez et al., 2013). The lack of a learner's spatial abilities has prompted some educators to create coursework in the engineering curriculum to aid learners who have demonstrated a weakness in spatial ability (Rafaelli et al., 2006). Research by Rafaelli et al. (2006) evaluated the content of a course with middle and high school students. The target audience for this study was K-12 educators, specifically focusing on eight grade students. Rafaelli et al. (2006) found that in the Michigan Educational Assessment Program (MEAP), students in math showed results a 100% pass rate and science students with an 88% pass rate. Pre- and post-testing was performed using a modification of the Purdue Spatial Visualization Test: Rotations

(PSVT:R) to measure improvements in spatial skills. Results from this study revealed that materials used for Michigan Tech's first-year engineering students are effective with a younger population.

A study by Basham and Kotrlik (2008) focused on a randomly selected ninth grade Technology Discovery population in Mississippi to investigate if instructional methods in 3-dimensional CADD software had an impact on spatial ability development. Using the Purdue Visualization of Rotations Test (PVRT; Bodner & Guay, 1997), Basham and Kotrlik collected student characteristics in gender, ethnicity, co-registration in art, and co-registration in geometry. Treatments consisted of various instructional methods where pretest scores, gender, ethnicity, co-registration in art, and co-registration in geometry were controlled. A quasi-experimental design was used where teachers used *Pro/Desktop®2 3-D CADD software.* Experimental treatments included *Teacher and Module, Module Only, Existing Material,* and *No CADD Instruction* (Control). An ANCOVA was used initially to test for interaction effects where the variable posttest and pretest were not significant. An ANCOVA was conducted for differences between student achievements among the instructional methods. Using a Levene's Test ($F_{(3, 460)} = .71; p = .548$) revealed equal variance across treatment groups. A lack of fit test revealed that effects were most likely linear ($F_{(88, 368)} = 1.25$; $p = .086$). There was a significant difference identified between posttest scores and teaching methods ($F_{(3, 459)} = 6.6, p < .001$, partial $eta^2 = .04$), revealing a "moderate relationship" (p. 39).

The results of Basham and Kotrlik's (2008) study indicated that there is a difference in spatial ability based on the instructional method using 3-D CADD modeling software. The *Teacher and Module* group showed a statistically significant difference from the *Existing Material* and *Module Only* groups. There was no difference in the *Module Only* group, the *Existing Materials* group, and the control group, *No CADD Instruction*. Results indicated that the method of instruction as a teacher-centered approach might have been the reason for those showing little to no gain. Basham and Kotrlik suggested a connection between this and constructivist theory, which suggests that a learner-centered approach is more effective in mathematics and other similar subjects.

Basham and Kotrlik (2008) argued that based on the findings, continued research is vital to the area of spatial ability achievement. They proposed replicating the study in other states as well as continuing the research of examining spatial ability through 3-D modeling software. This area of research could be the most "important contribution" that technology education can offer students (p. 44).

**Spatial Ability Used in Science Education**

Spatial ability and reasoning are highly valued in the teaching, learning, and practicing of science. Throughout the history of science, there are enough examples of scientists generating and using both physical and mental models to consider the practice a hallmark of the domain (Kuhn, 1996; McComas, 1998). Even entire fields of science are dedicated to collecting, analyzing, and explaining spatial data, as can be seen with the example of geoinformatics and many fields within the geosciences. Generating, rotating, and transforming mental images have historically been done by practicing scientists in order to better understand and explain natural phenomena (Lerner & Overton, 2010). This applies not only to the macro world but also the micro. For example, to date, no one has ever literally seen an atom, but pictures (i.e., models) abound. These mental models shape the questions asked and the assertions made. Given this, the science education community recognizes the importance of spatial ability in the practice of science (NGSS Lead States, 2013). Because best practice science education involves actively engaging students in developing and conducting authentic scientific inquiries (Cothron, Giese, & Rezba, 2006; Settlage & Southerland, 2007), it stands to reason that such authentic work would include the application of spatial abilities. Furthermore, the science education community recognizes that these abilities, like any other, need attention and support in order to reach their full potential (Wesson, 2011). Understanding which spatial abilities are most important to develop for particular content, and how to best support that development, continues to be an area in need of further research within science education (Ainsworth, 1999; Zhou, 2010; Duffy, 2012).

**Visualization**

Although research suggests "that spatial visualization ability can be improved through instructional methods . . . there has been no clear consensus on what combination and duration of instructional methods is most beneficial for improving spatial visualization ability" (Ferguson, Ball, McDaniel & Anderson, 2008, p. 2). To shift from a teacher-centered to a student-centered education paradigm model, there must be a critical analysis of the varying engineering courses and their inclusion in the curriculum (Contero et al., 2006). In particular, Contero, Naya, Company, and Saorín (2006) argue that "teachers of 'engineering graphics' should put the emphasis in spatial reasoning, since we do consider it to be a core competence for future engineers [as well as other technical fields]" (p. 471).

In a study conducted by Branoff and Dobelis (2012), the topic of whether or not students could still read and interpret engineering drawings was researched. They looked at whether the ability to read these drawings related to spatial visualization ability. Branoff and Dobelis discovered that a relationship does exist between reading engineering drawings and spatial visualization aptitude. Researchers in engineering education, the U.S. Department of Labor, and other major industry agents have called for the enhancement of spatial visualization ability in engineering and technology students (Ferguson et al., 2008). Research has also suggested positive correlations between visualization ability and the retention and achievement of a degree in engineering and technology students (Brus, Zhoa, & Jessop, 2004; Sorby, 2001). However, few research studies have explored the effectiveness of dynamic representations and its correlation to a learner's spatial ability (Froese, Tory, Evans & Shirkhande, 2013, Höffler & Leutner, 2011).

**Dynamic Visualizations for Different Disciplines**

Wu and Shah (2004) suggested that dynamic visualizations and 3-D animations offer an environment that supports a learner's inadequate mental model. While, some studies have not confirmed that dynamic visualizations enhance a learner's spatial ability, some research suggests that dynamic visualizations do enhance the learning process for learners with high spatial ability (Huk, 2006; Lewalter, 2003). In addition, some research proposes that dynamic visualizations may improve spatial ability in learners with low spatial ability, and may in fact have a *"compensating effect"* for the low spatial ability learners (Hegarty & Kriz, 2008; Höffler, 2010; Huk, 2006; Mayer & Sims, 1994). In short, research has failed to provide definitive findings reinforcing spatial ability as an enhancer for learners with low spatial ability (Hegarty & Kriz, 2008; Höffler, 2010; Huk, 2006; Mayer & Sims, 1994). Hegarty and Kriz (2008) contended that dynamic visualizations act as a "cognitive prosthetic" for learners possessing low spatial ability.

## Methodology

A causal-comparative study was selected as a means to perform the comparative analysis of spatial visualization ability during the fall of 2014. The study was conducted in an engineering graphics course, Computer Aided Drafting was required for engineering technology and industrial technology students. Three independent groups participated in this study: group one consisted of engineering technology students, group two consisted of industrial technology students, and group three consisted of science education students. The participants from the study are shown in Figure 1. Students from each discipline were placed into 3 individual groups. Using a convenience sample, there was a near equal distribution of the participants between the three groups.

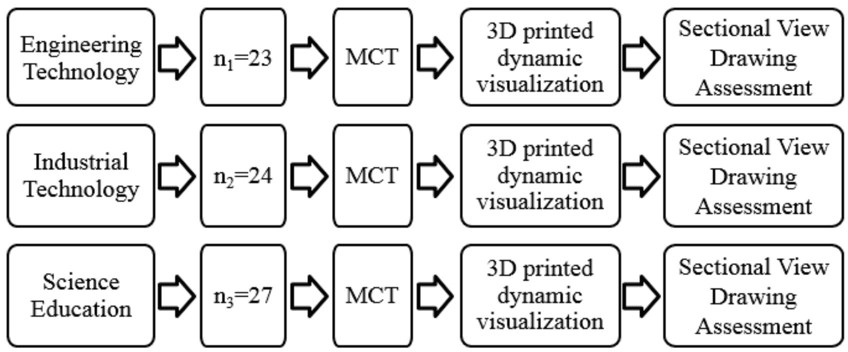


***Figure 1.*** Research design methodology.

The engineering graphics course emphasized hands-on practice using 3D AutoCAD software in the computer lab along with the various methods of editing, manipulation, visualization, and presentation of technical drawings. In addition, the course included the basic principles of engineering drawing or hand sketching, dimensions, and tolerance principles. The science course emphasized problem-based learning and hands-on practice using scientific modeling and simulation software along with the various methods of editing, manipulation, visualization, and presentation of scientific drawings.

The students attending the courses during the fall semester of 2014 were divided into three groups. The three groups ($n_1 = 23$, $n_2 = 24$, and $n_3 = 27$, with an overall population of $N = 74$) were presented with the same visual representation of an object (visualization) and were asked to create a sectional-view drawing. All groups received the same type of visualization (Dynamic 3D printed octahedron). This visualization was suggested as one that supports additional enhancement of spatial skills (between 3D Static, 3D PC Dynamic, and 3D Printed Dynamic) for individuals with higher spatial ability, such as engineering students (Katsioloudis, Jovanovic, & Jones, 2014).

All groups were asked to complete the Mental Cutting Test (MCT; College Entrance Examination Board [CEEB], 1939) 2 days prior to the completion of the sectional-view drawing in order to identify the level of visual ability and show equality between the three groups. According to Németh and Hoffman (2006), the MCT has been widely used in all age groups, making it a good choice for a well-rounded visual ability test. The Standard MCT consists of 25 problems. The Mental Cutting Test is a subset of the CEEB Special Aptitude Test in Spatial Relations, and "has also been used by Suzuki et al. [Suzuki, Wakita, & Nagano (1990)] to measure spatial abilities in relation to graphics curricula" (Tsutsumi, 2004). As part of the MCT, subjects were given a perspective drawing of a test solid that was to be cut with a hypothetical cutting plane. Subjects were then asked to choose one correct cross section from among five alternatives. There were two categories of problems in the test (Tsutsumi, 2004). Those of the first category are called *pattern recognition problems*, in which the correct answer is determined by identifying only the pattern of the section. The others are called *quantity problems*, or *dimension specification problems*, in which the correct answer is determined by identifying not only the correct pattern but also the quantity in the section (e.g., the length of the edges or the angles between the edges; Tsutsumi, 2004).

Upon completion of the MCT, the instructor of the course, who was the same for all three groups, placed the Dynamic 3D printed visualization in a central location in the classroom and then asked the students to create a sectional-view drawing of the octahedron (see Figure 2). This process took into consideration the fact that a learner's visualization ability and level of proficiency can easily be determined through sketching and drawing techniques (Contero et al., 2006; Mohler, 1997). All three groups had the privilege of close observation in addition to the ability of changing the view through the rotation of the visualization by using motor attached to the gamble.

The engineering drawing used in this research was a sectional view of the octahedron (see Figure 3). Sectional views are very useful engineering graphics tools, especially for parts that have complex interior geometry, because the sections are used to clarify the interior construction of a part that cannot be clearly described by hidden lines in exterior views (Plantenberg, 2013). By taking an imaginary cut through the object and removing a portion, the inside features could be seen more clearly. Students had to mentally discard the unwanted portion of the part and draw the remaining part. The rubric used included the following parts: (1) use of section view labels, (2) use of correct hatching style for cut materials, (3) accurate indication of cutting plane, (4) appropriate use of cutting plane lines, and (5) appropriate drawing of omitted hidden features. The maximum score for the drawing was 6 points.

**Limitations**

It is important to note that several factors might threaten the internal and external validity of this study. Results could be affected by the convenience sample, the potential bias of the instructor (who was also the researcher), the reliability of the MCT, the lack of controlled conditions that define the comparison groups, and the preexisting knowledge and skills of groups related to sketching skills, cross-sectional drawings, and 2D drawing principles.

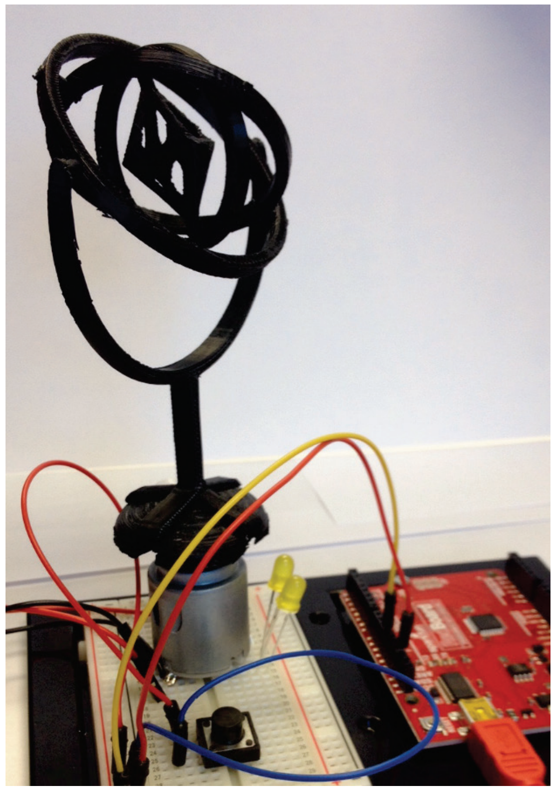

***Figure 2.*** Octahedron 3D printed solid dynamic visualization.

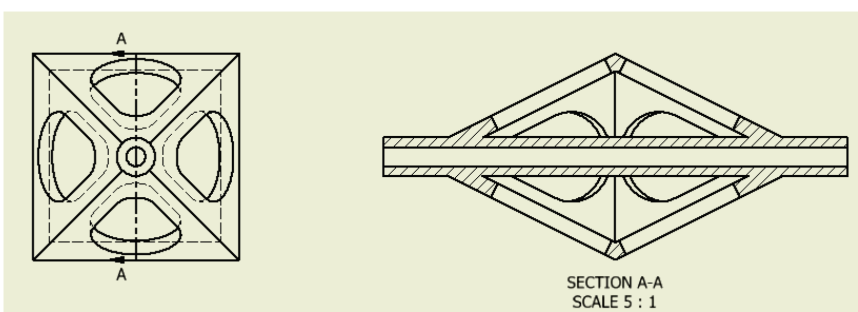


***Figure 3.*** Sectional views of octahedron.

## Data Analysis

### Analysis of MCT Scores

The first phase of data collection involved the completion of the MCT instrument prior to the treatment to show equality of spatial ability between the three different groups. The researchers graded the MCT instrument, as described in the guidelines of the MCT creators (CEEB, 1939). A standard paper-and-pencil MCT was conducted in which the subjects were instructed to draw intersecting lines on the surface of a test solid with a green pencil before selecting alternatives. The maximum score that could be received on the MCT was 25. As shown in Table 1, $n_1$ had a mean of 12.26, $n_2$ had a mean of 13.54, and $n_3$ had a mean of 12.78. There were no significant differences between the spatial abilities of the three groups, as measured by the MCT instrument.

**Table 1**
*MCT Descriptive Results*

| | | | | | 95% Confidence Interval for Mean | |
|---|---|---|---|---|---|---|
| **Discipline** | ***N*** | **Mean** | ***SD*** | **Std. Error** | **Lower Bound** | **Upper Bound** |
| Engineering Technology | 23 | 12.26 | 4.014 | 0.837 | 10.53 | 14.00 |
| Industrial Technology | 24 | 13.54 | 4.472 | 0.913 | 11.65 | 15.43 |
| Science Education | 27 | 12.78 | 4.200 | 0.808 | 11.12 | 14.44 |
| Total | 74 | 12.86 | 4.208 | 0.489 | 11.89 | 13.84 |

**Analysis of Drawing**

The second phase of data collection involved the creation of a sectional-view drawing. As shown in Table 2, the science student group ($n$ = 27) had a mean observation score of 4.52. The engineering technology group ($n$ = 23) and the industrial technology group ($n$ = 24) had higher scores of 4.63 and 4.70, respectively. The data was entered into a statistical software package, SPSS, and was coded to reflect the three groups. This data was then evaluated for normality of distribution and determined to be in violation.

Due to the relatively low numbers of the participants and the fact that we did not have random samples, a non-parametric Kruskal-Wallis test was run to compare the mean scores for significant differences, as it relates to special skills among the three groups. A Kruskal-Wallis test was run to compare the mean scores for significant differences among the three groups. The result of the Kruskal-Wallis test, as shown in Table 3, was not significant ($X^2 = 1.698$, $p < 0.428$).

**Table 2**
*Sectional-View Drawing Descriptive Results*

| Disciplines | *N* | Mean | *SD* | Std. Error | 95% Confidence Interval for Lower Bound | 95% Confidence Interval for Upper Bound |
|---|---|---|---|---|---|---|
| Engineering Technology | 23 | 4.63 | 1.452 | .303 | 4.00 | 23 |
| Industrial Technology | 24 | 4.70 | .704 | .144 | 4.41 | 24 |
| Science Education | 27 | 4.52 | .815 | .157 | 4.20 | 27 |
| Total | 74 | 4.61 | 1.017 | .118 | 4.38 | 74 |

**Table 3**
*Sectional-View Kruskal-Wallis H Test Analysis*

| Discipline | *N* | *DF* | Mean Rank | $X^2$ | *P*-value |
|---|---|---|---|---|---|
| Engineering Technology | 23 | 2 | 41.80 | 1.698 | .428 |
| Industrial Technology | 24 | | 37.33 | | |
| Science Education | 27 | | 33.98 | | |
| Total | 74 | | | | |

## Discussion

This study was done to determine the existence of statistically significant differences between engineering technology, industrial technology, and science education students' ability to correctly create a sectional-view sketch of the presented object. No differences were found between the sketching abilities of students who had engineering technology, industrial technology, or science education backgrounds. The results of the study have revealed some interesting results. Some of these results were consistent with previous studies and others were not, as can be seen below.

Research by Sorby (1999) placed an emphasis on sketching or hand drawing for the coursework. Two of the courses focused on computer-aided design (CAD), and the other two courses focused on sketching or had drawing. The findings indicated that sketching is the best way to develop 3-D spatial visualization skills. Pre- and post-testing in the courses that focused on sketching revealed that the gain scores on the Mental Rotation Test (MRT), the Mental Cutting Test (MCT), and the Purdue Spatial Visualization Test: Rotation (PSVT:R) were higher for all three tests than those of the CAD courses. In addition to sketching and physical models, Sorby also recommended courses be sequenced by having students work with physical models that allow them to move from concrete to semiconcrete (pictorial sketching). This sequence allows for a natural progression from concrete to abstract. Sketching and hand-held models, which students can see and touch, are especially significant in the development of 3-D spatial visualization skills in first-year engineering design courses.

In a qualitative research study by Mohler and Miller (2008), a teaching technique called *mentored sketching* was found to be a significant factor in teaching spatial visualization skills in first-year engineering courses. Student feedback regarding the use of lecture and homework sketching was favorable. Summative results indicated that this mentoring activity had a significant positive impact on student visualization and sketching skills. The study consisted of a population of approximately 950 students (annual enrollment) in a computer graphics technology course. One hour included theory lecture accompanied by a 1-hour laboratory preparation lecture and a 2-hour laboratory (CAD). Students felt that it was beneficial to see the professor doing the problem in order for them to follow along. Students also felt that it was important to have the professor's guidance through the "mental steps" of a problem (p. 24). In addition, students felt that *mentored sketching* allowed them to learn terminology as well as get an authentic experience in how to accomplish tasks.

In a study conducted by Sanger and Greenbowe (1997), the use of dynamic animations in a college chemistry class was investigated. The researchers first assessed students' conceptual understanding of salt bridges and electrochemical cells and found that many students held alternative conceptions of these topics. Computer-generated dynamic visualizations were then used as a part of the lecture to provide college general chemistry students with dynamic views of the chemical processes occurring in the salt bridge and electrolytes of an electro-chemical cell system. The dynamic computer-generated visualizations depicted current flow in the electro-chemical cell. According to Sanger and Greenbowe (1997), the percentage of students who held alternative conceptions after receiving the lecture using the dynamic computer-generated visualizations versus those who received a no animation lecture were compared. It was observed that a significantly lower percentage of students who received the visualization-enhanced lecture showed alternative conceptions than did students who had not viewed the animations. In addition, Sanger and Greenbowe (1997) supported the theory that a detailed dynamic visualization presentation provided by computer animations helped most students overcome their alternative conceptions. The researchers indicated that the dynamic visualizations helped students visualize complicated chemical reaction processes and led them to change their alternative conceptions to scientifically more acceptable conceptions (Sanger & Greenbowe, 1997).

## Conclusion and Future Plans

There is strong evidence that sketching, in particular, is a strong factor in the development of spatial visualization skills. Sorby's (1999) findings indicated that "sketching, sketching, sketching" should be favored over 3-D computer modeling as a method to build strong spatial visualization skills (p. 29). Coupled with physical models and sequencing topics, Sorby found these to be significant factors in the development of spatial visualization skills. These findings are significant to ensure students with low spatial skills can build their skills to increase retention in engineering programs, especially among women, who are typically identified as having low spatial abilities. It is, however, important to identify if specific groups, such as science, engineering, and industrial technology students, benefit from sketching at the same rate. Continued research in this area can be used to suggest changes to the curriculum.

In order to have a more thorough understanding of sketching ability and its implications for different disciplines and student learning, it is imperative to consider further research. Future plans include but are not limited to:

- Repeating the study to verify the results by using additional types of visualizations;
- Repeating the study using a different population such as mathematics and engineering education; and
- Repeating the study by adding visual cues during the display of 3D objects, including shadows, lighting, and size.

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# Engineering's Grand Challenges: Priorities and Integration Recommendations for Technology Education Curriculum Development

**Abstract**

In this study, the 14 Grand Challenges for Engineering in the 21st Century identified by the National Academy of Engineering were examined by a panel of experts in an effort to identify prospective curricular integration opportunities in the field of technology and engineering education. The study utilized a three-round modified Delphi methodology to forecast and build consensus pertaining to the beneficial role of the Grand Challenges in education and the level in which they should enter the K–12 scope and sequence. The findings of this study indicate that experts have dissimilar opinions about the role that the Grand Challenges should play in K–12 technology and engineering curricula. Most notably, there was strong agreement among participants concerning the integration of study and application associated with making solar energy economical for the masses. Educational implications of such incorporation are identified and explored.

***Keywords*****:** engineering education; curricula development; Delphi study; grand challenges; K–12 technology and engineering education curricula

Engineering and design function as core components of contemporary technology education classes, promoting and enabling within students technological literacy, college and career readiness, creativity, and a global, empirically driven perspective. Although the development of curricula pertaining to student explorations of authentic and realistic engineering design learning experiences is clearly a point of focus for K–12 and postsecondary attention, there are few fully developed programs of study.

In 2008, the National Academy of Engineering released a list of 14 challenges deemed critical to the continued advancement of civilization and human health (National Academy of Engineering [NAE], 2016). The scope of the list is broad, including topics from disciplines ranging from cyber and nuclear security to issues of sustainability and learning. The 14 Grand Challenges for Engineering in the 21st Century are listed in Table 1.

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On March 23, 2015, a letter of commitment from 122 U.S. schools of engineering was presented to President Barack Obama at the White House Science Fair pledging to train and formally recognize more than 20,000 "'Grand Challenge Engineers' over the next decade" (NAE, 2015, para. 2). In their letter of commitment, "U.S. Engineering School Deans' Response to President Obama on Educating Engineers to Meet the Grand Challenges," they state:

> We affirm the importance of such aims as a reflection of our core values, as a source of inspiration for drawing a generation to the call of improving the human condition, as a driver for our national and world economies, and as essential to U.S. and global security, sustainability, health, and joy of living in the decades ahead. We further note that achieving these Grand Challenges requires technology and engineering, but that none can be solved by engineering alone. Hence, there is a crucial need for a new educational model that builds upon essential engineering fundamentals to develop students' broader understanding of behavior, policy, entrepreneurship, and global perspective; one that kindles the passion necessary to take on challenges at humanity's grandest scale. (2015, para. 2–3)

**Table 1**
*Engineering's 14 Grand Challenges* (NAE, 2016)

| | |
|---|---|
| 1. | Make Solar Energy Economical |
| 2. | Provide Energy From Fusion |
| 3. | Develop Carbon Sequestration Methods |
| 4. | Manage the Nitrogen Cycle |
| 5. | Provide Access to Clean Water |
| 6. | Restore and Improve Urban Infrastructure |
| 7. | Advance Health Informatics |
| 8. | Engineer Better Machines |
| 9. | Reverse-Engineer the Brain |
| 10. | Prevent Nuclear Terror |
| 11. | Secure Cyberspace |
| 12. | Enhance Virtual Reality |
| 13. | Advance Personalized Learning |
| 14. | Engineer the Tools of Scientific Discovery |

In the 7 years since the NAE initially released the 14 Grand Challenges for Engineering in the 21st Century, efforts have been made toward addressing those challenges in K–12 technology and engineering curricula; however, experts working in these fields still have widely divergent views of what and how students should learn. The engineering schools' recent letter of commitment includes a list of key elements that each institution will address.

Among them are "a creative learning experience connected to the Grand Challenges such as research or design projects," "authentic experiential learning," and "entrepreneurship and innovation experience" (U.S. Engineering School Deans' Response to President Obama on Educating Engineers to Meet the Grand Challenges, 2015, para. 4). These objectives bear remarkable similarities to those found in the *Standards for Technological Literacy* (International Technology Education Association [ITEA], 2007).

In recent years, the field of technology education has strategically aligned initiatives and efforts with those of engineering education. In 2010, the International Technology Education Association (ITEA) fundamentally embraced engineering, becoming the International Technology and Engineering Educators Association (ITEEA), representing a curricular shift toward the active and holistic integration of STEM's *T* and *E*. Alongside this shift came ITEEA's support of Engineering byDesign (EbD™), a "standards-based national model for Grades K-12 that delivers technological literacy in a STEM context" (International Technology and Engineering Educators Association [ITEEA], 2016, para. 1).

Since 2003, ITEEA's curricular framework has been defined by the *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2007). This document identifies 20 standards outlining "what students should know and understand about technology, and what they should be able to do. . . . in order to be technologically literate" (p. 14). "The organization stated that the content contained within the STL standards was the foundation for students to develop 21st Century STEM literacy—the very core of abilities needed for students to become advanced problem solvers, innovators, technologists, engineers, and knowledgeable citizens" (Asunda, 2012, p. 50). Contention exists, however, as to whether this is sufficient. Gattie and Wicklein (2007) proposed "adjusting the focus of Technology Education to a defined emphasis on engineering design and the general process by which technology is developed" (p. 6). Rose (2010) noted the direct relationship between human technological innovation and the origins of many challenges that today's engineers face, giving particular attention to human threats to ecosystems and public health.

In addition to EbD™, at least two large-scale instructional materials providers have begun to offer pre-engineering content at the K–12 level: Engineering is Elementary® (EiE®), a product of the National Center for Technological Literacy at the Museum of Science, Boston, for Grades 1 through 8, and Project Lead the Way (PLTW), a nonprofit organization started in 1986 by a high school pre-engineering teacher and developed with support from the Charitable Leadership Foundation (Project Lead the Way [PLTW], 2014). The EiE® website states that they address "America's pressing need for effective STEM education in three ways: curriculum development and dissemination, professional development (PD), and educational research" (Engineering is

Elementary [EiE], 2016a, para. 2). Similarly, PLTW claims to have "grown to become the nation's leading provider of science, technology, engineering, and mathematics (STEM) programs for students in grades K–12" by preparing "students to be the next generation of problem solvers, critical thinkers, and innovators for the global economy" (2014, para. 1).

"More than 6,500 schools in all 50 states and the District of Columbia offer PLTW courses to their students" (PLTW, 2014, para. 4). Although PLTW's program offerings in engineering, biomedical science, and computer science offer potential learning contexts for alignment with the Grand Challenges, documentation of programmatic alignment is unavailable at present.
EiE® similarly offers potential learning contexts for alignment with the Grand Challenges, and EiE® curriculum units such as "To Get to the Other Side: Designing Bridges" and Now "You're Cooking: Designing Solar Ovens" provide curricular entry points to the basic concepts underlying the Grand Challenges (EiE, 2016b). Although EiE® has published alignment guides demonstrating standards alignment with the *Standards for Technological Literacy*, *Next Generation Science Standards*, Georgia Performance Standards for K–5 Science, and Common Core State Standards, no such guide is available for alignment with the Grand Challenges at present.

Engineering by Design (EbD) is offered to K–12 students in more than 20 states and Engineering is Elementary (EiE) is a Grade 1–8 curriculum that is offered in schools in all 50 states and the District of Columbia. EbD and ITEEA published a matrix (ITEEA, 2012) of course alignment with the Grand Challenges, including a scaled indicator of the level of detailed content integration and assessment ranging from 1 (*Topics and lessons refer to previous knowledge*) to 4 (*Content is directly integrated into lessons in detail and assessed*).

Examination of the matrix (ITEEA, 2012) reveals room for additional curriculum development designed to specifically address the content of the Grand Challenges. The number of Grand Challenges referenced at any level ranges from one to eight across a semester. Of the 15 EbD courses mapped on the matrix, the mean number of Grand Challenges referenced at any level is 5.07. Although *Restore Urban Infrastructure* is reported to be aligned with 11 EbD courses at either the 3 or 4 level, *Advance Personalized Learning* is addressed only in a single EbD course, Foundations of Technology 3. At present, documentation more extensively reporting on the nature of EbD course alignment with the Grand Challenges has not been published.

In recent years, supplementary teaching and learning materials have been published, some at no cost, for teachers who wish to address the Grand Challenges at some level alongside current curricula. The NAE Grand Challenge K12 Partners Program (2016) outlines the "5-Part Make It Happen Plans," structured on the steps: "Learn It," "Do It," "Share It," "Create It," and "Teach It." The Partners Program website functions as a repository for 5-part plans created by a community of stakeholders, including those interested in becoming partners. These plans offer blueprints of a sort for the development of curricula, but they are not fully developed lessons.

Further compounding the national dialogue on the direction of pre-engineering education in the United States, in spring 2013, the *Next Generation Science Standards* (NGSS) were released, stressing the *interdependence* of science, engineering, and technology and the influence of science, engineering, and technology on society and the natural world (NGSS Lead States, 2013). Although the *Framework for K–12 Science Education* document, which "provided the foundation for" the NGSS, took "a big step toward widespread inclusion of engineering at the K-12 level, this document does not articulate a complete set of core ideas in engineering appropriate for K-12 students as the 2010 NRC report recommends" (Moore et al., 2014, p. 3). Furthermore, the "limited treatment of engineering" in the NGSS (p. 3) is directly addressed in the standards document itself. Appendix I states: "It is important to point out that the NGSS do not put forward a full set of standards for engineering education, but rather include only practices and ideas about engineering design that are considered necessary for literate citizens" (NGSS Lead States, 2013, p. 104).

In spite of the availability of materials from providers such as EbD, PLTW, and EiE as well as supplementary content from providers such as the NAE Grand Challenge K12 Partners Program, there appears to be a need for the development of additional content for K–12 education that not only introduces the basic concepts underlying the Grand Challenges but also supports substantive and authentic inquiry into concepts critical to the pursuit of solutions to those challenges. The purpose of this study was to explore that need using a panel of experts selected from technology and engineering education.

## Research Questions

A study was proposed and initiated to investigate elements of the Grand Challenges that are currently deemed relevant and accessible to the field of technology and engineering education. The central goal for this study was to arrive at a concise listing of engineering's Grand Challenges that should actively be pursued in the development of curriculum materials. The following research questions guided this investigation:

1. Which of the Grand Challenges identified by the National Academy of Engineering lend themselves to curricular integration in the field of K–12 technology and engineering education?
2. Are there additional challenges that should be added to the list for purposes of curriculum development that are appropriate and beneficial to the study of technology and engineering education?

3. How important are individual challenges to the K–12 technology and engineering curriculum?
4. At what point (elementary, middle, or high school) is it appropriate to introduce each challenge to students?

## Rationale and Background

The researchers selected a modified Delphi technique for attaining consensus from experts in fields related to engineering and technology education as the most appropriate design for this study. It allows for participants to be anonymous during the process; only the researchers know who is responding, and no one individual can dominate the discussion (Wright & Geroy, 1988). A number of individuals have used or suggested the use of this method for curriculum development, including many researchers in fields related to technology and engineering education (e.g., Dalkey, 1972; Paige, Dugger, & Wolansky, 1996; Volk, 1993; Zargari, Campbell, & Savage, 1995). The conventional Delphi methodology consists of three to four rounds of instruments designed to achieve consensus among experts (Meyer & Booker, 1990). The overall procedures for conducting this type of research came from sources that recommend the use of a panel of experts to compile a list of program characteristics (e.g., Delbecq, Van de Ven, & Gustafson, 1986; Linstone & Turoff, 1975; Meyer & Booker, 1990). By adopting this method, researchers were assured that the participants in the study represented a variety of different professional backgrounds (i.e., experts) in fields related to engineering and technology education. By using email for communication and the Internet for sharing resources, the study could be completed in an economical and efficient manner (Clark & Scales, 2003).

The Delphi technique was developed by the RAND Corporation in the 1950s as a forecasting tool for the U.S. military for the purpose of soliciting reliable responses from a group of experts (Stitt-Gohdes & Crews, 2004). The method begins with an open-ended solicitation for expert opinions on a topic or problem, followed by additional rounds of inquiry in which participants are charged with rating the importance of items and fine-tuning the phrasing and substance of item content (Custer, Scarcella, & Stewart, 1999). The modified approach—specifically, the choice to begin with the NAE's list of Grand Challenges as well as an open-ended write-in option—was deemed preferable to the traditional approach because of the pre-existing support in the research literature of the value of the Grand Challenges to future technology curriculum development.

The Delphi method has a history of implementation in technology education research (Clark & Wenig, 1999; Custer, Scarcella, & Stewart, 1999; Scott, Washer, & Wright, 2006). Wicklein (1993) used a modified Delphi to "determine the present and future critical issues and problems facing the technology education profession" (p. 56). Katsioloudis (2010) used the method to identify quality visual-based learning materials [such as tables and photographs] for technology education. Clark and Wenig (1999) used the Delphi for identifying "quality indicators for technology education programs" (p. 23).

Further influencing the selection of the modified Delphi procedure for obtaining consensus from a nationally dispersed panel of experts in technology and engineering education were the numerous simultaneous influences on the trajectory of technology and engineering curriculum development described above. Stitt-Gohdes and Crews (2004) identified common reasons for choosing the Delphi over alternative methodologies:

- The problem does not lend itself to precise analytical techniques but can benefit from subjective judgments on a collective basis.
- More individuals are needed than can effectively interact in a face-to-face exchange.
- Time and cost make frequent group meetings infeasible.
- Disagreements among individuals are so severe or politically unpalatable that the communication process must be refereed and/or anonymity assured.
- The heterogeneity of the participants must be preserved to assure validity of the results, i.e., avoidance of domination by quantity or my strength of personality (Linstone & Turoff, 1975). (p. 56-57)

## Methods

Three rounds of surveys were conducted digitally using the modified Delphi technique in order to identify the Grand Challenges as well as related challenges that experts in the field believe to be valuable content for curriculum development in technology and engineering education.

### The Panel

The panel of experts ($n$ = 27) was randomly selected for participation from each of the following strata: ITEEA's published list of Distinguished Technology and Engineering Professionals (DTEs) ($n$ = 6); ITEEA's Teacher Excellence Award recipients at the elementary ($n$ = 1), middle ($n$ = 6) and high school ($n$ = 4) levels for 2009–2013; self and peer nominees from the 2013 active membership of the ITEEA Council for Supervision and Leadership ($n$ = 5); and the American Society for Engineering Education K–12 Division 2013 active membership ($n$ = 5). Participants averaged 17.43 years of professional experience in technology and engineering education. The panel consisted of 14 females and 13 males. Participants represented all regions of the United States: South ($n$ = 13), Northeast ($n$ = 7), Midwest ($n$ = 6), and West ($n$ = 1).

**Round 1**

Round 1 provided participants with a brief overview of and links for additional information about the National Academy of Engineering's Grand Challenges, ITEEA, and NGSS. In Round 1, participants were asked the following questions.

1. "Which of the Grand Challenges identified by the National Academy of Engineering lend themselves to curricular integration in the field of K–12 technology and engineering education?" The response options for this question were *keep* or *reject*.
2. "Are there additional challenges that should be added to the list for purposes of curriculum development that are appropriate and beneficial to the study of technology and engineering education?" This question allowed for write-in responses.

Descriptive statistics were used to determine the challenges that would be eliminated from further inquiry. Commonalities among written responses led to the addition of three additional challenges to be presented in Round 2. Notification of Round 1 results and a period of participant feedback led to the acceptance of the eliminations and additions prior to the release of Round 2 surveys.

**Round 2**

In Round 2, participants were asked to do the following.

1. "Rank the 13 challenges (the remaining 10 Grand Challenges, along with the three new challenges) on the importance of their role in the K–12 technology and engineering curriculum, " using both a Likert-type ranking ranging from *is not needed* to *must be included* as well as a drag-and-drop rank ordering feature; and
2. "Indicate the appropriate point (elementary, middle, or high school) at which the topic should be introduced to students," a multiple choice prompt.

Statistical analysis led to the elimination of three additional challenges from further inquiry as well as the categorization of the remaining challenges into elementary, middle, and high school groupings.

**Round 3**

A final list of challenges, including the suggested additions, was presented to participants in Round 3 for acceptance or rejection for each level (elementary, middle, and high school) and for rank ordering in terms of importance at each level.

## Findings

The first Delphi round eliminated the following Grand Challenges, which fell into the upper quartile (most often rejected), from further consideration in this study: *Provide Energy from Fusion*, *Develop Carbon Sequestration Methods*, *Manage the Nitrogen Cycle*, and *Reverse-Engineer the Brain*. Round 1 results suggested the need to identify a developmentally appropriate point of introduction to the curriculum (elementary, middle, or high school) for each challenge. Commonalities among responses to the write-in question about additional relevant challenges led to the addition of three new challenges to be presented in Round 2: *Provide Access to Adequate Nutrition*, *Develop Assistive Technologies for the Disabled*, and *Advance Nanotechnology*.

In Round 2, the Grand Challenges were ranked based on the importance of their role in the K–12 technology and engineering curriculum, ranging from "is not needed" to "must be included." *Prevent Nuclear Terror*, the single challenge receiving a mean score less than 3.0, was eliminated from further investigation. Challenges were rank ordered using the Qualtrics drag-and-drop feature, and the three challenges falling into the upper quartile (ranked as least important)—*Advance Health Informatics*, *Enhance Virtual Reality*, and *Prevent Nuclear Terror*—were eliminated from further investigation (Figure 1).[1]

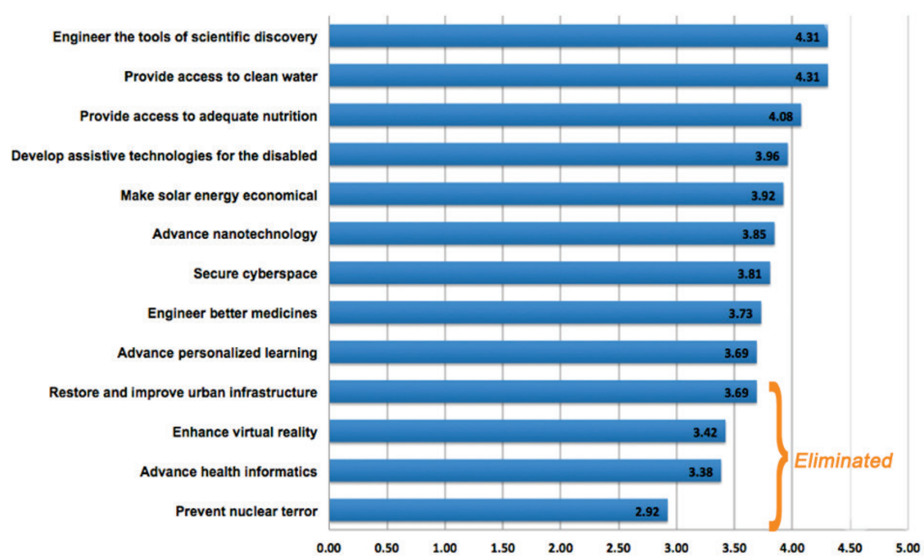


***Figure 1.*** Round 2 mean rankings of challenges: importance to K–12 technology and engineering curriculum.

[1] The Grand Challenge *Prevent Nuclear Terror* was eliminated in both question types during Round 2.

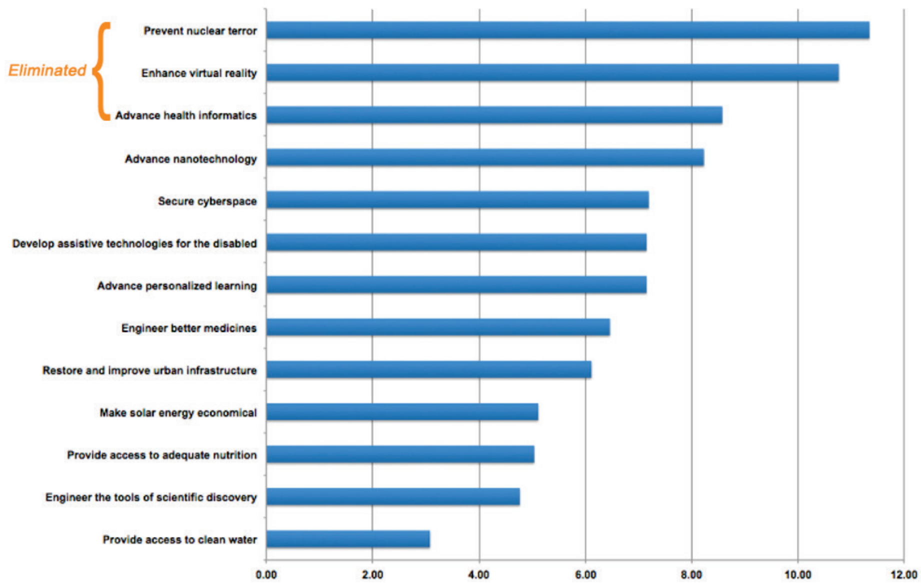


***Figure 2.*** Round 2 mean rankings of challenges: relative importance for 10 accepted challenges and three suggested challenges.

Based on Round 2 results, challenges were categorized by recommended point of introduction: elementary, middle, or high school (see Table 2). For two challenges—*Make Solar Energy Economical* and *Advance Personalized Learning*—recommendations were evenly dispersed among elementary, middle ,and high school; therefore, inquiry moved forward, keeping those challenges in all three categories.

**Table 2**
*Round 2: Points of Introduction for Retained Challenges*

| Challenge | Elementary | Middle School | High School |
|---|---|---|---|
| Provide access to clean water | 19 (73.1%) | 4 (15.4%) | 2 (7.7%) |
| Provide access to adequate nutrition | 18 (69.2%) | 8 (30.8%) | 0 (0%) |
| Develop assistive technologies for the disabled | 13 (50.0%) | 6 (23.1%) | 7 (26.9%) |
| Engineer the tools of scientific discovery | 13 (50.0%) | 9 (34.6%) | 4 (15.4%) |
| Make solar energy economical[a] | 9 (34.6%) | 9 (34.6%) | 8 (30.8%) |
| Advance personalized learning[a] | 9 (34.6%) | 9 (34.6%) | 8 (30.8%) |
| Secure cyberspace | 8 (30.8%) | 10 (38.5%) | 7 (26.9%) |
| Engineer better medicines | 4 (15.4%) | 13 (50.0%) | 9 (34.6%) |
| Restore and improve urban infrastructure | 7 (26.9%) | 11 (42.3%) | 8 (30.8%) |
| Advance nanotechnology | 1 (3.8%) | 9 (34.6%) | 16 61.5%) |

*Note.* $N$ = 26 panelists. [a] Recommendations were evenly dispersed for these two challenges, so they were kept at all three levels.

Validation of the categorization of challenges at developmental levels was pursued via a third Delphi round in which participants were asked to accept or reject each challenge at each level. Within developmental-level categories, participants were asked to rank order challenges from most to least important. Table 3 indicates rankings and acceptance rates for each developmental level.

**Table 3**
*Round 3 Results: Ranks and Acceptance Rates of Retained Challenges for Elementary, Middle, and High School Levels*

| Challenge | Rank | *M* | *SD* | IQR | *Mdn* | Acceptance Rate |
|---|---|---|---|---|---|---|
| | | | Elementary Level | | | |
| Provide Access to Clean Water | 1 | 1.4 | 0.63 | 1 | 1 | 100.00% |
| Engineer the Tools of Scientific Discovery | 2 | 3.27 | 1.58 | 2.5 | 3 | 73.00% |
| Develop Assistive Technologies for the Disabled | 3 | 3.53 | 1.46 | 2.75 | 3 | 100.00% |
| Provide Access to Adequate Nutrition | 4 | 3.47 | 1.77 | 3 | 3 | 67.00% |
| Make Solar Energy Economical | 5 | 4.07 | 1.03 | 1.75 | 4 | 73.00% |
| Advance Personalized Learning | 6 | 5.27 | 1.03 | 1.75 | 6 | 53.00% |
| | | | Middle School Level | | | |
| Restore and Improve Urban Infrastructure | 1 | 2.27 | 1.62 | 2 | 2 | 85.71% |
| Make Solar Energy Economical | 2 | 2.73 | 1.44 | 1.75 | 2 | 100% |
| Secure Cyberspace | 3 | 3.67 | 1.68 | 2.75 | 4 | 50% |
| Engineer Better Medicines | 4 | 4 | 1.65 | 1.75 | 4 | 42.86% |
| Advance Personalized Learning | 5 | 5.07 | 1.16 | 2 | 6 | 57.14% |
| | | | High School Level | | | |
| Advance Nanotechnology | 1 | 2 | 1.25 | 2 | 1 | 85.71% |
| Make Solar Energy Economical | 2 | 2.4 | 1.12 | 1.75 | 2 | 100.00% |
| Advance Personalized Learning | 3 | 3.6 | 1.35 | 2 | 3 | 71.43% |

## Discussion and Conclusions

Participants in this study indicated a familiarity with and understanding of the Grand Challenges and were provided with links to relevant sites for reading prior to participation in Round 1. However, upon examination of the write-in responses, it became evident that an opportunity exists for deeper inquiry into, and likely professional development for, methodical learning about the Grand Challenges. One commonality among participants was the belief that technology education offers a suitable environment for the study of solar energy, and that it is accessible to students at all levels, K–12. However, the Grand Challenge associated with that concept is more specific: *Make Solar Energy Economical*. Claims of curricular alignment with this challenge do not consistently address the concept of solar energy from the perspective of economics and affordability. Therefore, in order to substantively address this challenge, technology lessons must be expanded to assume a broader and more global perspective. Opportunities for integrative STEM lessons are abundant.

Security and defense themed challenges, *Prevent Nuclear Terror* and *Secure Cyberspace*, were not deemed as important to K–12 technology education as other challenges were. One explanation for that might be that as issues of cybersecurity constantly evolve. Study participants may not have a deep understanding of how these concepts manifest in and affect society or how they could be broken down into manageable, developmentally appropriate, up-to-date lessons. Alternately, participants may not perceive cybersecurity or the prevention of nuclear terror as relevant to the pursuit of technological literacy. Concerns about the introduction of frightening content at an inappropriately young age may have also driven decision making. The rationale for such choices warrants further investigation. Technology educators and curriculum developers might look to programs already in place such as CyberPatriot, the National Youth Cyber Education Program originally conceived by the Air Force Association and presented by the Northrop Grumman Foundation “to inspire students toward careers in cybersecurity or other science, technology, engineering, and mathematics (STEM) disciplines critical to our nation's future” (Air Force Association, 2015, para. 1). CyberPatriot currently serves middle school and high school students and is expanding its reach to serve elementary school children in the near future.

The challenges *Provide Energy from Fusion*, *Develop Carbon Sequestration Methods*, *Manage the Nitrogen Cycle*, and *Reverse-Engineer the Brain* were eliminated as appropriate for the technology curriculum at any level during the first round of this study. This could potentially be due to the perceived learner-level appropriateness or understanding of these challenge areas in the context of core literacies within technology and engineering education curricula. That said, *Reverse-Engineer the Brain* is reported to already be aligned with one EbD course at the 4 level, “Content is directly integrated into lessons in detail and assessed”; *Manage the Nitrogen Cycle* is aligned with three courses; *Provide Energy from Fusion* is aligned with two courses; and *Develop Carbon Sequestration Methods* is aligned with four courses (ITEEA, 2012).

Engineering design experiences, and attendant curricula for technology education, reinforce core ideas and enact a process for the attainment of set benchmarks in a meaningful societal STEM context. Given the commitment that the field of technology education has made to integrate engineering at all levels, given the NDSS' emphasis on the interdependence of science, engineering, and technology, and given the recent large-scale display of support from schools of engineering for using the Grand Challenges to guide the design of their programs, it stands to reason that the field of technology and engineering education would serve students well through significant and explicit focus on the Grand Challenges in its work toward preparing technologically literate citizens.

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# Changes in Attitudes Toward Craft and Technology During the Last 20 Years

**Abstract**

There has been technology as long as there have been human beings. We can suppose that technology was as indispensable in the past as it is now. However, nowadays, the great speed at which technological changes come and new techniques are introduced is even more evident. Technology is affecting our lives more and more. It has consequences to every human being, and we find ourselves faced with both positive and negative aspects of technology. Certainly, this has an effect on our attitudes towards technology. In this study, we tried to find out if there have been any changes in attitudes towards technology among Finnish school children during the last 20 years. The attitudes measured in 1993 were compared with the results from 2012. The number of test participants was 267 in the first measurement and 317 in the second. The age of the student respondents was 11–13 years. The measurements were done with exactly the same Likert scale attitude questionnaire in both years. Mostly positive changes were found in attitudes towards technology in girls. Unfortunately, the development was not as positive among boys. The development in attitudes can be explained by the changes in technology education curriculum. From a broader point of view, the development in attitudes can be due to the changes in society as a whole.

***Keywords:*** craft and technology; curriculum; technology education

Technology education in Finland has a long and rich history dating back to the 19th century when Uno Cygnaeus defined *sloyd* (handicraft). Since the first days of craft education, 150 years ago, students have made things using a variety of craft tools. In the beginning, work was based on copying and imitation and was mainly geared toward the development of lower level thinking skills, but craft and technology education should offer an all-around learning environment for understanding about different forms of technology and an opportunity to use the tools of modern society. As early as 1970, a committee report suggested that both technical and textile crafts should be compulsory for both boys and girls. Since then, the national curriculum has been revised several times. However, a suitable solution for the curriculum of craft education has not been found, and the interpretation and practical accomplishment of craft and technology education has faced many problems. Different solutions for the practical implementation of craft and technology education were tested in 1993, and

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students' attitudes towards technology were measured with a questionnaire consisting of 14 Likert-type statements. This article builds on that earlier study, and the results from the 1993 study were compared with a comparable sample from 2012. Measurements were made with exactly the same test instruments, and participants were selected from the same schools as the 1993 study.

The main goal of this study was to find out if fundamental changes in attitudes towards technology can be seen during the last 20 years. Furthermore, we tried to find out which elements in those attitudes were the most positive and negative. The main intention of the research was not to compare boys and girls; however, the comparison resulted in some new and interesting data. The research questions were:

1. Are there differences in students' attitudes towards technology in Finland between the years 1993 and 2012?
2. Is there a difference between boys and girls in attitudes towards technology?
3. Which elements in the attitudes were valued the most positive and the most negative?

Between the years 1993 and 2012, there have been several changes in the national curriculum concerning craft and technology education. The Framework Curriculum Guidelines (National Board of Education, 1994) for compulsory education states in its general section that the technical development of society makes it necessary for all citizens to have a new readiness to use technical adaptations and be able to exert an influence on the direction of technical development. Furthermore, students without any regard to sex must have the chance to acquaint themselves with technology and to learn to understand and avail themselves of technology. What is especially important is to take a critical look at the effects that technology has on the interaction between the man and nature, to be able to make use of the opportunities it offers and understand their consequences. The curriculum also emphasizes that extensive knowledge is necessary when participating in technology-related discussions and problem solving. Moreover, in the general part of the curriculum, it is said that the ability to use different forms of technology, especially information and communication technology (ICT), gives students the chance to use the tools of modern society and, in general, offers a versatile environment for the understanding and the development of different forms of technology.

During 2001, there was an active discussion about the role of technology education in Finnish compulsory education. Spokespersons from the industry side were active in organizing national seminars for developing technology education in Finnish schools, especially the goals and content of technology education in the curriculum. Moreover, several development projects aimed at developing the curriculum and technology education were started (Järvinen, Lindh, & Sääskilahti, 2000; Lavonen, Meisalo, Autio, & Lindh, 1998; Parikka, 1998; Santakallio, 1999).

The results obtained from the various development projects in the field of technology and from international discussion about the role of modern technology had an effect on the formulation of the goals and contents of technology education in the national curriculum framework for compulsory school (National Board of Education, 2004). Hence, the 2004 curriculum emphasized the meaning of technology from the point of view of everyday life, society, industry, and environment as well as human dependency on technology. The students should be familiar with new technology, including ICT, how it is developed, and what kind of influence it has. Students' technological skills should be developed through using and working with different tools and devices. Studying technology helps students to discuss and think about ethical, moral, and value issues related to technology. The goals mentioned in the new curriculum are compatible with the nature of literacy in technology described in the *Standards for Technological Literacy: Content for the Study of Technology* (International Technology Education Association, 2007). Although, technology education was introduced for the first time in the framework curriculum, a separate technology education subject has not been established.

Since the national curriculum's (National Board of Education, 2004) emphasis on technology, the demand for technology as a school subject has increased considerably. However, in Finland the process proceeds with great difficulty, and it may take years before technology is taught to all pupils. The curriculum states that technical craft and textile craft should be compulsory for boys and girls in Grades 3–7. However, because of practical reasons such as timetabling and the number of teachers employed in many schools, students have to select just one of the craft subjects. The main problem in Finland is that even though there is more technology-related content that our children should be familiar with, the amount of craft lessons is still the same as 20 years ago. Furthermore, because craft and technology education is nowadays divided into technologically based technical craft and artistically based textile craft, girls have more technologically based lessons than 20 years ago. Unfortunately, boys have fewer technologically based lessons than they had in 1993. We can suppose that this phenomenon has an effect on students' attitudes towards technology.

The most common definition for *attitudes* is "psychological tendencies that are expressed by evaluating a particular entity with some degree of favour or disfavour" (Eagly & Chaiken, 1993, p. 1). According to de Klerk Wolters (1989) the attitude towards technology is "a certain feeling with reference to technology, based on a certain concept of technology, and that carries with it an intention to behaviour in favour of or against technology" (p. 15).

> Dyrenfurth (1990) and Layton (1994) referred to attitudes in technology education using the concept of 'technological will'. According to these authors, technology is determined and guided by human emotions,

> motivation, values and personal qualities. Thus, the development of technology is dependent on the students' will to take part in lessons and technological decisions. (Autio, Soobik, Thorsteinsson, & Olafsson, 2015, p. 27).

Whether or not the attitude towards technology contains the cognitive dimension is often discussed. According to Ardies, De Maeyer, and van Keulen (2012), technological knowledge or "technological literacy correlates with the attitude towards technology" (p. 22).

**Methods**

The main aim of this research was to answer the first research question: Are there differences in students' attitudes towards technology in Finland between the years 1993 and 2012? In this kind of research, which is aimed at relatively large group of students, the test instrument should be easy to use and suitable for large-scale research. Likert scales are by far the most used in attitude measurements. We can assume that this is mostly due to practical reasons. The Likert scales can easily be constructed, and depending on the nature and structure of the test, they usually offer an acceptable reliability and validity. As self-report instruments, they are quite simple to use, and they are not time consuming.

Research on students' attitudes toward technology has a long history. Pupils Attitudes Toward Technology (PATT) is the first instrument specifically made for this purpose. This instrument was first used in the Netherlands. Since 1984, researchers have been using it in several different formats, and a number of different instruments have been made for measuring attitudes in the field of technology (Garmire & Pearson, 2006).

In order to evaluate students' attitudes towards technology in Finland, a questionnaire was devised that consisted of 14 statements. For each Likert-type item, there were five options, from *strongly disagree* (1) to *strongly agree* (5). The questionnaire was based on the most common PATT instrument, which was designed and validated by Raat and de Vries (1985) and van der Velde (1992). The original instrument, which consisted of 78 items, turned out to be too complicated and time consuming for 11- to 13-year-old students. Hence, for this study, a shorter version of attitude questionnaire was developed. The researcher removed many items that had small item-rest correlation (i.e., correlations between item score and total score of the rest of the scale). Finally, the questionnaire consisted of the following six factors: interest in technology, consequences of technology, difficulty of technology, role pattern, technological career, and technology as school subject.

The same problems with the original 78-item instrument were also noticed by Ardies, De Maeyer, and van Keulen (2012). They wanted to develop an instrument that was easier to use and needed less time from teachers using it in the classroom. "The idea was to investigate the possibilities of using a 'subset of scales' with a maximum [of] 5 items for each scale" (p. 24). Their instrument consists of "six subscales and 24 items of attitudes towards technology. The six items are: Career Aspirations, Interest in Technology, Tediousness of Technology, Positive Perception of Effects of Technology, Perception of Difficulty[,] and Perception of Technology as a Subject for Boys or for Boys and Girls" (p. 22). Hence, the instrument used in this research in 1993 and 2012 seems to be congruous with previous and later developed PATT instruments. From this point of view, the internal consistency of the questionnaire was relevant. According to the researcher's observations, it was easy to use and not time consuming. In addition, the students could fully concentrate on answering all of the items. Reliability of the questionnaire was 0.85 in 1993 and 0.84 in 2012.

To find out whether there were any differences between the measurements in 1993 and 2012, the researcher employed a two-tailed *t*-test with the same variance because there was no hypothesis of the development in attitudes towards technology based on the previous research. Instead, boys and girls were compared with a one-tailed *t*-test because there is plenty of research evidence available about the difference. The number of test participants was 267 in the first measurement and 317 in the second. The age of the student respondents was 11–13 years. In both samples (1993 and 2012), the schools were the same. Those schools were originally selected to ensure that schools with different curriculums as well as rural and city schools were represented.

The sample from 1993 was based on a research design in which different solutions for the practical implementation of craft and technology education were tested. At that time, only a few schools were using a curriculum in which textile and technical craft was introduced to both boys and girls. These schools were selected for the sample from 1993, and the same schools were selected in 2012. To ensure that different curriculum solutions and schools from rural and city areas were represented, some country schools were selected. These country schools used a traditional curriculum. In practice, this curriculum included traditional wood and metal work as well as engineering projects with electronics, mostly for boys, and textile education, mostly for girls. In 2012, all schools with 11-year-old students had moved to a new curriculum that provided textile and technical craft for both boys and girls. The number of research participants in technical and textile craft as well as participants in city and country schools is presented in Table 1.

**Table 1**
*Number of Participants in Technical and Textile Craft in City and Country Schools*

| | Technical | | | Textile | | | Both | | |
|---|---|---|---|---|---|---|---|---|---|
| | City | Country | Total | City | Country | Total | City | Country | Total |
| | | | | 1993 | | | | | |
| 11-year-old girls | 0 | 0 | 0 | 0 | 23 | 23 | 22 | 0 | 22 |
| 11-year-old boys | 0 | 46 | 46 | 0 | 0 | 0 | 22 | 0 | 22 |
| 13-year-old girls | 0 | 4 | 4 | 0 | 20 | 20 | 37 | 0 | 37 |
| 13-year-old boys | 9 | 48 | 57 | 1 | 0 | 1 | 35 | 0 | 35 |
| | | | | 2012 | | | | | |
| 11-year-old girls | 0 | 0 | 0 | 0 | 0 | 0 | 27 | 31 | 58 |
| 11-year-old boys | 0 | 0 | 0 | 0 | 0 | 0 | 32 | 58 | 90 |
| 13-year-old girls | 0 | 7 | 7 | 0 | 20 | 20 | 48 | 0 | 48 |
| 13-year-old boys | 0 | 26 | 26 | 0 | 1 | 1 | 67 | 0 | 67 |

## Results

In this section, the results are first presented in general, discussing the differences in attitudes towards technology between the years 1993 and 2012. Then, the results are discussed in more detail, discussing specific items of the questionnaire while also taking into account differences between 11- and 13-year-old students.

Significant differences in students' attitudes towards technology were found in Finland between 1993 and 2012. The average response in our Likert-style (1–5) questionnaire to 14 items was 2.88 among Finnish girls in 1993 and 3.24 in 2012. The development in girls' attitudes was statistically significant ($p < 0.01$). For boys, the average response was 3.54 in 1993 and 3.75 in 2012 ($p = 0.04$). Furthermore, it can be seen that for girls, the development in attitudes was positive in almost all statements and statistically significant ($p < 0.05$) in 10 out of 14 statements. For boys, statistically significant ($p < 0.05$) development was found in seven items.

The difference between boys' and girls' attitudes was not surprising because similar results have been reported during recent years in several studies

(Allsop 1986; Autio, 1997; Autio & Soobik, 2013; Autio, Thorsteinsson, & Olafsson, 2012; de Klerk Wolters, 1989; Grant & Harding, 1987; Johnson & Murphy, 1986; Streumer, 1988). The average values for each statement are listed in the Table 2 below.

**Table 2**
*Average Values for Each Statement Regarding Students' Attitudes Toward Craft and Technology*

| | 1993 | | 2012 | | *p*-value | |
|---|---|---|---|---|---|---|
| **Statement number** | **Girls** | **Boys** | **Girls** | **Boys** | **Girls** | **Boys** |
| 1. I am interested in engineering and the phenomena related to it | 2.80 | 3.98 | 3.17 | 4.21 | 0.00 | 0.04 |
| 2. I spend a lot of time with engineering-related hobby activities | 1.72 | 3.01 | 2.62 | 3.01 | 0.000 | 0.99 |
| 3. Newspapers, magazines, and articles from the field of engineering are interesting for me | 2.07 | 3.06 | 2.35 | 2.90 | 0.01 | 0.19 |
| 4. Understanding engineering-related phenomena will be beneficial in the future | 2.92 | 3.79 | 3.25 | 3.86 | 0.01 | 0.53 |
| 5. Understanding engineering-related phenomena requires a special wit | 2.93 | 3.35 | 3.26 | 3.53 | 0.01 | 0.12 |
| 6. Both boys and girls may understand engineering-related phenomena | 4.56 | 4.06 | 4.55 | 4.36 | 0.96 | 0.01 |
| 7. Mankind has rather benefited than sustained damage from the development of engineering | 3.59 | 3.81 | 3.87 | 4.21 | 0.08 | 0.01 |
| 8. In the future I would like to choose a speciality or a profession related to engineering | 1.95 | 3.09 | 2.30 | 3.23 | 0.00 | 0.25 |
| 9. My parents have a lot of engineering-related hobbies | 2.32 | 2.70 | 2.94 | 3.01 | 0.00 | 0.01 |
| 10. The atmosphere in the Technology Education / craft lessons is pleasant and inspiring | 3.03 | 3.78 | 3.50 | 4.28 | 0.00 | 0.00 |
| 11. Technology Education /craft lessons considerably contribute to the development of my manual skills | 3.58 | 4.27 | 3.69 | 4.25 | 0.57 | 0.87 |
| 12. Technology Education / craft lessons develop my logical thinking | 2.98 | 3.49 | 3.42 | 3.84 | 0.00 | 0.00 |
| 13. I have been successful in Technology Education / craft lessons | 2.89 | 3.48 | 3.35 | 3.91 | 0.00 | 0.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 14. Technology Education / craft lessons will be beneficial in the future for me | 3.00 | 3.85 | 3.14 | 3.88 | 0.31 | 0.83 |
| All 14 items | 2.88 | 3.54 | 3.24 | 3.75 | 0.00 | 0.04 |

**Differences in Students' Attitudes Toward Technology Between the Years 1993 and 2012**

Based on the average values for the 14 items on the questionnaire, the most remarkable development was found in 11-year-old girls test group for whom the average response was 2.88 in 1993 and 3.37 in 2012 ($p < 0.001$). Although the change in attitudes was also positive for 11-year-old boys, their average responses were 3.59 in 1993 and 3.78 in 2012 ($p = 0.06$). The standard deviation was the highest among 11-year-old girls in 1993 (0.75). In general, the standard deviation was higher in 1993 than in 2012. These results are presented in Table 3.

**Table 3**
*Differences in Attitudes Toward Technology in 1993 and 2012*

| | 1993 | | 2012 | | |
|---|---|---|---|---|---|
| **Group** | ***M*** | ***SD*** | ***M*** | ***SD*** | ***p*-value** |
| 11-year-old girls | 2.88 | 0.75 | 3.37 | 0.56 | $p < 0.001$ |
| 11-year-old boys | 3.59 | 0.69 | 3.78 | 0.48 | $p = 0.06$ |
| 13-year-old girls | 2.9 | 0.46 | 3.14 | 0.52 | $p = 0.003$ |
| 13-year-old boys | 3.51 | 0.69 | 3.72 | 0.56 | $p = 0.02$ |

In more detail, the most significant development was found for the statement "I spend a lot of time with engineering-related hobby activities." Girls' attitude in this area was 1.72 in 1993 and 2.62 in 2012 ($p < 0.001$). However, boys did not report more technologically related hobbies than 20 years ago, 3.01 in both 1993 and 2012. This may be due to the fact that especially girls are interested in technological everyday solutions (e.g., mobile phones, tablets) that were not in everyday use 20 years ago. Average values for that statement are presented in Figure 1.

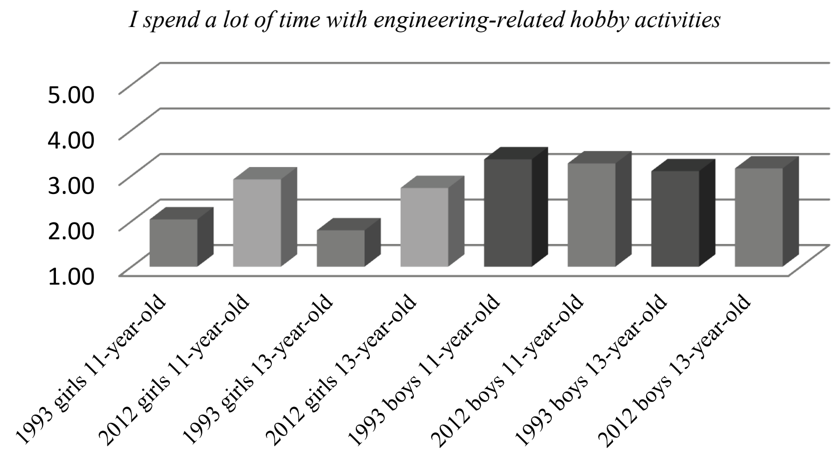


***Figure 1.*** Average values for the statement: "I spend a lot of time in engineering-related hobby activities."

The development of a technological environment is most probably seen also for the statement "My parents have a lot of engineering-related hobbies" (for girls, 2.32/2.94, and for boys, 2.70/3.01). Because parents have more technology-related hobbies, it is obvious that there are more examples from parents and role models in general. Support of students' autonomy is evident when an authority figure respects and takes the subordinate's perspective, promotes choices, and encourages decision making (Ratelle, Larose, Guay, & Senecal, 2005). Furthermore, if parents and teachers are more aware of technological phenomena, they can tell students what they are good at or not good at with more information on which to base such conclusions (Eccles, 2009).

Another very positive sign in attitudes was seen for the statement "The atmosphere in the Technology Education / craft lessons is pleasant and inspiring" (girls 3.03/3.50 and boys 3.78/4.28). It is not surprising that "both boys and girls are attracted to [craft and] technology education because they enjoy working with their hands and like the independence and chance for creativity provided by these classes" (Silverman & Pritchard, 1996, 48). It seems that several other school subjects have more motivational problems than technology education (Shernoff, Csikszentmihalyi, Schneider, & Shernoff, 2003). The development at attitudes in this study was slightly negative only in one statement "Newspapers, magazines and articles from the field of engineering are interesting for me" (boys 3.06/2.90). In practice, no difference was found in two statements: "Technology Education/craft lessons considerably contribute to the development of my manual skills" (boys 4.27/4.25) and "Both boys and girls may understand engineering-related phenomena" (girls 4.56/4.55).

**Difference Between Boys and Girls in Attitudes Towards Technology**

As mentioned earlier, several differences in attitudes were found between boys and girls. The highest statistical difference ($p < 0.001$) between boys and girls was found for the statement "I am interested in engineering and the phenomena related to it." The highest average value (4.34) was found among 11-year-old boys in 2012, followed by 13-year-old boys in 2012 (4.07) and 11-year-old boys in 1993 (4.01). The lowest average value, 2.53, was for 11-year-old girls in 1993; however, their attitudes' improved the most with a 3.43 in 2012. The difference between boys and girls interest areas can also be seen in practice, at least in Finland, because 88.2% of the boys still want to choose only technical craft studies, and the girls (62.9%) concentrate on textiles (Autio, 1997, 2013b). From the statistical point of view, this statement had the highest correlation (0.76, $p < 0.001$) to the average of other statements. In the factor analysis, this statement explained 57.7% of the total variance. Average values for the statement "I am interested in engineering and phenomena related to it" are presented in Figure 2.

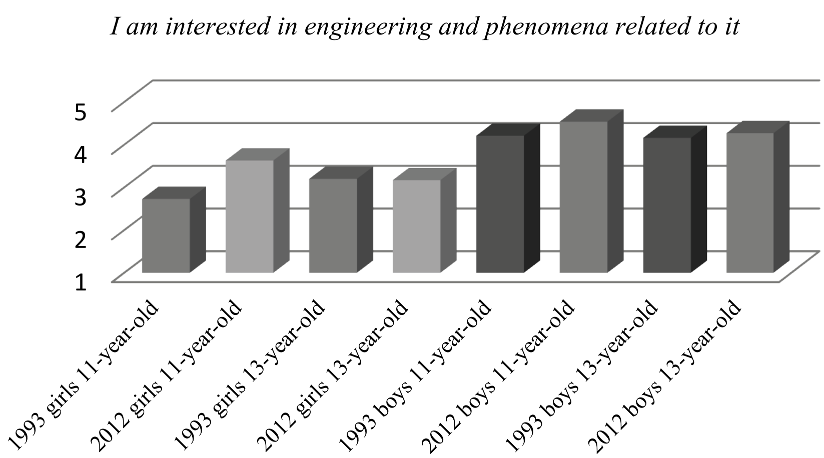


***Figure 2.*** Average values for the statement: "I am interested in engineering and phenomena related to it."

**Most positive and negative elements in attitudes towards technology**

Analyzing the results more precisely it can be seen that the highest average values were given for the statement “Both boys and girls may understand engineering-related phenomena” (girls 4.56/4.55 and boys 4.06/4.36). This is a clear sign that gender issues are important in Finnish technology education, and both boys and girls are aware of them. Average values for the statement “Both boys and girls may understand engineering-related phenomena” are presented in Figure 3.

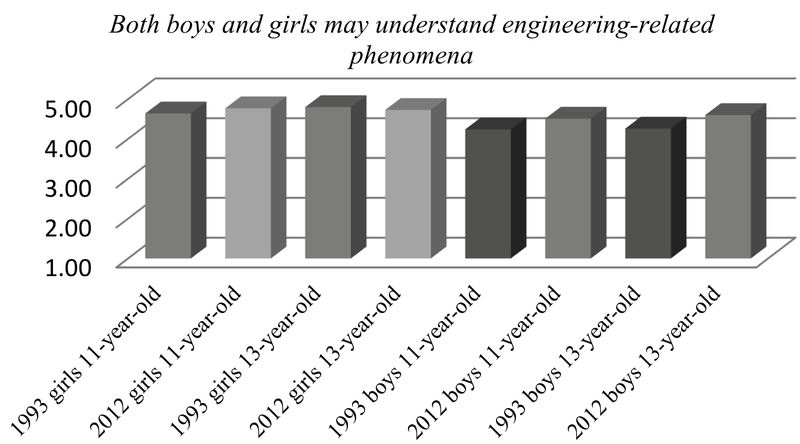


***Figure 3.*** Average values for the statement: “Both boys and girls may understand engineering-related phenomena.”

Relatively high average values were also found for the statements “Technology Education/craft lessons considerably contribute to the development of my manual skills” (boys 4.27/4.25), “The atmosphere in the Technology Education / craft lessons is pleasant and inspiring” (boys 3.78/4.28), “I am interested in engineering and the phenomena related to it” (boys 3.98/4.21), and “Mankind has rather benefited than sustained damage from the development of engineering” (boys 3.81/4.21).

The lowest average value was found for the statement “In the future I would like to choose a specialty or a profession related to engineering” (girls 1.95/2.30). Although attitudes have changed in a positive direction, it seems that the probability “of even considering these [engineering-related] occupations as appropriate is much lower for females than for males” (Eccles, 2007, p. 202; see also Autio, 2013a). Additionally, for this statement, there was still a difference when compared with boys (3.09/3.23). Furthermore, Eccles (2007) states that

> It is quite likely that males will receive more support for developing a strong interest in physical science and engineering from their parents, teachers, and peers than females. In addition, it is absolutely the case that all young people will see more examples of males engaged in these occupations than females. (p. 202)

Average values for the statement "In the future I would like to choose a specialty or a profession related to engineering" are presented in Figure 4.

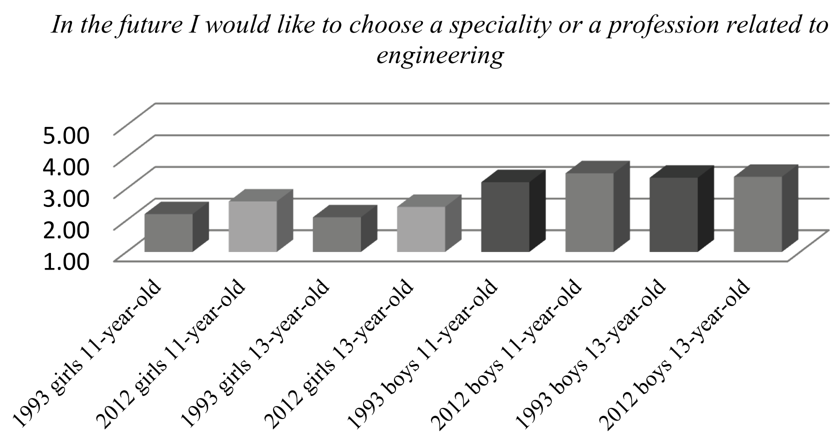


***Figure 4.*** Average values for the statement: "In the future I would like to choose a specialty or a profession related to engineering."

Another low average value compared with the other statements was found for the statements "I spend a lot of time with engineering-related hobby activities" (girls 1.72/2.62 and boys 3.01/3.01) and "Newspapers, magazines, and articles from the field of engineering are interesting for me" (girls 2.07/2.35 and boys 3.06/2.90).

## Discussion

The critical side of this research is that it is based on self-reports and measures only students' attitude, not their absolute technological will, which is shaped and guided by human emotions, motivation, values, personal qualities, and real-life choices regarding technology. In addition,

> The concept attitude is just a single one part of a larger concept, which is 'technological competence'. However, attitude is a crucial part of the competence as it has remarkable effect on [building] technological

> knowledge and technological skills in real life situations.. (Autio et al., 2015, p. 32)

Moreover, to achieve a relevant comparison, the measurements were made with the same attitude questionnaire in 1993 and in 2012. Because the questionnaire was not updated during the last 20 years, there has been some criticism, for example, that the statements should be fully neutral in terms of gender aspects. Moreover, the conceptual framework between attitudes and interest should be taken into account. These results should be observed and interpreted in the context of Finnish craft and technology education. Some criticism could be raised because the selection of the schools was made already in 1993 and the sample was discretionary rather than incidental. However, the difference between schools in Finland is very small, as reported in the 2012 PISA results (Kupari et al., 2013).

The main point of this research is that Finnish students' attitudes towards technology were definitely more positive in 2012 than in 1993. The average response in our Likert-style (1–5) questionnaire to all 14 items was 2.88 for Finnish girls in 1993 and 3.24 in 2012. The development in girls' attitudes was statistically significant ($p < 0.01$). Unfortunately, the development among boys was not as positive; the average response of boys was 3.54 in 1993 and 3.75 in 2012.

The most promising results were found for the statement "I spend a lot of time with engineering-related hobby activities" because girls seemed to have much more technology-related hobbies than 20 years ago. It can be concluded that this was because of changes in the technological environment in general as well as changes in the curriculum. There are plenty of different technological solutions (e.g., mobile phones, games consoles, tablets, interestingly themed construction kits) available for all children nowadays that did not exist 20 years ago. This will be a challenge for the curriculum development in the future. How can technology education benefit from the fact that especially girls are interested in technological everyday solutions rather than technological details, as reported in several other studies (Eccles, 2009; Mitts, 2008; Weber & Custer, 2005; Wender, 2004).

In addition, a positive phenomenon was noticed for the statement "The atmosphere in the Technology Education / craft lessons is pleasant and inspiring" because the average values were relatively high among both boys and girls. This corroborates the findings of previous studies. Students who typically enroll in technology education are attracted to the types of projects they will be engaged in (Weber & Custer, 2005).

Both boys and girls seem to strongly agree with the statement "Both boys and girls may understand engineering-related phenomena." This is probably because the Finnish curriculum has put great emphasis on gender equity since 1970. However, somewhat paradoxically, only a few girls are willing to challenge stereotypes about nontraditional careers for women, as could be concluded from responses to the statement "In the future I would like to choose a specialty or a profession related to engineering." Even though there has been much development in attitudes towards technology, only a few girls seemed to have technological hobbies or had a great interest in technological articles.

Another interesting phenomenon is that girls seem to find the atmosphere in technology education at least moderately enjoyable, and they mostly agree that technology or craft education has an effect on their manual skills. However, they do not think that technology education will beneficial for them in the future, as can be concluded from the statement "Technology Education / craft lessons will be beneficial in the future for me." Moreover, there is still a significant difference between boys and girls in attitudes towards technology in general. This gender-based segregation and falling recruitment for scientific and technological studies is a common phenomena in all the Nordic countries (Sjöberg, 2003). However, it is interesting that the phenomenon is still noticeable in Finland where gender equity has been a prime educational aim for decades.

## Conclusions

The main problem in Finland is that even though there is more technology-related content that our children should be familiar with, the amount of craft lessons is still the same as 20 years ago. Furthermore, because craft education is nowadays divided into technologically based technical craft and artistically based textile craft, girls have more technologically based lessons than 20 years ago. Unfortunately, boys have much fewer technologically based lessons than they had in 1993. This may be seen in the results of this study as well.

Furthermore, Finnish students' attitudes towards technology are still at a significantly lower level than in Iceland and Estonia, which have relatively different curriculum in technology education (Autio & Soobik, 2012; Autio, Thorsteinsson, & Olafsson, 2012). Moreover, 88.2% of boys still want to choose only technical craft studies, and 62.9% of girls want to choose textile craft studies (Autio, 1997, 2013b). It indicates that the curriculum, which includes two different compulsory craft subjects (technical craft and textile craft), is a suitable setup, especially for Finnish girls. Hence, it can be concluded that an ideal solution in technology education has not been found. Furthermore, the justifiable question of other points of view in equality arises: are all students without any regard to sex given an opportunity to choose study groups based on their wishes and interests, which allows them to study in greater detail the subject that they are really interested in?

Several development projects are made to promote interest in technology. According to Mammes (2004) attitudes towards technology can be significantly improved by developing special courses just for girls. "Because technology education has traditionally been such a male-oriented subject, teachers need to be aware of the differing interests of girls and consider ways of making the environment and the subject attractive to them "(Silverman & Pritchard, 1996, p. 50). Furthermore, some researchers believe that "in school situations where only females are present, the gender-related segment becomes relatively inactive, and interests could develop independently. So if girls' interests should be turned to technology (against the gender stereotype), gender separate teaching is advisable" (Hannover, 1998; Hannover & Kessels, 2002; as cited in Wender, 2004, p. 46–47). In addition, several preconditions are recommended such as support from female role models and an atmosphere that encourages confidence and inclusion of technical problems in everyday situations that have a relationship with people (Häussler & Hoffmann, 1998). However, the problem of the inequality in the field of technology seems to be far more complicated than we used to think. It is not just technology education that is responsible for solving such a complex problem but society as a whole.

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# *Book Review*

**Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads**

National Academy of Sciences, National Academy of Engineering, & Institute of Medicine. (2011). *Expanding underrepresented minority participation: America's science and technology talent at the crossroads*. Washington, DC: National Academies Press. doi:10.17226/12984 ISBN: 978-0-309-15968-5, $40 (Paperback), 286 pages.

Over the last few years, the national push to have a properly trained science, technology, engineering, and mathematics (STEM) workforce has been at the forefront of the nation's top priority list. In a recent report to the President, *Engage to Excel: Producing One-Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics*, President Barak Obama's Council of Advisors on Science and Technology (2012) offered five recommendations to address this priority. Recommendation 3 was to "launch a national experiment in postsecondary mathematics education to address the mathematics-preparation gap" (p. 27); Recommendation 4 was to "encourage partnerships among stakeholders to diversify pathways to STEM careers" (p. 30). These initiatives mirror *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads*, which aimed to address the need to strengthen the U.S. STEM workforce with diversity and the inclusion of underrepresentation minorities at the forefront of its mission.

**Overview and Motivation**

As a successor to *Rising Above the Gathering Storm* (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2007), a report that generated national attention to America's competiveness, the importance of research and innovation, and creating a strong STEM workforce, *Expanding Underrepresented Minority Participation* extended its reach to include underrepresented minorities as a means to create an inclusive and diverse science and engineering (S&E) workforce. This idea was initiated by four U.S. senators who requested a study of underrepresented minorities, "citing the need to develop a strong and diverse S&E workforce" (p. 2). The National Academies formed a committee of experienced persons with diverse

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educational, institutional, legislative, and program evaluation backgrounds. Beyond involving leaders in science, technology, engineering, and mathematics (STEM), *Expanding Underrepresented Minority Participation* advocates for a direct program development plan to address underrepresentation. It suggests that "a successful national effort to increase the participation and success of underrepresented minorities in STEM will be urgent, sustained, comprehensive, intensive, coordinated, and informed" (p. 11). The report describes the impact and necessity of including underrepresented minorities in the economy's research and innovation capabilities. Three reasons for this approach are offered, including: (a) the uncertainty of "our sources for the future of the S&E workforce," (b) the shifting "demographics of our domestic population," and (c) the strength of diversity in S&E (pp. 2–3). The committee advises that international students are a cause of uncertainty in S&E because, in previous years, international students "have accounted for almost all growth in STEM doctorate awards and, in some engineering fields, have for some time comprised the majority of new doctorate awards" (p. 22). This is a cause for concern for the S&E workforce because uncertainty remains about whether they will remain in the United States or return to their country after graduation. The committee also provides data that supports the shift in demographics of the S&E workforce. "In 2006[,] underrepresented minority groups represented 28.5 percent of our national population but just 9.1 percent of college-educated Americans in science and engineering occupations" (p. 36). This would imply that "the proportion of underrepresented minorities in S&E would need to *triple* to match their share of the U.S. population" (p. 36). Emphasis is also placed on the multidimensional effects of diversity, which aides in the goals for research innovation, involves a culmination of ideas from a variety of sources, and is deemed essential for developing S&E workforce.

**Developing Scientists and Engineers**

Members of congress asked for recommendations that would assist in the growth in degrees obtained by underrepresented minorities in S&E. The committee describes the path to developing a strong S&E workforce by examining avenues that currently exists. The case is made for instituting a strategic pipeline to S&E because "no single career pathway or pipeline exists in STEM education" (p. 4). In Chapters 3–6, they clearly identify issues that underrepresented minorities face throughout their educational careers. Detailed programmatic measures are suggested in hopes of reversing this trend to include educational stakeholders focusing on "preparation, access and motivation, financial aid, academic support, and social integration" (p. 5). Preparation examines training received at the K–12 level. The committee notes that the current system, with the various laws and initiatives enacted throughout the years, has not properly addressed underrepresented minorities' needs for academic preparation. Data shows the increase of minority populations within the K–12 system throughout the years; therefore, the proposed pipeline “must be a major focal point of intervention to cultivate the diverse talent pool is needed to sustain the nation’s future in STEM” (p. 56). In addition, a connection is shown “between teacher quality and student achievement” as an indicator of preparation (p. 54). A strong emphasis is also placed on transitioning from high school to college, retention, and sustaining interest in STEM when considering access and motivation of underrepresented minorities. Data suggest “underrepresented minorities who do begin at four-year institutions and aspire to major in STEM, as we have seen, have a lower four- and five-year completion rate than whites and Asian Americans” (p. 93). The committee offers institutional changes that can be made at the departmental level to address motivation and interest, such as hands-on activities in programs outside of the classroom, STEM outreach initiatives, and increasing STEM career and college awareness. They also point out the need for transformative measures in organizations who allocate resources to assist students seeking to persist in STEM fields. A call for action is issued to federal programs, such as the Louis Stokes for Minority Participation and NIH training programs, to be transformed in order to increase participation. In addition, the report ascertains that creating an inclusive climate for learning and support through student success programs, retention models, social support, and advising can be an avenue of support for underrepresented minority students.

The committee targets higher education institutional administrators at all levels, stakeholders, and funding partners to pledge to create a climate of inclusion at their prospective institutions. There has been emphasis placed on predominately white institutions, minority-serving institutions, and community colleges to implement best practices by identifying successes at institutions that fall within their designated Carnegie classification. They make it clear that this approach to creating scientists and engineers involves national and local stakeholders’ assistance to ensure that all students receive a quality education. This includes highlighting “the need to provide substantial support to high-need schools, including professional development for teachers and school leaders” (p. 89) with innovative practices that incorporate STEM in the classroom.

**Moving Forward to Inclusion in S&E**

After establishing a clear rationale for the need to expand underrepresented minority participation in the S&E workforce, the committee recommends six action plans to move beyond the crossroads (see Figure 1). The recommendations were driven by a set of principles to enact immediate plans of actions, including: (a) recognizing the urgency of the problem, (2) sustainability, (3) educational pathways from all levels that will secure pathways for all students, (4) increased intensive efforts to assist students with inadequate preparation for STEM, (5) allocation of funding, and (6) STEM program evaluation (pp. 143–148). These priorities extend to institutional roles and leadership, program design, program development, and characteristics of successful STEM program models. The committee further suggests offering research experiences, mentoring, and think tanks amongst stakeholders to share practices. For instance, important factors (retention) that contribute to African American success at Historically Black Colleges and Universities (HBCUs) are described; although S&E minority numbers are smaller in comparison to predominantly White institutions, the fact that they "graduate a larger percentage speaks to the efficacy of these institutions in retaining these students" (p. 156). The importance of retention practices is emphasized throughout this report. Although recommendations were provided, given the immediate action needed to advance report findings, the committee provides further justifications for increasing diversity and inclusion by identifying two priority initiatives. Priority 1 addresses all programmatic and financial support needed to increase retention and completion of undergraduate degrees in STEM, and Priority 2 warrants transitional support from secondary to graduate school initiatives as well as support for teacher preparation programs (pp. 186–188).

**Table 1**
Committee recommendations from *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads* (pp. 11–12).

| **Preparation** | | **Postsecondary Success** | |
|---|---|---|---|
| Recommendation 1: Preschool-Grade 3 Education | Prepare America's children for school through preschool and early education programs that develop reading readiness, provide early mathematics skills, and introduce concepts of creativity and discovery. | Recommendation 4: Access and Motivation | Improve access to all postsecondary education and technical training and increase underrepresented minority student awareness of and motivation for STEM education and careers through improved information, counseling, and outreach. |

| | | | |
|---|---|---|---|
| Recommendation 2: K-12 Mathematics and Science | Increase America's talent pool by vastly improving K-12 mathematics and science education for underrepresented minorities. | Recommendation 5: Affordability | Develop America's advanced STEM workforce by providing adequate financial support to underrepresented minority students in undergraduate and graduate STEM education. |
| Recommendation 3: K-12 Teacher Preparation and Retention | Improve K-12 mathematics and science education for underrepresented minorities overall by improving the preparedness of those who teach them those subjects. Postsecondary Success | Recommendation 6: Academic and Social Support | Take coordinated action to transform the nation's higher education institutions to increase inclusion of and college completion and success in STEM education for underrepresented minorities. |

**Final Analysis**

*Expanding Underrepresented Minority Participation* calls for the higher education community to help increase degree production in underrepresented minorities in the S&E workforce. Its efforts include providing sustainable measures such as retention, academic, and non-academic support that serve as a roadmap to the inclusion of underrepresented minorities in S&E throughout all levels of education. As the nation strives to increase the number of additional STEM degrees, transformational changes must include initiatives that support underrepresented minorities, as reflected through demographic data provided in this report. *Expanding Underrepresented Minority Participation* engages national leaders, policy makers, local administrators, and educational communities in a conversation that will assist in keeping America competitive globally. This report offers a sustainable option to inclusion and diversity of underrepresented minorities in S&E and a direct pathway of completion success. However, it is important to recognize that as congress changes, a new paradigm will arise based on the agenda of local and federal constituents. As the 2016 presidential election approaches, one must wonder if America will find itself at the crossroads again.

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Technology and Engineering Education (T&EE) is a program that resides at the P-12 school levels for all students and at post-secondary institutions for those students interested in teaching or obtaining employment in the technology or engineering fields. Technology and engineering education is primarily taught by technology and engineering teachers, with a focus on engineering design. T&EE may be considered a stand-alone discipline or part of a larger discipline in science, technology, engineering, and mathematics (STEM). Regardless of the approach, T&EE focuses on technological literacy and engineering design; engineering design is the verb tense of engineering.

At the P-12 grade levels, the goal is for students to develop technological and engineering literacy, regardless of career aspirations, through hands-on, contextual applications of technological and engineering concepts. T&EE students, use a hands-on approach to solve technological problems using problem solving and creativity, while working under constraints, which involves the use of optimization and predictive analysis. At the P-5 grade levels, technology and engineering concepts are integrated into existing coursework such as reading, mathematics, science, and social studies. Typical courses students would take at the 6-12 grade levels in a T&EE program would consist of (a) information and communication technologies, including computer-aided drafting and design, (b) engineering design, (c) construction technology, (d) manufacturing technology, (e) energy, power, and transportation technology, and (f) medical, agricultural, and related biotechnologies. Within these courses, students would utilize troubleshooting, research and development, invention and innovation, and problem solving. The focus of T&EE at the P-12 levels is not to prepare future engineering majors/students, but to provide an education for all students.

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