Contents

Articles

2 Status of Elementary Teacher Development: Preparing Elementary Teachers to Deliver Technology and Engineering Experiences
Mary Annette Rose, Vinson Carter, Josh Brown, and Steven Shumway

19 Wanted For 21st Century Schools: Renaissance STEM Teacher Preferred
Tyler Ames, Edward Reeve, Gary Stewardson, and Kimberly Lott

31 Important Engineering and Technology Concepts and Skills for All High School Students in the United States: Comparing Perceptions of Engineering Educators and High School Teachers
Michael Hacker and Moshe Barak

53 Peer Evaluation of Team Member Effectiveness as a Formative Educational Intervention
Nathan Mentzer, Dawn Laux, Angelika Zissimopoulos, and K. Andrew R. Richards

83 Examining Elementary School Students' Transfer of Learning Through Engineering Design Using Think-Aloud Protocol Analysis
Todd Kelley and Euisuk Sung

Miscellany

109 Scope of the JTE
Editorial Review Process
Manuscript Submission Guidelines
Subscription Information
JTE Co-sponsors and Membership Information
JTE Editorial Review Board
Electronic Access to the JTE

Status of Elementary Teacher Development: Preparing Elementary Teachers to Deliver Technology and Engineering Experiences

Mary Annette Rose, Vinson Carter, Josh Brown, and Steven Shumway

Abstract

For over a century, teacher preparation programs (TPPs) have experienced peaks and valleys in preparing preservice teachers to deliver technology and engineering (TE) experiences in elementary classrooms. Calls to integrate engineering concepts into elementary education (Katehi, Pearson, & Feder, 2009; Kimmel, Carpinelli, Curr-Alexander, & Rockland, 2006)—especially as it relates to the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013) and science, technology, engineering and mathematics (STEM) education—compels TE teacher educators to evaluate their curricular programs relative to elementary education. To assist teacher educators in this self-assessment, the Teacher Preparation Committee of the Council on Technology and Engineering Teacher Education undertook a mixed methods study, the purpose of which was to identify and characterize the models of teacher preparation programs that prepared preservice elementary teachers to deliver TE experiences in elementary classrooms.

Keywords: Elementary teacher education, Technology education, STEM

Review of Literature

During the evolution from manual arts into industrial arts (IA) in the initial decades of the 1900s, teacher educators encouraged elementary teachers to integrate constructive and investigative activities and content about how people transform materials to solve life's problems into general elementary education. In particular, Bonser and Mossman (1923) emphasized the *health*, *economic*, *aesthetic*, *social*, and *recreational* outcomes of IA (p. 7) as they related to becoming "efficient in the selection, care, and use of the products of industry, and . . . [becoming] intelligent and humane in the regulation and control of industrial production" (p. 6). Furthermore, they noted the efficiency and integrative power of IA to enhance the school curriculum as a method of teaching. Other manual training educators, however, advanced elementary industrial education from a more practical perspective, emphasizing instruction in tool use and handcrafts for students who were unlikely to attend school beyond the eighth grade (Foster, 1999).

By midcentury, elementary school industrial arts (ESIA) was evident within university curricula. Loats' (1950) survey suggested that 44 of 90 IA teacher training institutions in the United States offered a total of 91 IA courses for the preparation of elementary teachers with 10 of these institutions offering five courses each (pp. 144–145). Knowledge of “materials of industry,” “finishing materials,” and “general tools of industry” were the most frequently cited competencies stressed in these courses (p. 157). For example, the State University Teachers College in Oswego, New York, offered two programs to study ESIA (Kroh, 1957); one offered general elementary majors the opportunity to take a minor sequence in IA, and the other enabled IA majors to take a minor sequence in ESIA.

A decade later, Bruce’s (1964) survey of industrial education departments indicated that 94 of 165 responding departments offered at least one IA course for elementary teacher education with a total of 143 separate courses identified (p. 41). All respondents indicated that constructional activities were valued within these courses with 83% of respondents emphasizing “their use in integrating other areas of study in the elementary curriculum” (pp. 81-82). In 1971, Ingram and Pace (1974) conducted a similar survey of IA teacher education departments with 80 of 103 respondents indicating that they offer coursework in ESIA through 125 separate courses. Required ESIA coursework was minimal among elementary majors (18.7% required), special education majors (12.5%), and IA majors (13.7%; p. 204).

During this same time frame, several textbooks and professional initiatives were evident. Scobey’s (1968) textbook offered “a theoretical and pedagogical basis for the study of technology in the elementary school” (p. v), background information about industry, and classroom activities. The American Council for Elementary School Industrial Arts (ACESIA) was established in an attempt “to define, stimulate, and strive for the ideal form of industrial arts education in the elementary school” (Stunard, 1971, p. ii), and the *23rd Yearbook of the American Council on Industrial Arts Teacher Education* was dedicated to describing “a revival of [ESIA] theory building and program research and development” (Ray, 1974, p. 5).

During the 1980s and 1990s, many embraced technological literacy as a critical educational mission. The National Aeronautics and Space Administration (NASA) funded the Mission 21 project at Virginia Tech that demonstrated a framework to implement the study of technology in the elementary curriculum by developing and testing resource guides designed around problem-solving themes and design challenges requiring the integration of science, social studies, and math (Brusic, Dunlap, Dugger, & LaPorte, 1988). Within the profession, the *46th Yearbook of the Council on Technology Teacher Education* (Kirkwood & Foster, 1997) was dedicated to elementary school technology education (ESTE). In 1998, the Children’s Council of the International Technology Education Association was formed “to build a collaborative network of educators dedicated to the advancement of technological literacy at the elementary level” (2017, para. 2). Yet in the face of enthusiasm for ESTE, technology TPPs at both the elementary and secondary levels experienced “a precipitous decline [in student enrollment] from the 1970 levels” (Volk, 1997, p. 66) with an estimate of only five IA or TE TPPs in the United States identifying ESTE courses (Dennis, 1994; as cited in Kieft, 1997).

The *Standards for Technological Literacy* (STL), originally published in 2000 by the International Technology Education Association, offered guidance to teacher educators and elementary teachers by identifying critical content for K–2, 3–5, and 6–8 grade bands, requiring that students “develop an understanding of the relationships among technologies and the connections between technology and other fields of study” (Standard 3), “the attributes of design” (Standard 8), and “ engineering design” (Standard 9), and “develop the abilities to apply the design process” (Standard 11; 2007, p. 210). During this same time period, political leaders argued that improving STEM education is a necessary precondition to preserving the nation’s pipeline of scientists and engineers as well as its’ capacity for innovation and global economic competitiveness (e.g., *Engineering in K–12 Education*, 2009). The emphasis upon STEM education created opportunities for engineering to enter students’ K–12 experiences (Pearson, 2014). Several professional development and curriculum development projects emerged to enhance in-service elementary teachers’ STEM understanding and skills. From Hofstra University, the Integrating Mathematics, Science, and Technology in the Elementary Schools project prepared three-person leadership teams that, in turn, conducted workshops with over 1,200 elementary school teachers in New York (Burghardt & Hacker, 2002). The Children Designing & Engineering project at The College of New Jersey resulted in the development and evaluation of thematic instructional units that integrated science, technology, and mathematics standards (Hutchison, 2002). But perhaps, the Engineering is Elementary (EiE) curriculum, initiated by the Boston Museum of Science in 2003, has been the most extensively adopted curriculum with over 50,000 in-service teachers reporting that they used one or more of the 20 engineering units (Lachapelle & Cunningham, 2014).

The possibility of developing national K–12 engineering standards was explored, eventually dismissed, and replaced by a recommendation to identify core engineering concepts and skills across age bands (National Academy of Engineering, Committee on Standards for K–12 Engineering Education, 2010). Proponents of engineering education pushed for greater integration of engineering into the K–12 core curriculum (Miaoulis, 2014). Over time, engineering appeared within state curricular standards (e.g., Massachusetts Department of Elementary and Secondary Education, 2016), program evaluations (e.g., Public Schools of North Carolina, 2012), and a few elementary TPPs. For example, The College of New Jersey, which also prepared secondary TE teachers, initiated a K–5 Math/Science/Technology program in 1998 that continues today as Integrative-STEM with a specialization in TE (O’Brien, Karsnitz, Van Der Sandt, Bottomley, & Parry, 2014). In addition, elementary STEM programs associated with engineering institutions provided preservice TPPs. Hofstra University (2016), for example, offered a 36-hour "co-major" consisting mostly of science, math, and engineering courses, including courses like Designing the Human-Made World and Technology and Society, and "two STEM designated integrative courses that students will take at the end of the program" (para. 1).

More recently, the NGSS (NGSS Lead States, 2013) explicitly elevated "engineering design to the same level as scientific inquiry when teaching science disciplines at all levels" (p. 103) and strengthened existing linkages to the STL including crosscutting concepts of interdependence and influence of TE on society and environment (ETS2.A and ETS2.B; see National Research Council, 2012). Although elementary TPPs have traditionally been interdisciplinary, the focus for K–4 has been primarily upon teaching reading and writing with strong connections to social studies. The NGSS presents new engineering content and pedagogy and, thus, a need to update preservice teacher curriculum as it relates to TE content and pedagogies. A window of opportunity is open to the TE teacher preparation community to help prepare preservice elementary teachers to deliver engineering experiences. To inform this continuous improvement of TE TPPs, the current study attempts to identify and characterize TPPs that prepare elementary teachers to deliver TE experiences in elementary classrooms.

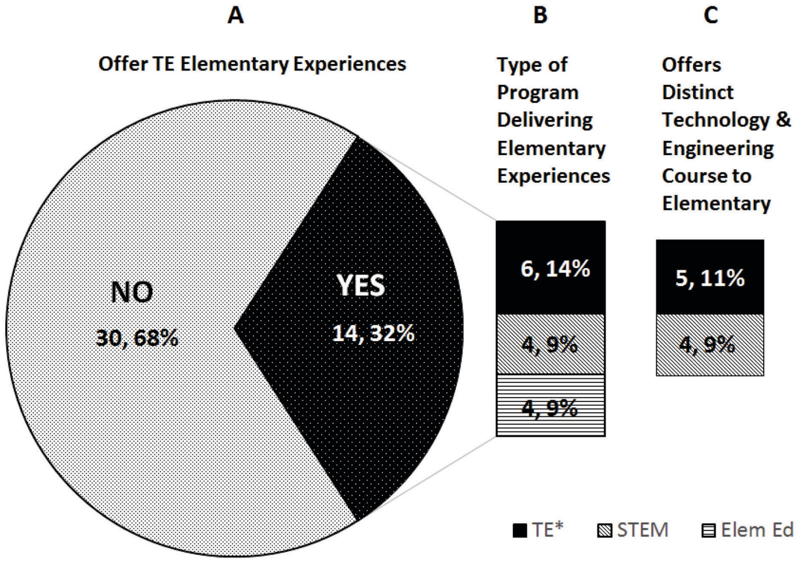
Methodology

A mixed methods approach using direct email, a questionnaire, document review, and telephone interviews were employed for data gathering. The researchers developed a questionnaire to solicit information about the nature of TE curricular offerings for preservice elementary teachers. The questionnaire included 19 items, such as type of program, standards, licensure, credentials, and clinical experiences. The final question asked respondents to provide contact information for another person or institution in their state or region that may offer TE opportunities for elementary preservice teachers.

The 53th edition of the *Technology & Engineering Teacher Education Directory* (Rogers, 2014) established the initial target population ($n = 45$). In October 2015, an email invitation was extended to the contact person of each institution asking them to complete the questionnaire, and a second invitation was extended two weeks later; 31 TPPs responded. In the case of non-respondents, the undergraduate catalog or course bulletin was acquired through a web search, and the program and course descriptions offered by the TPPs were reviewed. In addition, telephone interviews ($n = 15$) or email correspondence were conducted to expand and validate the nature of the TPPs. In all, data were gathered from 44 institutions that prepared TE teachers in the United States.

Results

Of the 44 institutions, 14 (32%) indicated that they provided learning experiences for preservice elementary teachers that prepared them to deliver TE experiences within elementary classrooms (Figure 1A). A wide range of program titles was evident, such as Elementary Technology Literacy, Integrative STEM, Integrated Science, and Elementary Education. When asked to classify the teacher preparation program that implements the TE experiences for elementary teachers, respondents indicated STEM (*n* = 4), elementary and elementary science education (*n* = 4), technology education (*n* = 2), technology and engineering education (*n* = 2), career and technical education (*n* = 1), and industrial arts or technology (*n* = 1; see Figure 1B). The reported student enrollment in STEM programs (*n* = 4) averaged to 100 students, whereas enrollment in non-STEM courses or programs (*n* = 4) averaged to 16 students.



* TE = programs emphasizing technology & engineering, technology education, career & technical education, and industrial arts.

Figure 1. Responses from institutions offering technology and engineering (TE) teacher preparation programs regarding opportunities for elementary education students.

An analysis of program and course descriptions was conducted to identify courses that served elementary education students, explicitly addressed TE content, and referenced STEM goals or content. Direct contact with program affiliates confirmed these findings. The results indicated that nine of 14 programs offered distinct coursework examining TE concepts for elementary education students (Figure 1C). No program classified as elementary or elementary science education (*n* = 4) offered a TE-content-based course. One respondent explained that engineering design was employed as a pedagogical strategy through methods courses, especially a science methods course. It should be noted that in only eight of the nine programs were courses delivered by faculty members positioned within a TE teacher preparation program; one elementary STEM program was delivered by faculty members from engineering education. Furthermore, STEM goals and content appeared prominently in the program title, course titles, or description for six of the nine programs.

Respondents identified the content standards with which their curricular program aligned. The two most common standards were the NGSS and STL, each with eight programs. Seven programs were reportedly aligned with the Common Core State Standards (CCSS), and three programs responded “other.”

Respondents were also asked to indicate how extensively specific standards from the STL and NGSS were emphasized in their program using a 5-point scale ranging from *never emphasized* to *extensive emphasis*. Relative to the STL, the average response from nine participants indicated *strong-to-extensive emphasis* (=> 4.0) on Apply the Design Process, Attributes of Design, and Engineering Design. *Moderate-to-strong emphasis* (3.6 to 3.9) was found for Characteristics and Scope of Technology, Core Concepts of Technology, Relationships Among Technologies and Other Fields of Study, and Effects of Technology on the Environment. Overall the *lowest emphasis* occurred for the standards in the Designed World, such as medical, agriculture, and construction technologies. Six participants responded to the engineering principles and practices of the NGSS indicating a *moderate-to-strong* response with the strongest emphasis on Identifying the Problem and Selecting a Solution.

Regarding clinical experience, respondents indicated the extent of clinical experiences dedicated to delivering TE content in elementary classrooms. A bimodal distribution was evident with highest frequencies occurring for *0 hours* (*n* = 4) and *11–20 hours* (*n* = 3; see Table 1). Those reporting *0 hours* were from programs offering only “courses” to elementary education students (*n* = 2) or those positioned within states providing K–12 TE certification (*n* = 2). Programs reporting the highest hourly requirements for clinical experiences were STEM-centric programs (*n* = 3) and elementary education (*n* = 1). Furthermore, respondents from two elementary education programs explained that students were required to plan and implement engineering experiences with elementary learners as part of their science pedagogy requirement.

Table 1
Summary of Clinical Experience Hours Delivering Technology and Engineering Content in Elementary Classrooms

Clinical experience	Count	%
0 hours	4	36
1–5 hours	1	9
6–10 hours	2	18
11–20 hours	3	27
More than 20 hours	1	9
Total	11	100

Additionally, participants were asked to identify the curriculum and instructional packages used to prepare elementary preservice teachers within their teacher preparation program. The choices included EiE, PLTW (Launch or Gateway), I^3 Project: Invention, Innovation, Inquiry, Designing Human Exploration, Lego WeDo Curriculum, Engineering by Design (EbD), and an open-ended response. Two institutions indicated that they use EiE, and one responded that they use EbD to prepare teachers. The other responses included content from Science Learning through Engineering Design (SLED), state-designed curriculum, self-developed curriculum, and Teach Engineering. One participant responded, “We expose the candidates to the national curriculum packages, but primarily prepare our candidates to develop their own curriculum.”

Credentialing practices were also examined. Completion of elementary-focused curricular programs was typically noted within institutional transcripts; in one instance in which this was not the case, a certificate was issued by the program. Relative to teacher licensing practices, the Pennsylvania Department of Education (2014) and the North Dakota Education Standards and Practices Board (2011) offered STEM endorsements to existing elementary teaching licenses, but these endorsements were not required for certified elementary teachers to deliver TE experiences or content in their self-contained classrooms. Although three states issued overlapping grade-level certification for TE teachers (i.e., Grades 5–12 in Wisconsin and K–12 in New York and New Jersey), two TPPs did not offer a specific course customized for elementary education students.

Models of Teacher Preparation

This study resulted in the identification of six models of TE teacher preparation for preservice elementary teachers, including the specific course, concentration, certificate, minor, major, and the combined undergraduate and graduate program. The following provides a glimpse of those models of elementary teacher preparation.

Specific course. The most basic way of integrating TE content into elementary teacher preparation was the specific course model. Both the University of Georgia (UG) and California University of Pennsylvania (CAL U) offered courses customized for elementary education majors. Undergraduates from UG (2016a) could have selected the Creative Activities for Teachers course (ETES2320-2320L) to fulfill a requirement of the Major in Elementary Childhood Education. The course offered students an opportunity to engage in "demonstration and hands-on learning, including problem solving, designing, construction, and testing of prototypes, and activities that increase aesthetic, psychomotor, and cognitive development" (2016b, "Course Description," para. 1). CAL U's Elementary School Technology Education course enabled students to "explore and develop instructional methodologies and assess student learning while addressing grade-level content standards for the study of technology in grades K-5" (2016, "TED 352," para. 1).

As part of their BS in Technology Education degree program that prepares teachers for 7–12 certification, CAL U (2016) also offered a required course entitled Teaching Technology in the Elementary School that focused on "teaching/learning activities that integrate concepts related to mathematics, science, communication and social science with technology" at the elementary level ("TED451," para. 1).

Concentration. A concentration—a coordinated set of courses with a common thread—was a model found among elementary education programs. For example, Ball State University (2015) required that all elementary education majors select a concentration of study consisting of 12 credit hours. As one among 13 options, the Technology concentration required students to take one TE course—Technology and Society—and two educational technology courses—Curricular Integration of Technology and Technology Policy and Ethics. Additionally, students could have taken the Capstone in Technology for the Elementary Grades course to fulfill the concentration requirements; this course provided hands-on laboratory experiences with technological systems, processes, and products (p. 111).

Certificate. Another model of teacher preparation was the certificate program, a coordinated set of courses that, when completed, resulted in a state-level credential. Unique among teacher education programs, Valley City State University (VCSU; 2014) offered several 100% online programs for undergraduates, graduates, and practicing teachers to enhance their understanding and pedagogical skills for delivering TE experiences to elementary learners. Majors in both elementary and secondary education at VCSU could have opted for a STEM Education Certificate of Completion consisting of 12 credits. Four of the required courses in the elementary certificate program were also required courses in the BS in Technology Education degree. Specifically, six credits were dedicated to the study of TE within courses called Invention and Innovation and Design/Technology/ Engineering for Elementary. In addition, a math course focused "on hands-on transdisciplinary investigations integrated with project-based engineering design activities" was required (p. 163). The state of North Dakota offered a license endorsement to students who completed the STEM Certificate if the student completed an approved field experience of 20 hours that included the implementation of TE experiences with elementary learners (Peder Gjovik, personal communication, December 10, 2015).

Minor. Two examples of minor programs were identified in the study. Millersville University (2016) offered a minor in Integrative STEM Education Methods for students majoring in early childhood education or special education. The minor was offered through the Department of Applied Engineering, Safety, and Technology and consisted of 18 credit hours. The required courses for the minor included Introduction to Early Childhood Education, Introduction to Integrative STEM Pedagogy, Product Design, Children's Engineering, Integrative Learning using Experiential Strategies, and Integrative STEM Education Practicum.

Additionally, Pittsburg State University (2013) offered a minor in Technological Literacy for preservice elementary teachers. The minor consisted of 20 credit hours with three educational technology courses and three technology education courses that illustrated the "practical use and implementation of computer skills, design and problem solving skills and teaming concepts into real world practices and experiences" (para. 1). The course sequence included STEM Experiences for Elementary Education, Technology for the Classroom, Overview of Technology and Engineering in STEM Education, Instructional Technology for Educators, and Integrated Technology for Educators. Additionally, students were required to complete a special topics course in both educational technology and technology education.

Bachelor's degree. One bachelor's degree program was identified in the study. The College of New Jersey (2016a, 2016b) had engineering-related experiences for elementary and secondary teacher education candidates in several areas. They offered a Bachelor of Science (BS) in Technology/Pre-Engineering Education in secondary K–12 technology and engineering education (2016b) and a BS in Integrative-STEM Education (2016a) in elementary K–6 STEM education. In the Integrative-STEM Education program, elementary teacher education candidates could choose from one of five tracks including: Deaf and Hard of Hearing, Early Childhood Education, Elementary

Education, Special Education, and Urban Education. All five of these sequences provided engineering-related course work.

Specific to this study, we investigated the BS in Integrative-STEM Education and the Elementary Education major. This program led to elementary education certification in the state of New Jersey. Courses required for this major included: Calculus, Creative Design, Multimedia Design, Structures and Mechanics, and Integrated M/S/T for the Child/Adolescent Learner. Inside this program, teacher education candidates could focus on elementary or early-childhood teaching, K–8 mathematics, or K–8 science.

Combined undergraduate and master's certificate program. A combined bachelor's and master's program at the University of Arkansas (UA) was the final model identified during the study. UA offered a graduate certificate program with a concentration in STEM Education for their Master of Arts (MAT) in Childhood Education (elementary) program in the Department of Curriculum and Instruction. This program was developed to meet the demand for highly qualified teachers with both knowledge of STEM disciplines and expertise with integrating STEM into the elementary classroom. The program consisted of five courses (University of Arkansas, 2016). Typically, two courses were offered at the undergraduate level, and three were completed during the MAT program. The first course, Introduction to STEM Education, was a required course for all preservice elementary teachers and students in the technology education program. Additionally, students completing the certificate program were required to take Creativity and Innovation, Problem-Based Mathematics, Problem-Based Science, and Curriculum Design Concepts for Teachers. After completing the program, students were issued a graduate certificate. However, students could have completed the five courses at the undergraduate level with a departmental certificate of completion.

Other teacher preparation programs. Future elementary teachers may have encountered TE content and pedagogy as part of their science or educational technology courses or as part of their field experience. For example, the Elementary Education Integrated Science Major program at Northern Michigan University actively promoted students' understanding and application of the NGSS, including those concepts and practices identified as "engineering, technology, and applications of science" (NGSS Lead States, 2013), through professional methods courses (12 hours) that included engineering design as a pedagogy and educational technology courses (6 hours) that incorporated relevant digital learning tools (e.g., Lego robotics; Joseph Lubig, personal communication, January 22, 2016). In addition, the program engaged students in 12 hours of progressive field experiences related to planning and delivering TE experiences, much of which occurred through the services of a regional science and mathematics center (e.g., hosting the Michigan Science Olympiad).

Discussion and Conclusions

This descriptive study was an attempt to identify and characterize the models of teacher education programs that prepare preservice elementary teachers to deliver technology and engineering experiences within elementary classrooms. The population of the study was limited to U.S. educational institutions known to prepare technology and engineering teachers; thus, these results do not apply to institutions that prepare only elementary or secondary teachers in science. Caution should be taken when interpreting these results as overlapping teaching licensure (e.g., Grades 5–12 and K–12 certification in Wisconsin and New York, respectively), ambiguous nomenclature (e.g., endorsement and certificate), contradictory sources of information, and dynamic transitions within institutions may have confounded results.

The results of this study suggest that nine programs in the United States provide courses or curricular programs customized for elementary education majors that enable them to develop content knowledge in technology and engineering. Compared to Litowitz's (2014) analysis of undergraduate curriculum identifying three ESTE courses in the United States, the current findings indicate a slight increase with nine programs providing TE coursework to elementary education students. Given that six of these nine programs have explicit STEM components and two states offer STEM teaching credentials, the slight increase in elementary offerings might be a result of contemporary pressures that all teachers and teacher education programs should become more integrative in their curriculum and instructional practices. The significantly larger enrollment reported by programs classified as STEM programs as compared to TE programs provides further evidence that STEM programs are addressing some of the challenges to STEM integration discussed by Honey, Pearson, and Schweingruber (2014), e.g., enhancing teachers' STEM content knowledge and expertise in teaching integrated STEM.

Six structural models were evident among teacher preparation programs delivering TE content to elementary education students: specific course, concentration, certificate, minor, bachelor's degree, and combined undergraduate and master's certificate program. With the exception of the specific course and concentration models, the models requiring 12 or more credit hours were predominantly STEM-centric; program and course descriptions addressed specific TE content as well as integrative STEM pedagogy. In addition, most of these STEM-centric programs required significant clinical experiences in which students implemented TE experiences with elementary learners.

To further characterize these curriculum models, content standards were considered. There was equally reported alignment with the STL and NGSS content standards with slightly fewer programs aligning to the CCSS. In contrast to the emphasis on the Designed World standards of the STL (ITEEA, 2010) among secondary TE education programs (Litowitz, 2014), the results of this study showed an extensive emphasis on the design standards from the STL. Furthermore, most elementary and elementary science education programs represented in this study reported using engineering design as a unifying pedagogical approach to further connect STEM areas through design-based instruction.

Recommendations

As pressure mounts to integrate TE content into elementary science or through elementary STEM programs, TE teacher educators have a brief window of opportunity to evaluate their elementary curricular offerings and then collaborate with faculty members in elementary education, science education, or engineering education to revise or develop courses and programs that build elementary education students' TE content knowledge and pedagogical expertise.

Several questions for guiding the evaluation of existing programs may be inferred from the successful programs identified in this study. To what extent does the program:

- Include coursework explicitly customized for elementary education students?
- Familiarize students with elementary curriculum and instructional packages that address TE learning goals?
- Include STEM-centric courses that enable students to build both discipline-specific content knowledge and integrative teaching expertise, such as an integrative methods course?
- Require students to align their own curriculum and instructional plans to both STL and NGSS standards?
- Require significant clinical TE experiences with elementary-aged students?
- Celebrate the completion of elementary-level TE or STEM programs by issuing certificates or designations on transcripts? (This credential may be presented to prospective employers as teachers seek future employment in schools with a STEM focus.)

After program evaluation, faculty members should consider revision or creation of a new curricular offering for elementary education students by collaborating with fellow education faculty members in elementary, science, engineering, or mathematics. When initiating contact, TE faculty members should be well prepared to communicate research evidence that an integrative approach to STEM education at the elementary level (Becker & Park, 2011) and design-based learning as an instructional approach (Wells, 2016) has been shown to positively impact student achievement. Furthermore, faculty members should extoll the unique expertise and resources that they can bring to the collaboration, such as expertise in ill-formed problem-based and project-based instruction and hands-on skills and resources that enable execution of engineering and design activities (e.g., planning, graphic representations, modeling, and prototype development).

Researchers should systematically examine the extent to which curriculum models for elementary teacher education, instructional approaches, curriculum resources, and clinical experiences contribute to the formation of appropriate content knowledge, self-efficacy, and integrative STEM teaching expertise, as suggested by Honey, Pearson, and Schweingruber (2014).

References

Ball State University. (2015). *Undergraduate catalog 2015–2016*. Retrieved from http://cms.bsu.edu/-/media/www/departmentalcontent/academicsystems/2015_2016/201516%20ucat%20pdf%20file%2032816.pdf

Becker, K., & Park, K. (2011). Effects of integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students' learning: A preliminary meta-analysis. *Journal of STEM Education: Innovations and Research*, 12(5–6), 23–37.

Bonser, F. G., & Mossman, L. C. (1923). *Industrial arts for elementary schools.* New York, NY: MacMillan.

Bruce, P. L. (1964). *Status, content, and appraisal of industrial arts courses for elementary teacher education in public higher educational institutions* (Unpublished doctoral dissertation). University of Missouri, Columbia, MO.

Brusic, S. A., Dunlap, D. D., Dugger, W. E., & LaPorte, J. E. (1988). Launching technology education into elementary classrooms. *The Technology Teacher*, 48(3), 23–25.

Burghardt, M. D., & Hacker, M. (2002). Large-scale teacher enhancement projects focusing on technology education. *Journal of Industrial Teacher Education*, *39*(3), 88–103. Retrieved from http://scholar.lib.vt.edu/ejournals/JITE/v39n3/burghardt.html

California University of Pennsylvania. (2016). TED—Technology education [Undergraduate Catalog]. Retrieved from http://www.calu.edu/current-students/academic-resources/catalogs/undergraduate/ted-st-courses.htm

Children’s Council of ITEEA. (2017). Retrieved from http://www.tecchome.org/index.html

The College of New Jersey. (2016a). Bachelor of science (BS) in integrative-STEM education. Retrieved from https://technologicalstudies.tcnj.edu/about/academic-programs/bachelor-of-science-bs-in-integrative-stem/

The College of New Jersey. (2016b). Bachelor of science (BS) in technology/pre-engineering education. Retrieved from http://technologicalstudies.tcnj.edu/curriculum/bachelor-of-science-bs-in-technology-pre-engineering-education/

Foster, P. N. (1999). The heritage of elementary school technology education in the U.S. *Journal of Vocational and Technical Education*, *15*(2), 28–43. doi:10.21061/jcte.v15i2.700

Hofstra University. (2016). Science, technology, engineering and mathematics (STEM), BA Major in [2016-2017 Undergraduate Bulletin]. Retrieved from http://bulletin.hofstra.edu/preview_program.php?catoid=80&poid=10529&returnto=8933

Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K–12 education: Status, prospects, and an agenda for research.* Washington, DC: National Academies Press. doi:10.17226/18612

Hutchison, P. (2002). Children designing & engineering: Contextual learning units in primary design and technology. *Journal of Industrial Teacher Education*, *39*(3), 122–145. Retrieved from http://scholar.lib.vt.edu/ejournals/JITE/v39n3/hutchinson.html

Ingram, F. C., & Pace, V. R. (1974). Teacher education. In R. G. Thrower & R. D. Weber (Eds.), *Industrial arts for the elementary school: The 23rd yearbook of the American Council on Industrial Arts Teacher Education* (pp. 196–208). Bloomington, IL: McKnight.

International Technology Education Association. (2007). *Standards for technological literacy: Content for the study of technology* (3rd ed.). Reston, VA: Author.

Katehi, L., Pearson, G., & Feder, M. (Eds.). (2009). *Engineering in K-12 education: Understanding the status and improving the prospects.* Washington, DC: National Academies Press. doi:10.17226/12635

Kieft, L. D. (1997). Teacher education. In J. J. Kirkwood & P. N. Foster (Eds.), *Elementary school technology education: The 46th yearbook of the Council on Technology Teacher Education* (pp. 251–279). Peoria, IL: Glencoe/McGraw-Hill.

Kimmel, H., Carpinelli, J., Burr-Alexander, L., & Rockland, R. (2006). *Bringing engineering into K-12 schools: A problem looking for a solution*. In *Proceedings of the 2006 ASEE Annual Conference & Exposition* (pp. 11.288.1–11.288.16). Washington, DC: American Society for Engineering Education. Retrieved from https://peer.asee.org/181

Kirkwood, J. J. & Foster, P. N. (Eds.). (1997). *Elementary school technology education: The 46th yearbook of the Council on Technology Teacher Education.* Peoria, IL: Glencoe/McGraw-Hill.

Kroh, D. K. (1957). *Relationship of industrial arts to the modern elementary school curriculum: Recommendations for improvements in elementary industrial arts undergraduate teacher education programs in New York state colleges* (Unpublished doctoral dissertation). New York University, New York, NY.

Lachapelle, C. P., & Cunningham, C. (2014). Engineering in elementary schools. In Ş. Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in pre-college settings*: *Synthesizing research, policy, and practices* (pp. 61–88). West Lafayette, Indiana: Purdue University Press.

Litowitz, L. S. (2014). A curricular analysis of undergraduate technology & engineering teacher preparation programs in the United States. *Journal of Technology Education*, *25*(2), 73–84. doi:10.21061/jte.v25i2.a.5

Loats, H. A. (1950). *A program of industrial arts for the preparation of elementary teachers, Ball State Teachers College, Muncie, Indiana* (Unpublished doctoral dissertation). The Ohio State University, Columbus, OH.

Massachusetts Department of Elementary and Secondary Education. (2016). *2016 Massachusetts science and technology/engineering curriculum framework*. Retrieved from http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf

Miaoulis, I. (2014). K–12 engineering: The missing core discipline. In Ş. Purzer, J. Strobel, & M. E., Cardella (Eds.), *Engineering in pre-college settings*: *Synthesizing research, policy, and practices* (pp. 21–33). West Lafayette, Indiana: Purdue University Press.

Millersville University. (2016). *Integrative STEM education methods (ISEM) minor*. Retrieved from http://www.millersville.edu/aest/info-sheets/istem-chart.pdf

National Academy of Engineering, Committee on Standards for K–12 Engineering Education. (2010). *Standards for K-12 engineering education?* Washington, DC: National Academies Press. doi:10.17226/12990

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press. doi:10.17226/13165

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* Washington, DC: National Academies Press. doi:10.17226/18290

North Dakota Education Standards and Practices Board. (2011). *STEM endorsement*. Retrieved from https://www.nd.gov/espb/licensure/forms/OtherEndorsements/59877.pdf

O'Brien, S., Karsnitz, J., Van Der Sandt, S., Bottomley, L., & Parry, E. (2014). Engineering in pre-service teacher education. In Ş. Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in pre-college settings*: *Synthesizing research, policy, and practices* (pp. 277–299). West Lafayette, IN: Purdue University Press.

Pearson, G. (2014). Foreword. In Ş. Purzer, J. Strobel, M. E. Cardella (Eds.), *Engineering in pre-college settings*: *Synthesizing research, policy, and practices* (pp. ix–x). West Lafayette, Indiana: Purdue University Press.

Pennsylvania Department of Education. (2014). *The framework for integrative science, technology, engineering, & mathematics (STEM) education* *endorsement guidelines.* Retrieved from http://www.education.pa.gov/Documents/Teachers-Administrators/Certification%20Preparation%20Programs/Specific%20Program%20Guidelines/Integrative%20Science,%20Technology,%20Engineering,%20Mathematics%20%28STEM%29%20Education%20Guidelines.pdf

Pittsburg State University. (2016). Minor in technological literacy [2016–2017 Catalog]. Retrieved from http://catalog.pittstate.edu/contentm/blueprints/blueprint_display.php?bp_listing_id=154&blueprint_id=250&sid=1&menu_id=6644

Public Schools of North Carolina. (2012). *Engineering connections aligned with the STEM rubric principles: Grades K-5 - Elementary School*. Retrieved from http://www.dpi.state.nc.us/docs/stem/resources/engineering-connections/gradesk-5.pdf

Ray, W. E. (1974). Foreword. In R. G. Thrower & R. D. Weber (Eds.), *Industrial arts for the elementary school: The 23rd yearbook of the American Council on Industrial Arts Teacher Education* (p. 5). Bloomington, IL: McKnight.

Rogers, G. E. (Ed.). (2014). *Technology & engineering teacher education directory* (53rd ed.). Reston, VA: Council on Technology & Engineering Teacher Education.

Scobey, M-M. (1968). *Teaching children about technology.* Bloomington, IL: McKnight & McKnight.

Stunard, E. A. (Ed). (1971). *“Books” annotated by American Council for Elementary School Industrial Arts*. Washington, DC: American Council for Elementary School Industrial Arts. Available from ERIC database. (Accession No. ED057236)

University of Arkansas. (2016). Elementary STEM certificate program. Retrieved from http://stem.uark.edu/stem-certificate.php

University of Georgia. (2016a). Early childhood education - B.S.Ed. [Spring 2016 UGA Bulletin]. Retrieved from http://bulletin.uga.edu/BulletinSpring2016/MajorSpecific.aspx?MajorId=56

University of Georgia. (2016b). ETES 2320-2320L: Creative activities for teachers laboratory [Spring 2016 UGA Bulletin]. Retrieved from http://bulletin.uga.edu/BulletinSpring2016/CoursesHome.aspx?cid=1356

Engineering in K–12 education: Hearing before the Subcommittee on Research and Science Education, U.S. House of Representatives, 111th Cong. 206 (2009). Retrieved from https://www.congress.gov/111/crpt/hrpt698/CRPT-111hrpt698.pdf

Valley City State University. (2014). *2014–16 Catalog: Undergraduate/graduate*. Retrieved from http://www.vcsu.edu/cmsfiles/139/c390c2435b.pdf

Volk, K. S. (1997). Going, going, gone? Recent trends in technology teacher education programs. *Journal of Technology Education*, *8*(2), 66–70. doi:10.21061/jte.v8i2.a.5

Wells, J. G. (2016). Efficacy of the technological/engineering design approach: Imposed cognitive demands within design-based biotechnology instruction. *Journal of Technology Education*, *27*(2), 4–20. doi:10.21061/jte.v27i2.a.1

About the Authors

Mary Annette Rose (arose@bsu.edu) is Associate Professor of Technology at Ball State University.

Vinson Carter (vcarter@uark.edu) is Assistant Professor of STEM Education at the University of Arkansas.

Josh Brown (jbrown4@ilstu.edu) is Associate Professor of Technology and Engineering Education at Illinois State University.

Steven Shumway (steve_shumway@byu.edu) is Professor of Technology and Engineering Education at Brigham Young University.

Journal of Technology Education | Vol. 28 No. 2, Spring 2017

Wanted For 21st Century Schools: Renaissance STEM Teacher Preferred

Tyler Ames, Edward Reeve, Gary Stewardson, and Kimberly Lott

Abstract

As education seeks to mold itself to fit the demands of the 21st century, STEM education will continue to be an important consideration. The integrated and crosscutting nature of STEM is incorporated into the *Next Generation Science Standards* in which engineering design is raised to the same level as scientific inquiry and is expected to be taught in science classrooms. This report analyzes a 2014 Utah survey of science teachers to understand how prepared Utah science teachers are to teach engineering design and the relationship between their preparedness and beliefs about whether building prototypes, computer modeling, and mathematical modeling belong in the instruction of engineering design. Ordinary least squares (OLS) regression results indicate that physics teachers are the most prepared to teach engineering design and that science teachers are significantly more prepared to teach an integrated STEM curriculum, such as engineering design, when they agree that modeling techniques from each STEM discipline should be used in instruction. It is recommended that teachers in STEM classrooms be comfortable and fluid in each STEM discipline, instead of representing one single subject expertise with some familiarity with the other three.

Keywords: STEM, Next Generation Science Standards, engineering design

Each year that passes brings us deeper into the 21st century. A long list of skills necessary to succeed in upcoming years has been suggested that includes practical ingenuity, creativity, communication, business and management, leadership, high ethical standards, professionalism, dynamism, agility, resilience, flexibility, lifelong learners, critical thinking, problem solving, collaboration, innovation, digital literacy, initiative, accountability, productivity, responsibility, and self-direction (National Academy of Engineering [NAE], 2004; Trilling & Fadel, 2009). These skills are "not new," but they need new attention in curricula (Rotherham & Willingham, 2010).

One venue for addressing the integration of 21st century skills and content is through science, technology, engineering, and mathematics (STEM) education. STEM is inherently interdisciplinary (Asghar, Ellington, Rice, Johnson, & Prime, 2012), and its disciplines have been described as "'vital for a thriving economy'" (Margaret A. Honey; as cited in National Academies of Sciences, Engineering, and Medicine, 2014, para. 2). One effort to deliver

STEM in an integrated format is found in the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013).

Citing a need for educational standards to be updated to reflect the most current educational research, the final draft of the NGSS was released in 2013 (Next Generation Science Standards [NGSS], 2017a). Prior to their publication, 40 states expressed interest in the standards (Branch, 2013), and all 26 states that were involved in the development process made commitments to "give serious consideration to adopting the resulting" standards (NGSS, 2017b, para. 1). As of 2016, 18 states and Washington, DC have voted to fully adopt the NGSS (Heitin, 2016). As a landmark publication, its influence is likely to be felt to some degree in almost all states, even if outright adoption does not occur.

As the effect of the NGSS reverberates throughout much of the country, one might ask if STEM education will become more prominent. One change in this regard is that engineering design, a problem-solving process used by engineers, has received increased weight and importance. In fact, "science and engineering are integrated into science education by raising engineering design to the same level as scientific inquiry in science classroom instruction at all levels and by emphasizing the core ideas of engineering design and technology applications" (NGSS Lead States, 2013, p. xiii).

The elevation and pronounced infusion of engineering into science standards appear to be in line with recommendations from the National Academy of Engineering (NAE) that encourage such infusions of engineering into other content areas (National Academy of Engineering, Committee on Standards for K–12 Engineering Education, 2010). Such infusion has already begun to happen in other STEM fields—most notably among technology teachers, who have largely adopted engineering. The adaptation from technology teachers into technology and engineering teachers is reflected in the title of the professional organization known today as the International Technology and Engineering Education Association (ITEEA). In 2010, the organization changed its name to properly position the association regarding "its increased role in delivering the 'T' & 'E'" in the strong STEM education movement that was occurring (International Technology and Engineering Education Association, 2012, para. 2).

The NAE has noted technology and engineering education's dedication to engineering-related content; however, they have also noted that technology and engineering education does not have the critical mass of 380,000 that they estimate are necessary to deliver engineering content to the entire country (National Academy of Engineering, Committee on Standards for K–12 Engineering Education, 2010). Hence, integrating engineering content into STEM fields with more teachers (i.e., science) appears to be a logical move.

Although the decision to integrate and give extra emphasis to engineering has been met with applause in many corners, it has also met with some concern about the readiness of science teachers to deliver deft STEM instruction. Using survey data from approximately 5,000 science teachers randomly sampled in discipline strata from 2,000 randomly sampled schools around the country, Banilower et al. (2013) reported that a mere 7% of high school science teachers felt that they were "very well prepared to teach" engineering (p. 26). This number should garner attention because "well prepared teachers produce higher student achievement" (National Council for Accreditation of Teacher Education, 2006, p. 3). Indeed, "the expertise of educators is a key factor—some would say *the* key factor—" in delivering STEM education well (NAE, 2014, p. 3).

The November 2013 issue of the *National Science Teacher Association Report* included a commentary from science education faculty members at Vanderbilt University who expressed their opinion about the state of preparedness of science teachers to teach engineering: "With the release of the Next Generation Science Standards (NGSS), it is clear engineering education will need to play a more prominent role in K–12 science classrooms. This creates a dilemma, as a second missing 'E' is all too often in engineering education: 'expertise.'" (Johnson & Cotterman, 2013, p. 3). Further, the National Academy of Sciences, Engineering, and Medicine (Wilson, Schweingruber, & Nielsen, 2015) has concluded that many teachers lack substantial experience with the engineering content laid out in the NGSS.

In this study, we use data from a 2014 survey of Utah science teachers to understand factors that contribute to a STEM teacher's preparedness or lack thereof to integrate STEM content from disciplines that are not native to them. Specifically, this question will be addressed in two steps. First, science teachers' feelings of preparedness for cutting across STEM content areas to address a subject such as engineering will be measured to determine if the sample reflects the low levels of preparedness found nationally. Second, science teachers' levels of preparedness will be examined for any potential relationship that they may have with teachers' opinions about appropriateness in cutting across all STEM disciplines to solve engineering (i.e., nonnative subject STEM) problems, which are referred to here as *modeling solutions*.

Research Design

Participants

Because science is sometimes thought to be the main discipline in STEM, we chose to survey a sample of science teachers. The survey used was administered through Utah's e-mail database of science teachers. At the time of data collection, Utah did not have a comprehensive list of science teacher e-mail addresses; however, the state did maintain a list of science teachers who voluntarily opted in to receive communications from state science leaders. In the 2013–2014 school year during which data were collected, approximately 650 of Utah's 1,517 science teachers were on the e-mail list that the state maintained. These teachers received the survey in an e-mail, and a follow-up e-mail was sent out to encourage further responses. All e-mails were sent through the office of

Sarah Young, the Utah state science coordinator. Participation was voluntary, and no incentives for participation were given.

Instrument

Because the NGSS were largely based on the *Framework for K–12 Science Education* (the Framework; National Research Council [NRC], 2012), the survey instrument was developed using the language found in the Framework to best reflect the definition and elements of engineering design as they are represented in the NGSS. The survey instrument contained 15 items, 11 items that were intended to capture a teacher's feelings of preparedness to engage with engineering design and four items that were intended to capture a composite score reflecting a teacher's likelihood to model solutions in various ways.

The 11 items relating to preparedness included statements about engineering design asking teachers to indicate how prepared they felt in each of the areas. A response key was provided next to each level of preparedness in order to unify interpretations of the various levels of preparedness (see Appendix).

The four items relating to modeling solutions included statements that cut across different types of modeling solutions. Because engineering design problems do not have "correct" answers (NRC, 2012), it is necessary to evaluate solutions on some other criteria. To this end, the teachers were asked to what extent they agreed that different types of solution modeling should be used in the instruction of engineering design in their classroom. These included mathematical modeling, computer modeling, scientific modeling, and construction or building of a prototype.

For accuracy in the distinctions between engineering and science, the 11 statements regarding preparedness and the four statements regarding statistical modeling were adapted directly from the Framework (NRC, 2012), which is also the document that provided the foundation for the NGSS.

The eight practices of science and engineering that the *Framework* identified as essential for all students to learn, and describes in detail, are:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information. (NGSS Lead States, 2013, p. 48)

Both disciplines, science and engineering, use all eight of these practices—albeit in slightly different ways. To accurately capture science teachers' feelings of preparedness about the engineering-specific use of these practices, and implementation of differing styles of solution modeling, the language of the survey closely paralleled that of the section in the Framework entitled "Distinguishing Practices in Science From Those in Engineering" (pp. 50–54) wherein a side-by-side comparison of science and engineering applications is presented. An excerpt from this section of the Framework is shown in Figure 1. The items on the survey instrument were either adapted or taken directly from this section of the Framework.

Distinguishing Practices in Science from Those in Engineering	
1. Asking Questions and Defining Problems	
Science begins with a question about a phenomenon, such as "Why is the sky blue?" or "What causes cancer?," and seeks to develop theories that can provide explanatory answers to such questions. A basic practice of the scientist is formulating empirically answerable questions about phenomena, establishing what is already known, and determining what questions have yet to be satisfactorily answered.	**Engineering** begins with a problem, need, or desire that suggests an engineering problem that needs to be solved. A societal problem such as reducing the nation's dependence on fossil fuels may engender a variety of engineering problems, such as designing more efficient transportation systems, or alternative power generation devices such as improved solar cells. Engineers ask questions to define the engineering problem, determine criteria for a successful solution, and identify constraints.

Figure 1. Excerpt from the *Framework for K–12 Science Education* showing a side-by-side comparison of science and engineering applications (NRC, 2012, p. 50).

To ensure a clear distinction between science and engineering and accurate representation of the various STEM modeling techniques, the instrument was also reviewed by a committee of STEM experts. A pilot group of high school teachers was consulted to ensure that the instrument's language was not too dense or difficult to understand.

Data

The data were collected in May 2014, which is important for two reasons. First, the school year was drawing to a close in Utah, and the timing likely affected the response rate, which was only 14%. Second, the data were drawn from a population of teachers whose state standards had not yet been affected by the NGSS in any way. At that time, the standards had been published for less than a year, and the state had not yet placed any expectations on teachers to follow them; it was also unlikely that teachers had received any professional development on implementing the NGSS. Thus, the participating science teachers had not been given any express engineering standards, expectations, or training regarding the NGSS—a window of opportunity that was likely closing. The data, therefore, can be interpreted as a snapshot in time of one STEM discipline's readiness to adopt a more integrated STEM curriculum—after the standards had been published and before any professional development was administered.

The data were analyzed using ordinary least squares (OLS) regression. OLS regression is robust to violations of the normality assumption when sample sizes are sufficiently large, which is true for these data. Robust standard errors were used in all calculations to account for any heteroscedasticity present in the data.

Results

The 11 survey items (α = 0.96) measuring feelings of preparedness to engage with engineering design indicated an average preparedness between *somewhat prepared* and *prepared* ($M = 3.45$, $SD = 0.97$). The four survey items (α = 0.84) measuring teachers' agreement with the use of different modeling solutions in instruction has a mean response just above *agree* ($M = 4.15$, $SD = 0.54$). This means that on the whole, science teachers agreed that modeling techniques from all STEM disciplines should be used when teaching engineering design.

Table 1
Summary of Regression Analysis on Secondary Science Teachers' Self-Reported Preparedness to Teach Engineering Design

	Model 1		Model 2	
Variable	β	*SE*	β	*SE*
Intercept	3.18^{***}	(0.25)	3.32^{***}	(0.23)
Number of years teaching	-0.01	(0.01)	-0.01	(0.01)
Biology endorsement	-0.07	(0.30)	-0.14	(0.30)
Physics endorsement	1.19^{***}	(0.29)	0.87^{**}	(0.32)
Physical science endorsement	0.35	(0.23)	0.36	(0.21)
Earth science endorsement	0.45	(0.29)	0.35	(0.27)
Chemistry endorsement	-0.04	(0.30)	-0.03	(0.31)

Environmental science endorsement	-0.15	(0.35)	-0.11	(0.34)
Integrated science endorsement	0.02	(0.27)	-0.03	(0.26)
Other science endorsement	0.11	(0.26)	-0.02	(0.24)
Modeling solutions			0.45^{*}	(0.19)
Observations	75		74	
R^2	0.27		0.33	
Adjusted R^2	0.17		0.22	
Residual *SE*	0.87 (*df* = 65)		0.83 (*df* = 63)	
F Statistic	2.69^{**} (*df* = 9; 65)		3.11^{***} (*df* = 10; 63)	

Note. The dependent or outcome variable is measured on a 5-point, 11-item (α = 0.96) Likert scale in which 5 = *very well prepared*, 4 = *prepared*, 3 = s*omewhat prepared*, 2 = *not very prepared*, 1 = n*ot prepared at all*. Output was created using the *R* statistical package developed by Hlavac (2015).
$^{*}p < 0.1$. $^{**}p < 0.05$. $^{***}p < 0.01$.

The data were collected from a group of licensed science teachers with varying endorsements in Utah. Therefore, Model 1 in Table 1 takes for its reference category a licensed teacher who is interested in teaching science, has no science endorsements, and has 0 years of teaching experience (e.g., a recent graduate). Model 1 in Table 1 has an intercept value of 3.18, indicating that such a teacher, on average, would feel slightly above *somewhat prepared*. If the new science teacher has a physics endorsement then he or she would, on average, report a 4.37 feeling of preparedness to interact with engineering practices. This rating would place the new physics teacher as being somewhere between *prepared* and *very well prepared*.

None of the other science teaching endorsements were statistically significant, nor was time spent teaching statistically significant. The physics coefficient is not only large in magnitude, but is also much larger than its standard error, leading to a high degree of statistical significance. This suggests that something about the preparation of physics teachers leads them to feel more prepared to teach engineering design than other science teachers.

When examining the teachers' agreement that modeling techniques from all STEM disciplines should be used when teaching engineering design, the impact of holding a physics endorsement is lessened, and most of the other nonsignificant coefficients are also reduced—as seen in Model 2 of Table 1. The intercept stays in approximately the same place, rising only slightly. The model's adjusted *R* squared is 0.22, reflecting an increase of .05, indicating that

5% more variance in the observed data can be explained by a person's agreement that modeling techniques from all STEM disciplines should be used when teaching engineering design. The effect of a physics endorsement is also lower. A one unit increase in modeling solutions represents an increase of 1 point a person's overall score on the four modeling solutions items (e.g., an average shift across all indicators from *somewhat prepared* to *prepared*). A one unit increase in modeling solutions can also be thought of as an increase of approximately two standard deviations.

In interpreting the data, an important consideration is that the data for modeling solutions have been centered at its mean (corresponding approximately with *likely* to use modeling). Therefore, if a person is average in their views about interdisciplinary STEM instruction, no increase in preparedness is predicted. A person's baseline preparedness, as indicated by the intercept, can go up or down depending on whether the teacher is above or below average in their likelihood to model solutions.

A teacher with a physics endorsement, who *strongly agrees* that one should use various STEM modeling techniques to create and test solutions—from mathematics all the way to construction—would have a predicted composite score of 4.64 on the preparedness to teach engineering survey items and would be categorized as closer to *very well prepared* than *prepared*.

Discussion

In interpreting the results of this study, one should be mindful of the cross-sectional nature of the dataset, which does not allow for causal inferences. Further, the convenience sample and low response rate likely introduce bias. More data should be collected in ways that do not have the same limitations to check for replication of the findings. As with many electronic surveys, the participants are left to their own internalized meaning for each number on the Likert scale. Although an attempt to unify understanding was made by providing participants with examples to clarify the meaning of each possible response, there is likely some variation among respondents in their interpretation of the scale, which damages the internal validity of the study.

The four survey items measuring a teacher's agreement regarding modeling solutions account for multiple methods of modeling, including: computer modeling, mathematical modeling, scientific modeling, and real-life construction and building models or prototypes. Embedded in these varying methods of modeling are the skillsets for each letter of the STEM acronym. A teacher who is strong in only one area is unlikely to have a composite score as high as a teacher who is strong in each area. Given the sample of science teachers, it is likely that an average score in the sample captured here reflects strong scientific prowess and that an above average score indicates additional skills in some combination of mathematics, technology, and engineering.

The finding that physics teachers in this sample felt more prepared to teach engineering design than other science teachers is interesting. The increased feelings of preparedness could be due to the location of the study; in Utah, Physics with Technology is offered as a secondary course, giving physics teachers more exposure to other STEM disciplines. It could also be due to the related nature of physics and engineering. There are undoubtedly traits about people that drive them to choose specific endorsements and careers. These same underlying and unknowable traits may contribute to the physics teachers' preparedness to engage with engineering content. Although we have suggested some possible reasons here, we do not know enough to make any causal judgements about why the physics teachers in this study felt more prepared to teach engineering design than other science teachers. This finding warrants further investigation.

The NGSS's inclusion of engineering design is a move toward a more integrated STEM curriculum. These data suggest that individuals who are comfortable in all of the fields—science, technology, engineering, and mathematics—are the most prepared to teach the integrated curriculum. As we move toward a more integrated curriculum and as STEM continues as a cornerstone of that movement, it will be important to provide all teachers involved with STEM opportunities to better learn each area with an emphasis on areas of personal weaknesses.

We recommend that future studies evaluate how well-rounded STEM teachers affect student outcomes in STEM courses, as compared to single-subject teachers (e.g., math teacher, science teacher, technology teacher) without additional training teaching STEM courses.

Conclusion

With the inclusion of STEM across the standards, it becomes clear that educators in the STEM disciplines must work together and break down personal silos in order to break down curricular silos. The message for administrators is to look to teachers from all STEM-related fields when selecting a teacher for STEM courses. When staffing STEM classrooms, math teachers and technology and engineering teachers should be considered along with science teachers. Furthermore, even the most well-rounded STEM teachers should be provided with professional development in the areas in which they are not certified.

Preservice instructors in science, technology, engineering, and mathematics should consider ways to incorporate more STEM preparation into teacher preparation. Policy makers and stakeholders should also realize that STEM is more than simply science and sometimes mathematics. STEM is a concept that breaks through silos and rewards those who are willing to blend content from multiple subjects. A teacher's willingness to go beyond scientific or mathematical modeling of solutions and engage with computer modeling as well as physical creation through the construction and building of prototypes is predictive of higher preparedness in teachers.

References

Asghar, A., Ellington, R., Rice, E., Johnson, F., & Prime, G. M. (2012). Supporting STEM education in secondary science contexts. *Interdisciplinary Journal of Problem-Based Learning*, *6*(2), 85–125. doi:10.7771/1541-5015.1349

Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). *Report of the 2012 national survey of science and mathematics education*. Chapel Hill, NC: Horizon Research. Retrieved from http://www.horizon-research.com/2012nssme/wp-content/uploads/2013/02/2012-NSSME-Full-Report-updated-11-13-13.pdf

Branch, G. (2013, April 9) Evolution and climate change in the NGSS. *National Center for Science Education News.* Retrieved from http://ncse.com/news/2013/04/evolution-climate-change-ngss-0014800

Heitin, L. (2016, February 17). Hawaii adopts the *Next Generation Science Standards*. *Education Week*. Retrieved from http://blogs.edweek.org/edweek/curriculum/2016/02/hawaii_adopts_the_next_generation_science_standards.html?cmp=SOC-SHR-TW

Hlavac, M. (2015). Stargazer: Well-formatted regression and summary statistics tables (R package version 5.2). Retrieved from http://CRAN.R-project.org/package=stargazer

International Technology and Engineering Educators Association. (2012, March 18). *The Council on Technology Teacher Education (CTTE) changes its name to the Council on Technology and Engineering Teacher Education (CTETE)* [Press release]. Retrieved from https://www.iteea.org/News/39955/40081.aspx

Johnson, H., & Cotterman, M. (2013). Collaborative efforts to put the ‘E’ back in STEM. *National Science Teachers Association Reports*, *25*(4), 3. Retrieved from http://www.nsta.org/docs/NSTAReportsNov13EntireIssueFinal.pdf

National Council for Accreditation of Teacher Education. (2006). *What makes a teacher effective?* Washington, DC: Author. Retrieved from www.ncate.org/LinkClick.aspx?fileticket=JFRrmWqa1jU=

National Academies of Sciences, Engineering, and Medicine. (2014, March 6). Connecting individual K-12 STEM subjects has potential advantages, poses challenges. *News from the National Academies.* Retrieved from http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=18612

National Academy of Engineering. (2004). *The engineer of 2020: Visions of engineering in the new century*. Washington, DC: National Academies Press. doi:10.17226/10999

National Academy of Engineering, Committee on Standards for K–12 Engineering Education. (2010). *Standards for K–12 engineering education?* Washington, DC: National Academies Press. doi:10.17226/12990

National Academy of Engineering. (2014, March). *STEM integration in K-12 education: Status, prospects, and an agenda for research* (Report brief). Retrieved from https://www.nae.edu/File.aspx?id=108921

Wilson, S., Schweingruber, H., & Nielsen, N. (Eds.). (2015). *Science teachers' learning: Enhancing opportunities, creating supportive contexts*. Washington, DC: National Academies Press. doi:10.17226/21836

Next Generation Science Standards. (2017a). The need for standards. Retrieved from http://www.nextgenscience.org/need-standards

Next Generation Science Standards. (2017b). Lead state partners. Retrieved from http://www.nextgenscience.org/lead-state-partners

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: National Academies Press. doi:10.17226/18290

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press. doi:10.17226/13165

Rotherham, A. J., & Willingham, D. T. (2010). "21st-century" skills: Not new, but a worthy challenge. *American Educator*, *34*(1), 17–20. Retrieved from http://www.aft.org/sites/default/files/periodicals/RotherhamWillingham.pdf

Trilling, B., & Fadel, C. (2009). *21st century skills: learning for life in our times*. San Francisco, CA: Jossey-Bass.

About the Authors

Tyler Ames (R.Tyler.Ames@gmail.com) is a Ph.D. candidate in the School of Education at The Johns Hopkins University.

Edward Reeve is the Interim Vice-Provost in the office of the Executive Vice President & Provost at Utah State University. He is also the current president of the International Technology and Engineering Educators Association.

Gary Stewardson is an Associate Professor in the Technology and Engineering Education Program in the School of Applied Sciences, Technology, and Education at Utah State University.

Kimberly Lott is an Associate Professor in the Emma Eccles Jones College of Education and Human Services in the School of Teacher Education and Leadership at Utah State University.

Appendix

Table A1

Possible Responses on the 11 Survey Items Regarding Preparedness to Teach Engineering Design and Their Corresponding Description

Response	Evaluated statement	Assigned value
Very well prepared	I have taught it before and feel prepared to teach it again.	5
Prepared	I know enough to teach it, but have never prepared a lesson with it.	4
Somewhat prepared	I know about it, but would need to brush up on it.	3
Not very prepared	I have seen it and know what preparation materials to consult, but I do not know much else about it.	2
Not prepared at all	I have never seen it before.	1

Important Engineering and Technology Concepts and Skills for All High School Students in the United States: Comparing Perceptions of Engineering Educators and High School Teachers

Michael Hacker and Moshe Barak

Abstract

Engineering and technology education (ETE) are receiving increased attention as components of STEM education. Curriculum development should be informed by perceptions of academic engineering educators (AEEs) and classroom technology teachers (CTTs) as both groups educate students to succeed in the technological world. The purpose of this study was to identify ETE concepts and skills needed by all high school students in the United States and to compare perceptions of AEEs and CTTs relative to their importance. This research was carried out using a modified Delphi research methodology involving three survey rounds interspersed with controlled opinion feedback.

Consensus was found on 14 of 38 survey items within five ETE domains (design, modeling, systems, resources, and human values) that are repeatedly referenced in the literature. The most important competencies for high school students to learn were to: (1) identify and discuss environmental, health, and safety issues; (2) use representational modeling to convey the essence of a design; (3) use verbal or visual means to explain why an engineering design decision was made; and (4) show evidence of considering human factors when proposing design solutions. The study established a consensus between AEEs and CTTs that contributes to the body of knowledge about what high school students should learn in ETE. Study results can inform curriculum development and revision of the *Standards for Technological Literacy*.

Keywords: Delphi; engineering and technology education; high school; STEM; survey

Because of the essential roles that engineering and technology play in addressing societal and environmental challenges, support for PreK–12 engineering and technology education (ETE) programs in the United States has been rapidly growing (Katehi, Pearson, & Feder, 2009). There is growing recognition that school-based ETE experiences can be pedagogically valuable for all students—not only in providing an effective way to contextualize and reinforce STEM skills but also in mobilizing engineering thinking as a way for young people to approach problems of all kinds (Brophy & Evangelou, 2007; Forlenza, 2010). The purpose of this study was to compare the perceptions of two constituencies whose missions focus on preparing students to succeed in our technological world through engineering and technology education: academic engineering educators (AEEs) who prepare future engineers at the university level and high school classroom technology teachers (CTTs) who teach engineering and technology courses at the secondary school level. The study established a consensus among the groups about the most important ETE concepts and skills that all students in the United States should learn by the time they graduate from high school.

Literature Review

A literature review established a basis for identifying competencies for the initial item set in the study's survey instrument. The review also determined how to optimally use Delphi research methodology to converge expert opinion to arrive at consensus (RAND Corporation, 2017) and examined differences between engineering and technology and the preparation of professionals in those fields.

Differences Between Engineering and Technology Engineering. According to the Engineers' Council for Professional Development (ECPD), the predecessor of the Accreditation Board for Engineering and Technology (ABET):

> Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind. (ECPD, 1979; as cited in National Research Council [NRC], 1986, p. 74)

An earlier (1941) definition advanced by ECPD the is that "engineering is the creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination" (Greefhorst & Proper, 2011, p. 9). Bloch (1986) wrote that "*engineering is the process of investigating how to solve problems.* This process leads to a body of engineering knowledge consisting of concepts, methods, data bases, and, frequently, physical expressions of results" (p. 28). Wulf and Fisher (2002) describe "what engineers do . . . [as] 'design under constraint'" (p. 36).

Technology. The National Assessment Governing Board (2013) defines technology as "any modification of the natural world done to fulfill human needs or desires" (p. xi). According to de Vries (2005), technology is "the human activity that transforms the natural environment to make it fit better with human needs, thereby using various kinds of information and knowledge, various kinds of natural (material, energy) and cultural resources (money, social relationships, etc.)" (p. 11). Kline (1985) suggests that technology is viewed in four ways: as an artifact, as a methodology or technique, as a system of production, and as a sociotechnical system. Swyt (1989), at the National Institute of Science and Technology, differentiates between engineering and technology by explaining that engineering is oriented toward the solution of specific problems, whereas technology is oriented toward development of new capability.

Preparation of Academic Engineering Educators and Classroom Technology Teachers

Academic engineering educators and classroom technology teachers in the United States come from different educational traditions, although both groups advocate the importance of technological literacy for the general population. Engineering emerged as a separate subject with the founding of the first schools of engineering and professional societies in the 18th century. AEEs typically have postgraduate degrees in engineering. In the United States, technology education emerged from industrial arts, and worldwide, technology education had its roots in crafts teaching. State-certified CTTs typically have master's degrees in technology education.

ABET Program Standards for Engineering Programs. The *Criteria for Accrediting Engineering Programs* by ABET's Engineering Accreditation Commission (2012) state that engineering graduates must have the ability to "apply knowledge of mathematics, science, and engineering"; "design and conduct experiments, as well as analyze and interpret data"; "design a system, component, or process to meet desired needs"; "function on multidisciplinary teams"; "identify, formulate, and solve engineering problems"; "communicate effectively"; and "use the techniques, skills, and tools necessary for engineering practice" (p. 3). Graduates must also "understand the impact of engineering solutions in a global, economic, environmental, and societal context"; recognize "the need for, and an ability to engage in life-long learning"; and understand "contemporary issues" (p. 3). ABET requires educational programs to include a major engineering design experience that builds upon the fundamental concepts of mathematics, basic sciences, the humanities and social sciences, engineering topics, and communication skills. Engineering topics must include subjects in the engineering sciences and engineering design, which "have their roots in mathematics and basic sciences but carry knowledge further toward creative application" (p. 4).

NCATE Program Standards for Technology Education Programs. The National Council for Accreditation of Teacher Education (NCATE) is the education profession's mechanism to help establish high-quality teacher preparation programs (National Council for Accreditation of Teacher Education [NCATE], 2008). NCATE has developed program standards (e.g., International Technology Education Association [ITEA] Council on Technology Teacher Education [CTTE], 2003; NCATE, 2008) that define the criteria for accrediting technology education programs in much the same manner as ABET has defined criteria for accrediting engineering programs. NCATE standards (ITEA, CTTE, 2003) state that "within the contexts of the *Designed World*," "technology teacher education program candidates [must] develop an understanding of the nature of technology" (p. 22), "of technology and society" (p. 24), "of design" (p. 26), and "of the designed world" (p. 30) as well as "develop abilities for a technological world" (p. 28). Candidates must also "design, implement, and evaluate curricula based upon Standards for Technological Literacy" (p. 32), "use a variety of effective teaching practices that enhance learning of technology" (p. 34), "design, create, and manage learning environments that promote technological literacy" (p. 36), "understand students as learners, and how commonality and diversity affect learning" (p. 38), and engage "in comprehensive and sustained professional growth" (p. 40).

In a comparison of professional competencies required by ABET for engineers and NCATE for technology teachers, Hacker (2005) found that ABET focused on technical content preparation for engineers, whereas NCATE focused on pedagogy for teachers; however, a high degree of alignment was evident with respect to other competencies. He also found that both professional groups were well prepared in areas of professional practice, design and problem solving, team functioning, ethical and professional responsibility, communication skills, social and cultural impacts, and professional growth. One clear difference between the groups was that engineers were much more rigorously prepared in mathematics and science than technology teachers.

Projects Oriented Toward Formulating an ETE Knowledge and Skill Base

Major projects that have identified student learning outcomes in ETE include the *Standards for Technological Literacy* (STL; International Technology Education Association [ITEA], 2007); the National Academy of Engineering (NAE) reports (Katehi, Pearson, & Feder, 2009; National Academy of Engineering [NAE], 2010); the National Research Council's (2012) *Framework for K–12 Science Education* and the *Next Generation Science Standards* (NGSS Lead States, 2013), which built upon it; the *Technology and Engineering Literacy Framework* for the National Assessment of Educational Progress (NAEP; National Assessment Governing Board [NAGB], 2013); and studies conducted by Custer, Daugherty, and Meyer (2010), Childress and Rhodes (2008), and Rossouw, Hacker, and de Vries (2010).

The International Technology Education Association (ITEA), now the International Technology and Engineering Educators Association (ITEEA), developed the STL to identify "what students should know and be able to do in order to be technologically literate" (ITEA, 2007, p. vii). The standards are divided into five knowledge categories (comprising 20 content standards and 98 benchmarks at the Grades 9–12 level): *the nature of technology*, *technology and society*, *design*, *abilities for a technological world*, and *the designed world*.

NAE's Committee on Standards for K–12 Engineering Education (2010) reviewed eight prior studies "that attempt[ed] to identify of core concepts, skills, and dispositions appropriate to K–12 engineering education" (p. 24). The 16 categories that they found included: design, STEM connections, engineering and society, constraints, communication, systems, systems thinking, modeling, optimization, analysis, collaboration and teamwork, creativity, knowledge of specific technologies, nature of engineering, prototyping, and experimentation (p. 35).

The *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013) grew from the National Research Council's (2012) *Framework for K–12 Science Education*. The NGSS integrated *disciplinary core ideas*, *science and engineering practices*, and *crosscutting concepts* related to technology and engineering (including design, modeling, and systems) into student performance expectations (NGSS Lead States, 2013).

The National Assessment of Educational Progress (NAEP) is an assessment of "what U.S. students know and are able to do in a range of subject areas" (NAGB, 2013, p. ix). In 2014, the NAEP Technology and Engineering Literacy Assessment was administered to 21,500 students in Grade 8 (The Nation's Report Card, 2016). "The assessment . . . consist[s] of technological content areas . . . and technological practices that characterize the field" among which are *design and systems*, *information and communication technology*, and *technology and society* (NAGB, 2013, p. A-9).

In a study titled "Formulating a Concept Base for Secondary Level Engineering: A Review and Synthesis," Custer, Daugherty, and Meyer (2010) identified 13 major engineering concepts (among them design, systems, and modeling) that were drawn from a variety of sources in the literature and from three focus groups of engineering experts.

In another study, Childress and Rhodes (2008) examined what high school students "should know and be able to do prior to entry into a postsecondary engineering program" (p. 5). Categories identified included *engineering design*, *applications of engineering design*, *engineering analysis*, *engineering and human values*, *engineering communication*, *engineering science*, and *emerging fields of engineering*.

As a part of the Concepts and Contexts in Engineering and Technology Education (CCETE) Project, a collaboration between Delft University of Technology in the Netherlands and Hofstra University in New York State, Rossouw et al. (2010) conducted a Delphi study with 32 international experts from nine countries to identify overarching themes and contexts that could be used to develop curricula for education about engineering and technology was developed. Table 1 lists the five main themes and associated subconcepts identified in that study.

Table 1
CCETE Project Overarching Themes and Subconcepts

Themes	Subconcepts
Design	Optimization and trade-offs; criteria and constraints; iteration
Modeling	Representational, explanatory, predictive
Systems	Systems/subsystems; input-process-output; feedback and control
Resources	Materials, energy, information, time, tools, humans, capital
Human values	Sustainability; technological assessment; creativity/innovation; ethical decisions

In this comparison of perceptions study, we used the five themes that emerged from the CCETE Project study as organizing categories because they aligned so well with those identified by other major projects. Further details about important ETE concepts and skills within these categories were added.

Summary of the Literature Review

Through the literature review, we identified ETE knowledge and skill sets that scholars believe to be important for all high school students to learn within their fundamental education. These concepts and skills informed the set of items that comprised this study's Round 1 survey instrument. We established the basis upon which expert panelists suggested additions, changes, or deletions to survey items in subsequent Delphi rounds.

Research Questions

The research questions for this comparison of perceptions study were:

1. **RQ1**: Where does the strongest consensus exist among the expert panelists relative to the importance of specific ETE concepts and skills that all high school students in the United States should attain as part of their fundamental education?
2. **RQ2**: Which ETE concepts and skills does the expert panel perceive to be most important for high school students to attain as part of their fundamental education?
3. **RQ3:** Where are there significant differences between academic engineering educators' and classroom technology teachers' perceptions of the importance of ETE concepts and skills?
4. **RQ4:** Which concepts and skills that academic engineering educators and classroom technology teachers agree are highly important are not presently addressed by the STL?

Methodology

In this study, we employed Delphi survey research methodology because it is effective in soliciting and converging experts' opinions to obtain consensus (Salancik, Wenger, & Helfer, 1971). Delphi methodology assures anonymity, provides ongoing feedback to participants, and reduces the effects of bias due to group interaction (Dalkey, 1972).

The purpose of a Delphi study is "to obtain the most reliable opinion consensus of a group of experts by subjecting them to a series of intensive questionnaires in depth interspersed with controlled opinion feedback" (Dalkey & Helmer, 1963, p. v). Studies comparing Delphi with other methods (Ulschak, 1983) confirmed its effectiveness in generating ideas and its efficient use participants' time.

Typically, a Delphi study starts by asking participants to respond to a specific question or issue. In subsequent rounds, participants are asked to consider feedback from the previous round, and the instrument is modified to reflect experts' opinions. "The essential feature is the use of quantitative feedback given to each participant" (Uebersax, 2000, 4.1 The Delphi Method, para. 1). When respondents' estimates for an item do not fall within the range of group responses, they are asked to reconsider their position and, when justified, change their response. Thus, an attempt is made to achieve consensus (Wicklein & Rojewski, 1999).

As is often done in Delphi studies (Chalmers, 2014; Greer, 2008; Iqbal & Pipon-Young, 2009; Scott, Washer, & Wright, 2006), we used open-ended text boxes to invite panel members to provide feedback during survey rounds and at the conclusion of the survey.

Modified Delphi Methodology

In this study, we used a modified Delphi research methodology, which "is similar to the full Delphi in terms of procedure (i.e., a series of rounds with selected experts) and intent (i.e., to predict future events and arrive at consensus)" (Custer, Scarcella, & Stewart, 1999, p. 51). Modifications included: (a) "beginning the process with a set of pre-selected items" (p. 51) that were drawn from the literature review and validated by experts and (b) adding validation panel meetings. Starting with a set of preselected items "(a) typically improves the initial round response rate, and (b) provides a solid grounding in previously developed work" (p. 51). Meetings of a validation panel verified the importance and level of abstraction of initial items, vetted prospective panelists to confirm their expertise, and added structure to the survey (Rossouw, Hacker, & de Vries, 2010).

In accordance with the method suggested by Fowles (1978), seven stages characterized this study's Delphi procedure.

- Stage 1: Define the research questions.
- Stage 2: Assemble the panel of experts (with help from the validation panel).

- Stage 3: Design and validate the initial set of survey items (with validation panel help).
- Stage 4: Conduct the three-round Delphi survey.
    - Round 1 included a beginning set of concepts drawn from the literature review.
    - Round 2 reflected changes based on panel input and solicited additional suggestions.
    - Round 3 included further changes based on final panel review.
- Stage 5: Analyze survey results.
- Stage 6: Summarize Conclusions.
- Stage 7: Convene validation panel to review researchers' conclusions and reach consensus.

In the literature, three Delphi rounds have been found sufficient to arrive at consensus (Brooks, 1979) because after three iterations, not enough new information is gained to warrant the cost of more administrations (Altschuld, 1993). Panelists were asked to rate each concept on a 7-point Likert scale using these descriptors: *strongly agree* (7), 6, *moderately agree* (6), *agree* (5), *indifferent* (4), *moderately disagree* (3), *disagree* (2), or *strongly disagree* (1). Panelists were invited to suggest and justify items that should be added or deleted. Panelists were informed that items would be modified based on their suggestions, and they were invited to reconsider item ratings if theirs were at variance with whole-group median ratings.

Participant Selection and Panel Size

Because the success of the Delphi technique relies upon experts' judgment, selection of panelists was critical, and random selection was not considered. "Large numbers of respondents generate many items and ideas making the summarizing process difficult" (Ludwig, 1997, Participation Selection, para. 1). Delbecq, Van deVen, and Gustafson (1975) suggest that 10 to 15 panelists are sufficient. Dalkey (1972) reported that reliability, with a correlation coefficient approaching 0.9, was found with a panel size of 13. J. G. Wells (personal communication, March 9, 2013) suggested that in research concerned with intragroup and intergroup judgments, subgroups of 16 panelists should be recruited. To allow for attrition, we recruited 18 AEEs and 17 CTTs (35 panel members in total) for this study.

Selection Criteria

Participants were selected because they were leading authorities in their fields with (a) documented participation in initiatives linking engineering and K–12 education, (b) a minimum of 5 years of experience teaching engineering or technology education, and (c) proven ability to formulate their thinking through research or active involvement in major funded projects. Participants were identified through recommendations from professional organizations and agencies (the American Society of Engineering Education, ITEEA, NAE, the

National Science Foundation, and the New York State Technology and Engineering Educators Association) and recommendations from validation panel members.

Validation Panel

The validation panel was composed of the researchers, two AEEs with over 10 years of K–12 ETE experience, and two CTTs who are professional leaders with over 10 years of K–12 ETE experience. Validation panel meetings were 3 hours in duration. A meeting was held at the onset of the study to assist us in selecting panelists and validating survey items. The second meeting was held after the study concluded to discuss results, frame conclusions, and establish a cutoff point for items to be deemed as highly important for all high school students to learn.

Instrumentation and Data Analysis Methodology

The survey was tested and conducted online using Qualtrics (2014) survey software. Data was exported to SPSS (Version 22.0) for analysis. With Likert scale data, the use of median scores is strongly favored (Hill & Fowles, 1975; Eckman, 1983; Jacobs, 1996). Data were treated as ordinal data (Comrey, 1973) and were reported using descriptive statistics: medians, frequencies, percentiles, and interquartile range (IQR) statistics. A nonparametric test (the Mann-Whitney U) was used to determine statistically significant differences between the two study groups, and *p*-values were reported at the $\alpha = 0.05$ level. Data provided insight into the study's research questions as follows:

Determining consensus (Research Question 1). Data analysis determined the *strength of consensus* on each item by subgroup and whole group. According to Rojewski and Meers (1991), "Consensus . . . [is] determined using the interquartile range of each research priority [or concept] statement. Interquartile Range is a descriptive statistic defined as the distance between the first and third quartiles (i.e., the middle 50% of scores)" (p. 36). Low IQRs are one measure of strong consensus on an item.

In this study, we used a 7-point scale, and whole-group IQRs ranged from 0.79 to 1.98. After an analysis of scores within each quartile for each item, the researchers and the validation panel established that an IQR of ≤ 1.61 should be considered an indicator of strong panel consensus because:

- Sixteen of the 17 highest rated items (with median ratings of ≥ 6.00, "agree") displayed IQRs of ≤ 1.61 (indicating whole-group agreement that those items were of high importance), and
- Three of the four lowest rated items (medians ≤ 5) displayed IQRs of ≤ 1.61 (indicating whole-group agreement that those items were of lower importance).

As suggested by Rayens and Hahn (2000), the IQR may be an insufficient criterion for determination of agreement. "Frequency distributions are often used to assess agreement (McKenna, 1994)" (Na, 2006, p. 44), and the criterion of some percentage of panelists responding to any given response category is used to determine consensus (Loughlin & Moore, 1979, p. 103; Seagle & Iverson, 2002, p. 1; Putnam, Speigel, & Bruininks, 1995; as cited in von der Gracht, 2008, p. 53).

In this study, factors determining consensus included the whole-group IQR and frequency of responses at the high end of the scale (respondents choosing scale points 6–7) and at the low end of the scale (respondents choosing scale points 1–4). These "consensus factors" are shown in Table 2.

Table 2
Consensus Factors

Item importance level	Determinants of consensus
Consensus that an item is of higher importance	If IQR ≤ 1.61 and frequency of high scores (6–7) ≥ 80%
Consensus that an item is of lower importance	If IQR ≤ 1.61 and frequency of low scores (1–4) ≥ 25%

Determining importance (Research Question 2). To determine importance, we examined Round 3 panelists' median ratings for each item. Whole-group and subgroup (AEE and CTT) median ratings for each survey item were determined using SPSS (Version 22.0) software. The medians were ranked using the data ranking function of Microsoft Excel. The ranking indicated which of the survey items that the subgroups and the entire panel perceived to be most important. Because median ratings for all items were quite high (ranging from 6.71 to 4.60 on a 7-point scale), the validation panel set the item cutoff point for "high importance" at median ratings of ≤ 6.0. No survey items were deemed unimportant by the validation panel.

Determining significant differences (Research Question 3). The Mann-Whitney U nonparametric test was used to analyze if intragroup median item ratings were significantly different. Nonparametric tests compare medians rather than means, and as a result, the influence of outliers is negated (Hayes, 1997). At the conclusion of the third survey round, a lack of consensus on any survey item reflected sustained differences between the groups in that perceptual differences persisted despite the use of the Delphi instrument as a means to develop consensus. An alpha level (α) = 0.05 was used for all statistical tests of significance. The null hypothesis (H_o) was: There is no significant difference between AEEs and CTTs in their perception of the importance of ETE concepts and skills. A P-value of ≤ 0.05 on any survey item led to a rejection of the null hypothesis for that item.

Gap analysis with the *Standards for Technological Literacy* (Research Question 4). In this study, we identified competencies deemed important for all high school students to attain as part of their fundamental education. We did a gap analysis with the STL to compare survey items rated "important" by the Delphi panel to existing benchmarks in the high school level standards. If items were similar, rewording of the STL benchmarks based on survey item wording was suggested. The validation panel confirmed the gap analysis.

Findings

Findings indicated where consensus between the AEEs and CTTs was reached about items that were of higher or lower importance. In discussing findings, items that were rated highest by the whole group and by each subgroup are identified, significant differences between subgroups are illuminated, and potential revisions to the STL are suggested. Additionally, findings determined the internal consistency (reliability) of the survey instrument and the mean value of the participants' responses with regard to design, modeling, systems, resources, and human values.

Initial survey items were based on the literature review and on recent projects probing the importance of ETE concepts. As a result of prelaunch trials, the Round 1 survey instrument was revised 11 times prior to first round administration as part of a continuous improvement process.

The response rate to survey Round 1 was 88.6%, and 192 comments were received from panelists. Based on panelists' suggestions, numerous changes were made. We attempted to be responsive to all suggestions; however, comments were sometimes contradictory, and we chose to accept suggested changes in wording that improved the clarity of the item. New items were added when two or more experts suggested its inclusion. Sixteen questions were reworded, and five new questions were added for the Round 2 survey.

The number of survey items increased from 32 items in Round 1 to 37 items in Round 2. In Round 2, panelists were asked to give high scores sparingly because the study was aiming to develop a list of the most essential concepts and skills. The response rate was again 88.6%. In Round 2, the IQRs of 13 of 32 items (40%) converged, attesting to the efficacy of the Delphi method at driving consensus.

In the final round, of the 34 panelists who were sent the Round 3 survey, 34 submitted responses (a 100% response rate). Respondents included 18 AEEs (four females and 12 males) and 16 CTTs (three females and 13 males). Appendix C presents the median ratings, standard deviations, percentiles, and whole-group IQRs by item. Findings are discussed below by research question.

Research Question 1

Where does the strongest consensus exist among the expert panelists relative to the importance of specific ETE concepts and skills that all high school students in the United States should attain as part of their fundamental education? AEE and CTT consensus about high importance was reached on 14 of 38 survey items based on both consensus factors (IQR ≤ 1.61 and frequency (6–7) ≥ 80%) being satisfied. The strongest consensus that items were highly important was found on Items R7 and M1: identify and discuss environmental, health, and safety issues involved in implementing an engineering project (Item R7) and use representational modeling (e.g., a sketch, drawing, or a simulation) to convey the essence of a design (Item M1). AEE and CTT consensus about lower importance was reached on two survey items based on both consensus factors (IQR ≤ 1.61 and frequency (1–4) ≥ 25%) being satisfied. The strongest consensus that items were of lower importance was found on Items D8 and D12: provide an example and an explanation of how design solutions can integrate universal design principles to help meet the needs and wants of people of all ages and abilities (Item D8) and describe, through an example, how the reliability of a system and the risks/consequences associated with its use have or have not been adequately considered prior to its implementation (Item D12). A list of items for which consensus was reached about higher and lower importance is included in Appendix A.

Research Question 2

Which ETE concepts and skills does the expert panel perceive to be most important for high school students in the United States to attain as part of their fundamental education? The ETE concept and skills perceived by the combined group to be most important for high school students to attain were: identify and discuss environmental, health, and safety issues involved in implementing an engineering project (Item R7); use representational modeling (e.g., a sketch, drawing, or a simulation) to convey the essence of a design (Item M1); explain why a particular engineering design decision was made, using verbal and/or visual means (e.g., writing, drawing, making 3-D models, using computer simulations; Item D6); show evidence of considering human factors (ergonomics, safety, matching designs to human and environmental needs) when proposing design solutions (Item HV6); and safely and correctly use tools and machines to produce a desired product or system (Item R4). Panelists' perceptions of the most important ETE items for high school students to learn, by whole-group median ratings and rankings, are included in Appendix B.

Research Question 3

Where are there significant differences between academic engineering educators' and classroom technology teachers' perceptions of the importance of ETE concepts and skills? Data analysis using the Mann-Whitney U test indicated that subgroup ratings were significantly different on four survey items at the $p < 0.05$ level (see Table 3). All of these items except the third (Item S5) were rated higher by AEEs than by CTTs. Not surprisingly, engineers, more than teachers, emphasized applying science and mathematics to the solution of design problems.

Table 3
Significant Differences in Median Item Ratings Between AEEs and CTTs Based on the Mann-Whitney U Test

		Median				
Item	Survey wording of item	AEEs (n = 18)	CTTs (n = 16)	Mann-Whitney *U* value	*df*	*p*-value exact sig. (2-tailed)
D2	Solve engineering design problems by identifying and applying appropriate science concepts.	6.35	5.80	81.00	33	.012
D11	Provide examples of how psychological factors (e.g., bias, overconfidence, human error) can impact the engineering design process.	5.27	4.69	91.00	33	.049
S5	Explain the difference between an open-loop control system and a closed-loop control system and give an example of each.	5.17	5.85	88.50	33	.040
S6	Develop and conduct empirical tests and analyze system and analyze test data to determine how well actual system results compare with measurable performance criteria.	6.21	5.36	89.00	33	.046

Research Question 4

Which concepts and skills that academic engineering educators and classroom technology teachers agree are highly important and are not presently addressed by the STL? The validation panel suggested that survey items with median ratings of ≥ 5.70 be considered for inclusion in the next iteration of the STL. Recommendations are made that the next iteration of the STL add, substitute, or reword standards based on 16 survey items that panelists agreed are highly important for high school students to attain as part of their fundamental education but are not presently addressed by the STL. Proposed changes to the STL are included in Appendix D.

Most STL benchmarks were written in terms of what students should learn; in this study, survey items were written in terms of what students should be able to do. Survey items might thus provide additional clarity to teachers and curriculum developers relative to measurable performances that would define important student capability. As an example, the present STL Standard 2Z indicates that students should know that: "Selecting resources involves trade-offs between competing values, such as availability, cost, desirability, and waste" (ITEA, 2007, p. 42). However, in the suggested additions, students should be able to:

- Improve an engineering design by identifying, making, and evaluating tradeoffs (D4);
- Give an example of and investigate the impact of a tradeoff a company might make between profitability and environmental, health, or safety concerns (HV4); and
- Engage in a group problem-solving activity to creatively generate several alternative design solutions and document the iterative process that resulted in the final design (D9).

Thus, students would be demonstrating their understanding of the above benchmark.

Additional Findings

Additional findings related to psychometric properties of the survey instrument (internal consistency reliability) and to comparing mean scores for all items within each of the five domains (subscales) of design, modeling, systems, resources, and human values.

Reliability. Often, Cronbach's alpha is used when investigating the reliability of instruments using continuous or interval data. However, because this study's data results from panelists' responses to items rated on a Likert scale (scale points 1–7), data is ordinal; therefore, an *ordinal alpha* index of reliability was used as an alternative. Reliability coefficients for each subscale were determined using statistical methods better suited to ordinal data analysis.

The SPSS Categories procedure *CATPCA* (a nonlinear Categorical Principal Components Analysis) uses optimal scaling to statistically transform ordinal data into a quantitative numerical variable (Meulman, Van der Kooij, & Heiser, 2004). CATPCA provides an ordinal alpha reliability measure, and the reliability coefficient calculated is for the transformed variables (IBM Support, 2013).

To compare and confirm reliability statistics, both Cronbach's Alpha and CATPCA ordinal alpha analyses were conducted (using SPSS, Version 22.0), and the results are shown in Table 4. Alpha reliability coefficients normally range between 0 and 1. "A reliability coefficient of 0.70 or higher is considered 'acceptable' in most social science research situations" (UCLA, Institute for Digital Research and Education, 2017, An Example, para. 2; see also George & Mallery, 2003; Kline, 1999). It is not surprising that the values for ordinal alpha were higher (because ordinal data is being analyzed) than those for Cronbach's alpha, which treats Likert scale data as interval data.

Mean values of responses by category. Although participants' answers to individual survey items are on an ordinal (Likert) scale, the answers to a group of items in a category can be regarded as close to normally distributed interval data. Therefore, these data were analyzed using mean values. A comparison of the means of each subgroup by category is shown in Table 4 and is also displayed graphically in Figure 1.

Table 4
Mean Values of AEEs (n = 18) and CTTs (n = 16) Final Round Responses Related to the Five Categories in the Questionnaire (Scale Points 1–7)

Category	Number of items	AEEs		CTTs		Cronbach's Alpha	CATPCA Ordinal Alpha
		Mean	*SD*	Mean	*SD*		
Design	12	5.8102	.63517	5.5885	.50412	.783	.857
Modeling	6	5.5926	.98389	5.6458	.62620	.773	.877
Systems	6	5.5926	.82490	5.7083	.40597	.595	.728
Resources	7	6.1429	.64635	6.2589	.53253	.623	.810
Human values	7	5.6825	.90159	5.5357	.53579	.794	.917

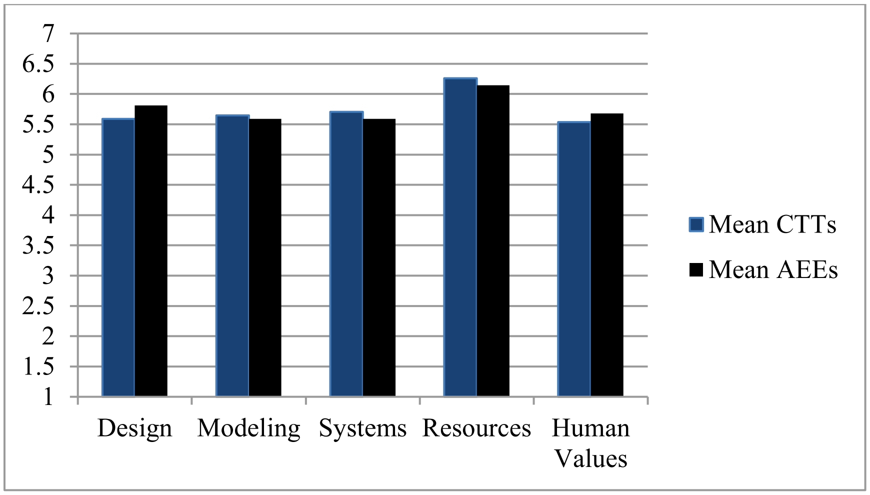


Figure 1. Mean scores for all items on each subscale by subgroup.

The highest mean scores for both subgroups were obtained in the Resources category. The lowest mean score for CTTs was in the Human Values category, and the lowest mean scores for AEEs were in the Systems and Modeling categories (tied).

In summary, salient findings included:

- Descriptive statistics including median ratings, standard deviations, and the Interquartile Range (IQR) for each item;
- A ranked analysis of the engineering and technology concepts and skills perceived to be most important for the general education of high school students by whole-group median rating;
- An identification of items for which differences between subgroups were statistically significant;
- A list of concepts and skills that experts agree are highly important for high school students to attain as part of their fundamental education that are not presently addressed by the STL; and
- Internal consistency reliability measures of the subscales.

Limitations

A limitation of the present research related to the selection of the expert panelists: there was a considerable imbalance between more experienced (presumably older) and less experience (presumably younger) panelists. Thus, perspectives of younger educators who might have reflected more contemporary views of the importance of certain ideas and skills may not have been adequately considered. Therefore, it is recommended that in selecting panelists for future studies, targeted efforts should be made to recruit younger panelists to determine if their perceptions about the importance of knowledge and skills related to contemporary technologies differ significantly from their more experienced, presumably older, colleagues.

Conclusions

Because engineering and technology education are receiving greater attention as components of STEM education, support for the establishment of PreK–12 ETE programs in the United States has been rapidly growing. Although university level academic engineering educators are an ideal professional constituency to ally with and support secondary school ETE programs, prior to this study, it was uncertain whether they held similar perceptions about the fundamental knowledge and skills that high school graduates need for life in a technological world to the classroom technology teachers who develop curriculum and deliver secondary school ETE instruction.

We have examined the alignment of the two constituencies' perceptions about the importance of key concepts and skills that all high school students in the United States should learn as part of their fundamental education. Our findings demonstrate that there is indeed a greater degree of concordance than there are perceptual differences between the two constituencies.

From a theoretical perspective, this research contributes to the body of knowledge about the most salient ideas and skills that students need to learn and understand in five overarching domains of engineering and technology that are repeatedly referenced in the literature: design, modeling, systems, resources, and human values. Additionally, this study provides the first research-based comparison of perceptions about important ETE ideas and skills between two constituencies whose missions focus on preparing students to succeed in our technological world through engineering and technology education.

From the methodological perspective, this study illustrates how the Delphi technique can be employed within an education research study in which the emphasis is on eliciting and comparing the perceptions of different groups of experts. On one hand, the Delphi technique was utilized to identify perceptual differences between expert groups with different backgrounds; on the other hand, it was used to bridge differences in background in order to forge consensus. The Delphi research methodology used in this study was modified from the classical Delphi approach in several ways. Modifications that could be considered by other researchers include: (1) beginning the Delphi process with a set of carefully preselected items that were drawn from the literature review, (2) adding validation panel reviews and meetings to help identify panelists and initial survey items and to reach post-survey consensus, (3) establishing a set of selection criteria for choosing expert panelists, (4) including open-ended text boxes to solicit and present arguments for or against items being included in the list of "important" survey items, (5) establishing an IQR range on a Likert scale as being indicative of strong consensus, and (6) establishing frequency distribution percentage criteria for responses at both the high end and the low end of the scale.

Within the framework of this research study, a method for examining internal consistency reliability suitable to interpreting ordinal data is proposed based on Categorical Principal Components Analysis (CATPCA), as a replacement for the Cronbach's alpha coefficient that is typically used to interpret interval data.

From a practical perspective, this research contributes to engineering and technology education by:

- Establishing a basis for educators to develop local, state, and national ETE curriculum frameworks, instructional materials for students and teachers, and assessments of teaching and learning;
- Informing a revision of the *Standards for Technological Literacy*;
- Elevating the status of school-based engineering and technology education by improving the rigor and robustness of curriculum and by increasing the advocacy of university faculty members and engineering educators;
- Guiding the design of proposals to foundations and government agencies to fund improvement of ETE curriculum and instruction.

References

Accreditation Board for Engineering and Technology. (2000). *Criteria for accrediting engineering programs*. Baltimore, MD: Author.

Accreditation Board for Engineering and Technology, Engineering Accreditation Commission. (2012). *Criteria for accrediting engineering programs: Effective for reviews during the 2013-2014 accreditation cycle*. Baltimore, MD: Author. Retrieved from http://www.abet.org/wp-content/uploads/2015/04/eac-criteria-2013-2014.pdf

Altschuld, J. W. (1993). *Delphi technique. Lecture. Evaluation Methods: Principles of Needs Assessment II*. Columbus: Department of Educational Services and Research, The Ohio State University.

Bloch, E. (1986). Science and engineering: A continuum. In National Research Council, *The new engineering research centers: Purposes, goals, and expectations* (p. 28–34). Washington, DC: National Academy Press. doi:10.17226/616

Brooks, K. W. (1979). Delphi technique: Expanding applications. *North Central Association Quarterly*, *53*(3), 377–385.

Brophy, S., & Evangelou, D. (2007). Precursors to engineering thinking (PET) project: Intentional Designs with Experimental Artifacts (IDEA). In *Proceedings of the 2007 Annual Conference & Exposition* (pp. 12.1169.1–12.1169.11). Washington, DC: American Society of Engineering Education. Retrieved from https://peer.asee.org/3011

Chalmers, K. J., Bond, K. S., Jorm, A. F, Kelly, C. M., Kitchener, B. A., & Williams-Tchen, A. J. (2014). Providing culturally appropriate mental health first aid to an aboriginal or Torres Strait Islander adolescent: Development of expert consensus guidelines. *International Journal of Mental Health Systems*, *8*(1). doi:10.1186/1752-4458-8-6

Comrey, A. (1973). *A first course on factor analysis*. London, England: Academic Press

Childress, V., & Rhodes, C. (2008). Engineering student outcomes for Grades 9–12. *The Technology Teacher*, *67*(7), 5–12.

Custer, R. L., Scarcella, J. A., & Stewart, B. R. (1999). The modified Delphi technique: A rotational modification. *Journal of Vocational and Technical Education*, *15*(2), 50–58. doi:10.21061/jcte.v15i2.702

Custer, R. L., Daugherty, J. L., & Meyer, J. P. (2010). Formulating a concept base for secondary level engineering: A review and synthesis. *Journal of Technology Education*, *22*(1), 4–21. doi:10.21061/jte.v22i1.a.1

Dalkey, N.C. (with Rourke, D.L., Lewis, R., & Snyder, D.). (1972). *Studies in the quality of life: Delphi and decision-making*. Lexington, MA: Lexington Books.

Dalkey, N. C., & Helmer, O. (1963). *An experimental application of the Delphi method to the use of experts* (Memorandum RM-727/1-Abridged). Santa Monica, CA: RAND Corporation. Retrieved from https://www.rand.org/content/dam/rand/pubs/research_memoranda/2009/RM727.1.pdf

Delbecq, A. L., Van deVen, A. H., & Gustafson, D. H. (1975). *Group techniques for program planning: A guide to nominal group and Delphi processes*. Glenview, IL: Scott, Foresman and Company.

de Vries, M. J. (2005). *Teaching about technology: An introduction to the philosophy of technology for non-philosophers*. Dordrecht, the Netherlands: Springer. doi:10.1007/1-4020-3410-5

Engineers' Council for Professional Development. (1979). 47th Annual Report 1978-79 (p. 56). New York, NY

Fowles, J. (1978). *Handbook of futures research*. Westport, CT: Greenwood Press.

George, D., & Mallery, P. (2003). *SPSS for Windows step by step: A simple guide and reference. 11.0 update* (4th ed.). Boston, MA: Allyn & Bacon.

Greefhorst, D., & Proper, E. (2011). *Architecture principles: The cornerstones of enterprise architecture*, (p.9). London, England: Springer Heidelberg Dordrecht. ISBN 978-3-642-20278-0. DOI 10.1007/978-3-642-20279-7

Greer, S. J. (2008). Convergence on the guidelines for designing a virtual irregular warfare internship: A Delphi study (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 3320644)

Hacker, M. (2005, November). *A comparison of professional competencies required by ABET for engineers and NCATE for technology teachers.* Paper presented at the Mississippi Valley Technology Teacher Education Conference, St. Louis, MO.

Hayes, A. (1997). *Research methods and statistics*. Armidale, New South Wales, Australia: School of Psychology, University of New England. Retrieved December 26, 2012 from http://www.une.edu.au/WebStat/unit_materials/c6_common_statistical_tests/nonparametric_test.html

Hill, K. Q., & Fowles, J. (1975). The methodological worth of the Delphi forecasting technique. *Technological Forecasting and Social Change*, *7*(2), 179–192. doi:10.1016/0040-1625(75)90057-8

IBM Support. (2016). Does SPSS provide an internal consistency measure for ordinal variables?. Retrieved from http://www-01.ibm.com/support/docview.wss?uid=swg21477603

International Technology Education Association. (2007). *Standards for technological literacy: Content for the study of technology* (3rd ed.). Reston, VA: Author.

International Technology Education Association, Council on Technology Teacher Education. (2003). *ITEA/CTTE/NCATE Curriculum Standards: Initial Programs in Technology Teacher Education*. Reston, VA: Author. Retrieved from http://ctete.org/wp-content/uploads/2016/02/NCATEStandards10.03.pdf

Iqbal, S., & Pipon-Young, L. (2009). The Delphi method. *The Psychologist*, *22*(7), 598–600.

Jacobs, J. M. (1996). *Essential assessment criteria for physical education teacher education programs: A Delphi study* (Unpublished doctoral dissertation). West Virginia University, Morgantown, WV.

Katehi, L., Pearson, G., & Feder, M. (Eds.). (2009). *Engineering in K–12 education: Understanding the status and improving the prospects*. Washington, DC: National Academies Press. doi:10.17226/12635

Kline, S. J. (1985). What is technology? *Bulletin of Science, Technology & Society*, *5*(3), 215–218. doi:10.1177/027046768500500301

Kline, P. (1999). *The handbook of psychological testing* (2nd ed.). London, England: Routledge

Ludwig, B. (1997). Predicting the future: Have you considered using the Delphi methodology? *Journal of Extension*, *35*(5). Retrieved from http://www.joe.org/joe/1997october/tt2.html

Meulman, J. J., Van Der Kooij, A. J., & Heiser, W. J. (2004). Principal components analysis with nonlinear optimal scaling transformations for ordinal and nominal data. In D. Kaplan (Ed.), *The Sage handbook of quantitative methodology for the social sciences* (pp. 49–70). Thousand Oaks, CA: Sage. doi:10.4135/9781412986311.n3

Na, S. (2006). A Delphi study to identify teaching competencies of teacher education faculty in 2015 (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 3225382)

National Academy of Engineering. (2010). *Standards for K–12 engineering education?* Washington, DC: National Academies Press. doi:10.17226/12990

National Assessment Governing Board. (2013). *Technology and engineering literacy framework for the 2014 National Assessment of Educational Progress*. Washington, DC: Author. Retrieved from https://www.nagb.org/content/nagb/assets/documents/publications/frameworks/technology/2014-technology-framework.pdf

National Council for Accreditation of Teacher Education. (2008). *Professional standards for the accreditation of teacher preparation institutions*. Washington, DC: Author. http://www.ncate.org/documents/standards/NCATE%20Standards%202008.pdf

National Research Council. (1986). *Engineering infrastructure diagramming and modeling*. Washington, DC: National Academy Press. doi:10.17226/587

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press. doi:10.17226/13165

The Nation's Report Card. (2016). 2014 technology & engineering literacy (TEL): About the TEL assessment. Retrieved from https://www.nationsreportcard.gov/tel_2014/#about/overview

NGSS Lead States. (2013). *Next generation science standards: For states, by state*s. Washington, DC: National Academies Press. doi:10.17226/18290

Qualtrics (2014) [Computer software]. Provo, UT: Qualtrics Labs.

RAND Corporation. (2017). Delphi method. Retrieved from http://www.rand.org/topics/delphi-method.html

Rayens, M. K., & Hahn, E. J. (2000). Building consensus using the policy Delphi method. *Policy, Politics, & Nursing Practice*, *1*(4), 308–315. doi:10.1177/152715440000100409

Rojewski, J. W., & Meers, G.D. (1991). Research priorities in vocational special needs education. *Journal for Vocational Special Needs Education*, *13*(2), 33–38.

Rossouw, A., Hacker, M. & de Vries, M. J. (2010). Concepts and contexts in engineering and technology education: An international and interdisciplinary Delphi study. *International Journal of Technology and Design Education*, *21*(4), 409–424. doi:10.1007/s10798-010-9129-1

Salancik, J. R., Wenger, W., & Helfer, E. (1971). *The construction of Delphi event statements*. Middletown, CT: Institute for the Future.

Scott, D. G., Washer, B. A., & Wright, M. D. (2006). A Delphi study to identify recommended biotechnology competencies for first-year/initially certified technology education teachers. *Journal of Technology Education*, *17*(2), 43–55. doi:10.21061/jte.v17i2.a.4

Smith, R.J. (2016). *Engineering*. Encyclopedia Britannica. Retrieved March 21, 2017 from https://www.britannica.com/technology/engineering

SPSS (Version 22.0) [Computer software]. Armonk, New York: IBM.

Swyt, D. A. (1989). *Knowledge, innovation, and the administration of publicly-funded research in technology*. Unpublished manuscript, National Institute of Science and Technology, Gaithersburg, MD.

UCLA, Institute for Digital Research and Education. (2017). SPSS FAQ: What does Cronbach's alpha mean? Retrieved from http://www.ats.ucla.edu/stat/spss/faq/alpha.html

Uebersax, J. (2000). Agreement on interval-level ratings. Retrieved from http://www.john-uebersax.com/stat/cont.htm

Ulschak, F. L. (Ed.). (1983). *Human resource development: The theory and practice of need assessment*. Reston, VA: Reston.

von der Gracht, H. A., (2008). *The future of logistics: Scenarios for 2025*. Wiesbaden, Germany: Gabler. doi:10.1007/978-3-8349-9764-7

Wicklein, R. C. & Rojewski, J. W. (1999). Toward a "unified curriculum framework" for technology education. *Journal of Industrial Teacher Education*, *36*(4), 38–56. Retrieved from http://scholar.lib.vt.edu/ejournals/JITE/v36n4/wicklein.html

Wulf, Wm. A., & Fisher, George M. C. (2002). A makeover for engineering education. *Issues in Science and Technology*, *18*(3), 35–39. Retrieved from http://issues.org/18-3/p_wulf/

About the Authors

Michael Hacker (michael.hacker@hofstra.edu) is Co-Director of the Center for STEM Research at Hofstra University in New York.

Moshe Barak (mbarak@bgu.ac.il) is Professor of Science and Technology Education at Ben Gurion University of the Negev in Beersheva, Israel.

Journal of Technology Education | *Vol. 28 No. 2, Spring 2017*

Peer Evaluation of Team Member Effectiveness as a Formative Educational Intervention

Nathan Mentzer, Dawn Laux, Angelika Zissimopoulos,
and K. Andrew R. Richards

Abstract

Peer evaluation of team member effectiveness is often used to complement cooperative learning in the classroom by holding students accountable for their team contributions. Drawing on the tenants of self-determination theory, this study investigated the impact of formative peer evaluation in university level team-based design projects. The hypothesis was that the introduction of formative peer evaluation cycles would result in a more student-centered learning climate, increased competence, reduced doubt, and improved student learning. Two semesters were compared in this quasi-experimental study in which results of peer evaluation became modifiers to students' grades in the final project. In the second semester, peer evaluation was also used multiple times formatively to provide students with feedback and encourage changes in behavior without impacting grades. When formative peer evaluation was implemented, students earned higher grades on the final project and in the course and perceived a more student-centered learning environment, more competence, and less doubt about the course.

Keywords: learning climate; peer evaluation; self-determination theory; team member effectiveness

To be a successful member of the modern workforce, an effective employee must anticipate change and adapt quickly, be able to apply critical thinking skills, collaborate professionally with others, and self-monitor performance in teams (National Research Council, 2011). Active learning techniques that encourage student engagement in the learning process, such as cooperative learning, provide opportunities for students to develop critical thinking skills, engage in collaboration, and evaluate team effectiveness. This study investigated the impact of evaluating and communicating team member effectiveness as an ongoing, iterative feedback mechanism (formative evaluation) on university freshman student performance and perceptions in a technological design course at a major U.S. research institution.

Prior research has found that student achievement is improved with the use of cooperative learning as opposed to an individual approach to learning (approximate effect size of 0.50, which is significant statistically and practically; Prince, 2004; Smith, Sheppard, Johnson, & Johnson, 2005). Research studies have reported that a group achieves greater benefits from the knowledge gained by each individual member (Johnson, Johnson, & Smith, 1998; Prince, 2004; Smith et al., 2005). Johnson, Johnson, and Smith (1998) also noted that cooperative learning (as opposed to working alone) improves the quality of student relationships (effect size = 0.55). Johnson et al. reported that this finding is consistent across ethnic, cultural, language, social class, ability, and gender groups by measuring internal attraction, esprit de corps, cohesiveness, and trust. Finally, evidence indicates that the psychological adjustment to college life positively correlates with cooperative learning (Smith et al., 2005). Self-esteem has also been found to increase with the use of cooperative learning (Prince, 2004). Millis (2010) suggested that group work can encourage critical thinking while inspiring students to value the contributions of others.

Free-Rider Problems in Collaborative Learning

Challenges have been noted regarding cooperative learning. Notably, one concern for students is how to adequately evaluate participation among team members (Topping, 2009). In research pertaining to attitudes toward social loafing (Jassawalla, Sashittal, & Malshe, 2009), students perceived that nonparticipating team members submit poor quality work and negatively contribute with distractive and disruptive behaviors. Jassawalla, Sashittal, and Malshe's (2009) data showed that student apathy and disconnectedness were precursors to the behavior, causing more work for the other team members.

One way to address the free-rider problem is with the use of peer evaluation. Brooks and Ammons (2003) found that by implementing a peer evaluation system at the conclusion of a series of short-term group projects, free-rider problems can be reduced by shaping student attitudes about their own participation. Peer evaluation of team member effectiveness is defined in this study as having each teammate rate themselves and their teammates on multiple dimensions of team member effectiveness. Peer evaluation of team member effectiveness has been found to be an effective accountability tool in various disciplines such as nursing, business, and engineering (Brooks & Ammons, 2003; Brutus & Donia, 2010; Elliott & Higgins, 2005; Fellenz, 2006; Kao, 2013; Kench, Field, Agudera, & Gill, 2009; Maiden & Perry, 2011; Tessier, 2012). Peer evaluations complement cooperative learning when it comes to individual accountability, social skills, and group processing as well as improve overall group performance (Brutus & Donia, 2010). In a study by Elliott and Higgins (2005), the majority of students considered self and peer evaluations to be a fair system for measuring the contribution made by each member of the group. The participants also reported that a majority of students found that the peer evaluation process motivated them to actively participate in the assessed group work.

Timeliness of Peer Evaluations

In a comparison-of-methods study, Baker (2008) discussed peer evaluation methodology and described the difference between formative and summative peer evaluation. When using peer evaluations for formative purposes, evaluation occurs during the project, and results are provided to students prior to the project ending so that students are given the opportunity to improve team skills before the conclusion of the group activity (Cestone, Levine, & Lane, 2008). Summative peer evaluation is typically administered at the end of a team project, and members of the team evaluate the individual performance based on a predetermined set of requirements (Elliott & Higgins, 2005; Goldfinch & Raeside, 1990; Holland & Feigenbaum, 1998). Because summative peer evaluation takes place at the end of the project, individuals do not have the opportunity to take corrective action as they might with formative evaluation (Baker, 2008; Brooks & Ammons, 2003; Reese-Durham, 2005). In a study on the perceptions of social loafing, Jassawalla et al. (2009) discovered that some of the students who received a summative peer evaluation were unaware, until the end of the team activity, that their participation was perceived as lacking. These self-reports may be biased as students claim to be unaware that they were not meeting teammate's expectations when in fact this is a defense mechanism (Oakley, 2002). However, assuming some students were unaware, Jassawalla et al. (2009) suggested that instruction on teamwork skills could alleviate this issue. Based on the developmental peer evaluation research, this level of disconnectedness within the team could possibly be alleviated with peer feedback during the activity rather than after the activity is over. A formative evaluation earlier in the team project may be the needed motivation to participate (Baker, 2008).

Understanding Human Motivation

Self-determination theory (Deci & Ryan, 1985, 2000) provides a framework to explain how human motivation influences behavior. Central to self-determination theory is the notion that humans have three basic psychological needs that they seek to satisfy through their interactions with one another and the environment: relatedness, autonomy, and competence (Deci & Ryan, 1985). *Relatedness* refers to individuals' feelings of connectedness to others and leads to a sense of belonging within the social setting. *Autonomy* results from having the ability to make choices and exercise a sense of volition but does not mean that individuals act autonomously and without supervision. Rather, autonomy can be fostered when students have the ability to make choices within a structure that is defined by the instructor. *Competence* is related to the notion of *self-efficacy* (Bandura, 1986) and relates to individuals' feelings that they are able to meet contextual demands. The inverse of competence is sometimes referred to as *doubt* and describes situations in which individuals do not feel able to accomplish tasks or achieve goals.

Self-determination theory has been applied in educational settings to explain student motivation that results from different types of learning environments (e.g., Black & Deci, 2000; Levesque-Bristol, Knapp, & Fisher, 2010). When these interactions foster student-centered learning environments, students' basic psychological needs will be satisfied and they will be more intrinsically motivated to learn. In contrast, when learning environments are perceived to be controlling and instructor-centered, the basic psychological needs are less likely to be satisfied, and motivation is extrinsically regulated (Deci, Ryan, & Williams, 1996). When students are extrinsically motivated they feel as if they are engaging in learning activities in order to achieve a reward (e.g., a good grade) or avoid a punishment (e.g., a failing grade) and are less likely to feel personally invested in the coursework. Related to self-determination theory, active learning strategies such as cooperative learning can help to create student-centered learning environments, which satisfy the basic psychological needs and lead to more positive perceptions of the learning environment and better student-level outcomes.

Purpose of Study

The purpose of this study was to investigate the impact of using peer evaluation as a formative learning tool. It was hypothesized that peer evaluation might also have the potential to improve student performance if used as a formative tool during early stages of the final project in addition to its use as a summative tool at the conclusion. The underlying assumption here was that not all teams are fully functional. The hypothesis driving this inquiry was that peer evaluation used as formative feedback on a long-term final project will improve student performance, improve students' perceptions of the learning climate, increase perceived competence, and reduce perceived doubt over a comparison group using cooperative learning with only summative feedback. This hypothesis builds on the work of Brooks and Ammons (2003) who suggested that multiple peer feedback evaluation points reduce the occurrence of free-riding when used after each separate learning module. Although Brooks and Ammons (2003) administered multiple peer evaluation points, each was summative, and the main focus of their study was on alleviating free-riding on subsequent learning modules rather than the effects of formative peer evaluation on student performance during an extended project.

Research Questions

Two research questions guided the investigation. Multiple data sets and analysis strategies were required to address each question and are discussed separately. The research questions were:

1. Does formative peer evaluation improve student learning, as measured by final project grade and course grade, over summative only peer feedback?

2. Does formative peer evaluation improve students' perceptions of the learning climate, increase competence, and reduce doubt over summative only peer feedback?

Methods

Data for this quasi-experimental study were drawn from students enrolled in a university freshman level design thinking course in the fall 2012 and fall 2013 semesters. In both semesters, peer evaluation was used as a summative tool to impact student grades based on the degree to which their teammates perceived that they contributed to the final project. The use of formative peer evaluation was piloted during spring 2013 and implemented in fall 2013. Therefore, data from fall 2013 included both formative and summative peer evaluation ratings, whereas data from fall 2012 only included summative peer evaluation. The Institutional Review Board approved this study as exempt because it involved typical educational procedures. All data were made anonymous and analyses were not conducted until after the conclusion of the fall 2013 semester.

Learning Environment

The course chosen for the study was a college core course focused on design thinking in a major research university. Most students were freshmen or transfers (mainly from other colleges at the university). This user-centered design course was initially implemented in the 2011–2012 academic year as the first course in a three-course sequence required for all undergraduate students in the college. Faculty members implementing the course participated in course redesign workshops the year before this study was implemented. Faculty members worked with pedagogical, technological, and information literacy experts to redesign the course from a traditional, large lecture format to a flipped model in which a blend of distance and face-to-face modalities were implemented. Changes were made in learning outcomes, pedagogy, and content using research-backed strategies for sound student-centered teaching and learning. Changes made and described here as part of a course redesign were completed prior to the implementation of this study.

During the semesters in which this research study was conducted, students spent substantial time engaged in small-group learning experiences and team-based projects. Sections of the course were limited to 40 students each and situated in a technology-enabled classroom in which each student had a computer. Students were arranged in pods ranging from 4–6 students, and each pod had the ability to project on a large screen with a data projector. White boards and cameras were accessible for group work and documentation.

Multiple instructors were used in course implementation. However, to control for instructor differences, data for this study were drawn from classes taught by one tenure-track assistant professor who, at the start of this study, was in his fourth year at the university. Course content and delivery were held constant during the study with the only change being the treatment, which was the addition of formative feedback during the fall 2013 semester.

The following learning outcomes for the course were developed and approved. Students will be able to:

1. Write a narrowly focused problem statement.
2. Apply ethnographic methods to understand technological problems.
3. Develop a search strategy, access technical databases, and evaluate results and source quality.
4. Create a technical report documenting results of the design process.
5. Manage design projects, develop project timelines, and negotiate individual responsibilities and accountability in the team environment.
6. Apply strategies of ideation to develop novel and innovative solutions.
7. Rapidly prototype solutions for purposes of design, testing, and communication.

Learning experiences based on these outcomes were developed and thematically linked to the domain of technology through the lens of design. Students began the semester generally working individually outside of class and in pairs or small groups in class. As the semester progressed, students gradually transitioned to working outside of class in small groups and working in small and large groups in class. Students typically completed two assignments per week. One assignment was given prior to each class session to engage students in content and prepare them for class, and one assignment was given in class.

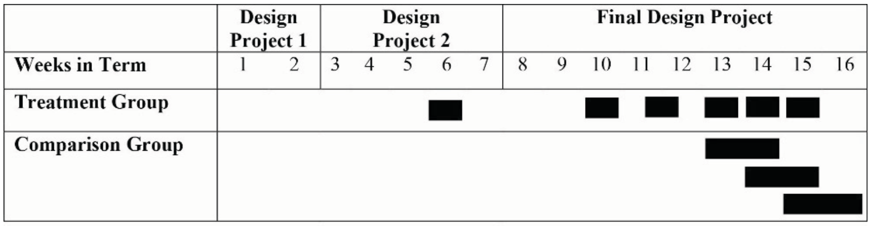
Assignments were based on course materials and included readings, videos, field work, and student creation of artifacts. As an example, students would read about design thinking, watch a video on ethnography in the context of a design problem, conduct and document observations, and synthesize results based on their data collection leading to defining a problem. An example assignment would include developing constraints and criteria, refining them to be measurable, and identifying solutions for potential development. Students have online access to procedures and rubrics used to grade their submissions. Submissions were graded quickly (in less than 1 week) and returned to the students with feedback and explanation of missed points so that students could improve their approach to coursework.

The course grade included 1,000 points, and each assignment was weighted based on its relative complexity so that the student could easily interpret the percentage of their semester grade associated with the assignment. Small projects introduced students to design thinking using a human-centered design model including problem definition, stakeholder identification, benchmarking, solution generation, decision making, prototyping, feedback from stakeholders, and presentation. Students engaged in the final project during the second half of the semester. The project provided students with a context in which to apply concepts learned during the first half of the course to an 8-week learning experience during the second half of the course, culminating with a presentation of the refined conceptual design. Prototypes at the conclusion of the course demonstrated a proof of concept but were not ready for implementation. Final project topics had loose boundaries so that students from various disciplines in the college had the autonomy to focus on a common area of interest, which may or may not have been directly central to their major (although the connection was encouraged). In both the fall 2012 and fall 2013 semesters, final projects were done in teams ranging from 2–6 students with the typical group being 4–5 students, which is consistent with research on cooperative learning (Slavin, 1991). Final project teams were created at the beginning of the project (around midterm of the semester). Student teams were self-selected, and each team negotiated the definition of their team's problem statement.

Treatment Method

Various methods of approaching peer evaluation have been developed and published including paper- and computer-based surveys. A web-based survey called the Comprehensive Assessment for Team-Member Effectiveness (CATME), which is available for a nominal fee to educational institutions, was used in this study (for more information about CATME, see www.CATME.org). CATME was selected because it has been determined to be reliable and valid (Loughry, Ohland, & Moore, 2007; Ohland et al., 2012), which is essential when the results will be factored into student grades (Baker, 2008). The CATME instrument is a behaviorally anchored rating scale that describes behaviors typical of various levels of performance. Raters select the category of behaviors that most closely matches the actual behavior of each student (including themselves) on their team (Ohland et al., 2012). Five scales of teamwork are included in this survey: Contributing to the Team's Work, Interacting with Teammates, Keeping the Team on Track, Expecting Quality, and Having Relevant Knowledge Skills and Abilities. The CATME interface asks students to rate themselves and their peers by selecting one of five behavioral descriptions per metric selected by the instructor. For Interacting with Teammates, for example, which best describes your peer: "asks for and shows an interest in teammates' ideas and contributions," "respects and responds to feedback from teammates," or "interrupts, ignores, bosses, or makes fun of teammates?" (Ohland et al., 2005). (Please note that the descriptions are greatly abbreviated here; please see the survey for more detailed descriptions.) The instrument quantifies these behavioral ratings such that high-quality interactions receive a 5, average interactions receive a 3, and poor interactions receive a 1. After students were surveyed, the instructor released results back to the students. Results included the student's self-rating compared to how their peers rated them and the average of their team for each metric.

In both comparison and treatment semesters, peer evaluations were administered during each of three major project deliverables, as shown in Figure 1. During the comparison semester, the peer evaluations were functionally summative because of the timing. The process of administering the survey and receiving feedback spanned at least 2 weeks and overlapped the next project component. Therefore, students did not have a chance to learn from the evaluation results prior to the next evaluation period. In the treatment semester, the evaluation process was rescheduled such that cycles of work, peer evaluation, and feedback occurred more rapidly. This rapid succession resulted in students having the ability to receive feedback prior to engaging in the next main deliverable, and the evaluation experience was more formative in nature. During the treatment semester, peer evaluation was also implemented an additional two times during early stages of the final project. These two additional formative evaluations were spaced apart so that students had an opportunity to review results and discuss them in class prior to the next iteration. As a result, students in the comparison semester experienced predominately summative evaluation, whereas students in the treatment semester experienced five cycles of formative evaluation.



	Design Project 1		Design Project 2					Final Design Project								
Weeks in Term	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Treatment Group						■				■	■		■	■	■	
Comparison Group													■	■		
														■	■	
															■	■

Figure 1. Peer evaluation schedule for comparison and treatment groups by weeks in the term and design project. The schedule is approximate and represents the time cycles from survey administration to release.

In addition to the formative evaluations, the treatment group received an opportunity to experience peer evaluation at the end of a small short-term group project early in the semester. This evaluation was not included in the data for the study because it was considered practice and because student groups differed from the final project groups. During this practice evaluation, students were required to complete a peer evaluation for a short-term team project. Students were provided with instruction on how to give and receive feedback and interpret the results through a brief in a class discussion, as suggested by Cestone, Levine, and Lane (2008). The second and third implementations of peer evaluation occurred at the beginning of the final projects after teams had formed. These evaluations had no impact on student grades, and implementation timing provided students with an opportunity to practice with the interface, see the results, and discuss the results with their teammates and instructor.

Participants

There were 193 students enrolled in the course in the fall 2012 semester and 140 enrolled in the fall 2013 semester. However, data were incomplete for 13 students in the fall 2012 semester (6.74%) and 19 students in the fall 2013 semester (13.57%). Given that the incomplete data made it impossible to complete the analyses, these cases were omitted from the study. The final sample included 301 students (180 from fall 2012 and 121 from fall 2013).

To answer research question one, data were drawn from all 301 students (259 males and 42 females) from a single instructor's sections of the course. The average student was 20.63 years old (*SD* = 3.52). Most of the students were White (*n* = 218, 72.4%) and were born in the United States (*n* = 283, 94%). Over three-quarters of the students were freshmen (*n* = 241, 80.1%) with only a few sophomores (*n* = 39, 13%), juniors (*n* = 12, 4%), and seniors (n = 9, 3%). The average student had a combined SAT math and verbal (SAT composite) score of 1119.97 (*SD* = 130.59, approximately 69th percentile) and an SAT writing score of 522.56 (SD = 73.26, approximately 57th percentile). [1]

Data to answer research question two were drawn from a subset of 80 students (64 males, 16 females) who completed a voluntary course perceptions survey at the end of each semester. There were 22 students (12.22%) in fall 2012 and 58 students (47.93%) in fall 2013. The average student was 21.03 years old (*SD* = 4.86). Most of the students were White (*n* = 65, 81.3%) and were born in the United States (*n* = 75, 93.8%). Three-quarters of the participants were freshmen (*n* = 60, 75%) with a few sophomores (*n* = 11, 13.8%), juniors (*n* = 3, 3.8%), and seniors (*n* = 6, 7.5%). The average student had a SAT composite score of 1096.87 (*SD* = 132.83, approximately 66th percentile) and an SAT writing score of 513.13 (SD = 74.35, approximately 54th percentile).

Data Collection

Demographic data. The quasi-experimental research design assumes that both groups began the semester being similar and that the instructor manipulated only the reported variable. Demographic data were gathered from the university database to permit comparisons between students in both semesters. Demographic data included SAT scores, class rank, gender, and racial or ethnic identity. Students entering the university are required to either take the SAT or the ACT college entrance exams. To standardize comparisons, ACT exam scores were converted to SAT comparable scores using the College Board Concordance Tables (The College Board, 2009).

Student performance data. Evidence of student learning data were collected in two forms: overall course grades and grades in components of the final project. Course grades were composed of a series of assignments, typically two per week, in which rubrics were used to evaluate authentic application

---

[1] Based on total group rankings for 2013 college bound high school seniors.

experiences. Students had access to the rubrics in advance. Assignments included individual and small-group work outside of class and in class.

The final project included three main components: a planning document, a written technical document, and a video. Each component was submitted separately with at least 1week between submissions. The planning document included a Gantt chart, evidence of a finalized prototype, a storyboard, and a draft technical document. The video was limited to 60 seconds in length and was expected to communicate the problem, the existing but inadequate solutions, and the proposed solution and to demonstrate the proposed solution in action. The instructor and a teaching assistant used a rubric to rate each of these three main final project components. Prior to analysis, it was discovered that an error in the fall 2012 video rubric caused artificial final project grade inflation on this component (the impact of this error on the semester grade may account for less than 1% of the overall course grade based on point values for some students in the fall 2012 semester only). As a result, the video component of the final project was not considered in the analysis. In the final project, individual scores for each student were derived as a function of the group score and the individual student's effectiveness as a team member. The group score was determined by rubrics used to measure the quality of the submitted product. The individual score was the result of the group score multiplied by an individual effectiveness indicator extracted from CATME. The team effectiveness value ranged from approximately 0.20–1.05. This process was conducted to calculate individual student grades for the two components of the final project included in this study (the *final project planning component* and the *final project technical document component*).

Overall course grade was determined by a series of existing assignments. Prior to the start of the fall 2012 semester, assignments, instructions, and rubrics were generated collaboratively by a group of four faculty members under the guidance of two course-design experts from the university's center for teaching and learning. The use of instructor-generated assignments as a measure of student learning is consistent with previous studies (Fraenkel & Wallen, 2009; Gay, Mills, & Airasian, 2009). During both semesters of this study, the instructor and a graduate student grader met weekly to establish consistency and ensure calibration in the use of rubrics to grade the student submissions. Calibration was established between the graduate student and the instructor by discussing the assignment instructions and rubrics and collaboratively evaluating approximately 5% of the submissions. In addition, the instructor occasionally spot-checked assignments after the graduate student had evaluated them to confirm appropriate application of the rubrics. In addition, students in the course had access to the rubrics before and after grading and were encouraged to review the rubrics to learn from their mistakes and also to confirm that grading was done appropriately.

Student perception data. An online survey was administered at the end of each semester to measure students' perceptions of the learning environment. This survey included measures of the *learning climate*, *competence*, and *doubt* (refer to the Appendix for the instrument). The survey was administered by the university's center for teaching and learning during both semesters of this study. Fall 2012 was the first semester that this survey was used on campus and the instructors, campus wide, were not well informed. As a result, instructors typically did not encourage students to participate, which explains the low response rate during that semester.

Students' perceptions of the learning climate were measured using the Learning Climate Questionnaire (Williams & Deci, 1996). This instrument measures students' perceptions of the "autonomy supportiveness" of the learning environment. High scores reflect a more student-centered learning climate, whereas lower scores reflect a more instructor-centered environment. Participants responded to the seven questions on a 7-point, Likert-type scale ranging from *strongly disagree* (1) to *strongly agree* (7). Example items included: "my instructor provided me with choices and options on how to complete the work," "my instructor understood my perspective," and "my instructor encouraged me to ask questions." Validity and internal consistency for the instrument have been established through prior research (Levesque-Bristol et al., 2010; Williams & Deci, 1996), and internal consistency was excellent in the current study (Cronbach's $\alpha = .93$).

Perceptions of competence and doubt were measured using the competence subscale of the Basic Psychological Needs at Work Scale (Deci & Ryan, 2000), which was modified to reflect a classroom situation (Levesque-Bristol et al., 2010). The subscale contains three positively worded items and three negatively worded items. Participants responded to the six questions on a 7-point, Likert-type scale ranging from *strongly disagree* (1) to *strongly agree* (7). Example items included: "When I was in this course, I often did not feel very capable," and "I was capable of learning the materials in this course." In the current study, an exploratory factor analysis using maximum likelihood extraction and a varimax rotation (orthogonal) indicated that the six items were better represented as two subscales, each of which contained three items. The first subscale included the positively worded items related to competence. The second subscale included the negatively worded items and was taken to reflect doubt in one's abilities to meet the demands of the course environment. Validity and internal consistency for the Basic Psychological Needs at Work Scale has been documented through prior research (Deci & Ryan, 2000; Levesque-Bristol et al., 2010), and was adequate for both competence and doubt in the current study (Cronbach's $\alpha = .82$ and .77, respectively).

Data Analysis

Data were first screened as recommended by Tabachnick and Fidell (2007), and it was determined that the data met the basic requirements for inferential statistics (scores on the dependent variable approximate an interval level of measurement, scores on the dependent variable are normally distributed, observations are independent, and homogeneity of variance).

Prior to conducting analyses to answer the research questions, the researchers performed two separate manipulation checks. The first examined differences in demographic and performance variables between the students who were enrolled in the course in fall 2012 and those who were enrolled in fall 2013. The second examined differences in demographic and performance variables for student survey responders and nonresponders in each semester separately. Pearson χ^2 tests were used to determine if student groups differed in terms of gender (male or female), class rank (freshman, sophomore, junior, or senior), ethnicity (White or other), and nationality (international or domestic student). Independent samples *t*-tests were used to examine if students differed in terms of SAT composite (math + verbal) and writing scores. SAT data were used because most students were first-semester college freshmen, and college-level measures of performance (e.g., overall GPA) were not available.

The first research question was: Does formative peer evaluation improve student learning, as measured by final project grade and course grade, over summative only peer feedback? For question one, three analyses were conducted. Course grades were compared between semesters as well as between two of the main components of the cooperative learning-based final project. Analysis of Covariance (ANCOVA) procedures were used to examine differences in student performance on the three components (the final project planning component, the final project technical document component, and course grade) between the fall 2012 and fall 2013 semesters while controlling for SAT composite and SAT writing scores.

The second research question was: Does formative peer evaluation improve students' perceptions of the learning climate, increase competence, and reduce doubt over summative only peer feedback? To address question two, composite scores were created by averaging the items related to each of the three constructs (learning climate, competence, and doubt) included in the study. Analysis of Covariance (ANCOVA) procedures were used to examine differences in student perceptions of the learning climate, competence, and doubt in the fall 2012 and fall 2013 semesters while controlling for SAT composite and SAT writing scores.

For all of the ANCOVA procedures, η^2 is presented as a measure of effect size. A η^2 value between .01 and .06 is associated with a small effect, between .06 and .14 with a medium effect, and above .14 with a large effect (Warner, 2013). When using independent samples *t*-tests, Cohen's *d* is presented as a measure of effect size. A Cohen's *d* value between .15 and .40 is associated with a small effect, between .40 and .75 with a medium effect, and above .75 with a large effect (Cohen, 1992).

Results

Pre-analysis Manipulation Checks: Comparison of Demographic and Performance Variables

Prior to conducting analyses to answer the research questions, two pre-analysis manipulation checks were performed to examine differences related to student demographic and prior performance data. The first check sought to examine if there were differences between students enrolled in the class in the fall 2012 and fall 2013 semesters. Pearson χ^2 tests were used for the categorical variables of gender, class rank, ethnicity, and nationality. Table 1 summarizes the results of the Pearson χ^2 tests. There was a higher percentage of females in fall 2013, and there was a lower percentage of freshmen and a higher percentage of seniors in fall 2013. There were no differences in the distribution of ethnicity or international student status between the two semesters.

Table 1
Results of Pearson χ^2 Analyses Examining Differences in Demographic Variables by Semester

Demographic variable		Semester		Pearson χ^2
		Fall 2012	Fall 2013	
Gender**	Male Female	163 (90.6%) 17 (9.4%)	96 (79.3%) 25 (20.7%)	$\chi^2(1) = 7.58$, $p = .006$
Class rank*	Freshman Sophomore Junior Senior	152 (84.4%) 20 (11.1%) 7 (3.9%) 1 (0.6%)	89 (73.6%) 19 (15.7%) 5 (4.1%) 8 (6.6%)	$\chi^2(3) = 11.14$, $p = .011$
Ethnicity	White Other	127 (70.6%) 53 (29.4%)	91 (75.2%) 30 (24.8%)	$\chi^2(1) = .78$, $p = .376$
International status	Domestic International	168 (93.3%) 12 (6.7%)	115 (95.0%) 6 (5.0%)	$\chi^2(1) = .38$, $p = .540$

Note. Number of cases reported and percentage of the students in each semester.
$*p < .05$. $**p < .01$.

Independent samples *t*-tests were used to examine differences in SAT composite and writing scores of students in the fall 2012 and fall 2013 semesters. Results of the analyses are reported in Table 2. For SAT composite scores, the *t*-test was significant($t(299) = 2.05$, $p = .041$, $d = .24$), which indicates that students in the fall 2012 semester had a higher average SAT composite score than their peers in the fall 2013 semester (the Levene's test was not significant, so the equal variances assumed *t*-test was used).

Table 2
Results of Independent Samples t-test Examining Differences in SAT Scores by Semester

Dependent variable	Fall 2012 (*N* = 180)		Fall 2013 (*N* = 121)		*t*	*p*	*d*
	M	*SD*	*M*	*SD*			
SAT composite*	1132.56	132.51	1101.24	125.89	2.05	.041	.24
SAT writing	525.83	70.78	517.69	76.81	.95	.345	.11

$^*p < .05$.

The second manipulation check identified whether there were differences between students who elected to respond to the class perceptions survey and those who did not in each semester. Pearson χ^2 tests were used for the categorical variables of gender, class rank, ethnicity, and nationality of students in the fall 2012 and fall 2013 semesters separately. Tables 3 and 4 summarize the results of the Pearson χ^2 tests. There were no demographic differences between responders and non-responders in fall 2012. In fall 2013, the only demographic difference was that a lower percentage of students who completed the survey were classified as other ethnicity compared to those who did not complete it.

Table 3
Results of Pearson χ^2 Analyses Examining Differences in Demographic Variables by Survey Completion Status in Fall 2012

Demographic variable		Completed survey		Pearson χ^2
		No	Yes	
Gender	Male	143 (90.5%)	20 (90.9%)	$\chi^2(1) = .42$,
	Female	15 (9.5%)	2 (9.1%)	$p = .517$
Class rank	Freshman	134 (84.8%)	18 (81.8%)	
	Sophomore	18 (11.4%)	2 (9.1%)	$\chi^2(3) = 7.33$,
	Junior	6 (3.8%)	1 (4.5%)	$p = .062$
	Senior	0 (0.0%)	1 (4.5%)	
Ethnicity	White	112 (70.9%)	15 (68.2%)	$\chi^2(1) = .07$,
	Other	46 (29.1%)	7 (31.8%)	$p = .485$
International status	Domestic	149 (94.3%)	19 (86.4%)	$\chi^2(1) = 1.96$,
	International	9 (5.7%)	3 (13.6%)	$p = .162$

Note. Number of cases reported and percentage of the students who completed or did not complete the survey.

Table 4
Results of Pearson χ^2 Analyses Examining Differences in Demographic Variables by Survey Completion Status in Fall 2013

Demographic variable		Completed survey		Pearson χ^2
		No	Yes	
Gender	Male	52 (82.5%)	44 (75.9%)	$\chi^2(1) = .81$,
	Female	11 (17.5%)	14 (24.1%)	$p = .365$
Class rank	Freshman	47 (74.6%)	42 (72.4%)	
	Sophomore	10 (15.9%)	9 (15.5%)	$\chi^2(3) = .83$,
	Junior	3 (4.8%)	2 (3.4%)	$p = .843$
	Senior	3 (4.8%)	5 (8.6%)	
Ethnicity*	White	41 (65.1%)	50 (86.2%)	$\chi^2(1) = 7.23$,
	Other	22 (34.9%)	8 (13.8%)	$p = .006$
International status	Domestic	59 (93.7%)	56 (96.6%)	$\chi^2(1) = .54$,
	International	4 (6.3%)	2 (3.4%)	$p = .463$

Note. Number of cases reported and percentage of the students who completed or did not complete the survey.
$^*p < .01$.

Independent samples *t*-tests were used to examine differences in SAT composite and writing scores of survey respondents and nonrespondents in the fall 2012 and fall 2013 semesters separately. Results of the analyses are reported in Tables 5 and 6 and indicate that in fall 2012, completers and noncompleters were not significantly different in terms of SAT composite and SAT writing scores. In fall 2013, SAT writing scores were not significantly different for completers and noncompleters, but noncompleters had significantly higher SAT composite scores, t(119) = 2.01, $p = .047$, $d = .37$ (the Levene's test was not significant, so the equal variances assumed *t*-test was used).

Table 5
Results of Independent Samples t-test Examining Differences in SAT Scores for Responders and Non-responders in Fall 2012

Dependent variable	Non-completers (N = 158)		Completers (N = 22)					
	M	*SD*	*M*	*SD*	*t*	*df*	*p*	*d*
SAT composite	1138.44	131.09	1147.73	144.65	-.57	178	.568	.13
SAT writing	525.70	72.83	526.82	55.41	-.07	178	.945	.02

Note. Levene's test indicated equality of variances for all tests.

Table 6
Results of Independent Samples t-test Examining Differences in SAT Scores for Responders and Non-responders in Fall 2013

Dependent variable	Non-completers (N = 63)		Completers (N = 58)		*t*	*df*	*p*	*d*
	M	*SD*	*M*	*SD*				
SAT composite*	1123.02	124.65	1077.59	123.97	2.01	119	.047	.37
SAT writing	526.67	73.04	507.93	80.19	1.35	119	.181	.25

Note. Levene's test indicated equality of variances for all tests.
*p < .05.

Research Question 1: Relationship Between Formative Peer Feedback and Student Performance

ANCOVA procedures were used to examine differences in student performance as measured by the final project planning component, the final project technical document component, and course grade in the fall 2012 and fall 2013 semesters while controlling for SAT composite and SAT writing scores (see Table 7). There was a significant difference between fall 2012 and fall 2013 for the final project planning component after controlling for SAT composite and SAT writing scores, F(1,297) = 15.76, $p < .001$, $\eta^2 = .050$. This significant difference indicates that students in the fall 2013 semester ($M = .95$, $SD = .11$) earned higher scores on the final project technical document component than those in the fall 2012 semester ($M = .88$, $SD = .15$). Neither of the covariates were significant.

Table 7

Results of ANCOVAs to Examine Differences in Student Performance Variables in Fall 2012 and Fall 2013 While Controlling for SAT Composite and Writing Scores

Final project planning component score ANCOVA	*df*	*F*-Value	*p*-value	Partial-η^2
Model	3	6.48	< .001	.061
Control variables				
SAT composite	1	.94	.334	.003
SAT writing	1	.01	.969	< .001
Project 1 score**	1	15.76	< .001	.050

Final project technical document score ANCOVA	*df*	*F*-Value	*p*-value	Partial-η^2
Model	3	2.65	.049	.026
Control variables				
SAT composite	1	.33	.568	.001
SAT writing	1	.30	.583	.001
Project 2 score**	1	7.16	.008	.024

Course grade ANCOVA	*df*	*F*-Value	*p*-value	Partial-η^2
Model	3	4.18	.006	.040
Control variables				
SAT composite*	1	4.90	.028	.016
SAT writing	1	2.88	.091	.010
Final grade*	1	6.17	.014	.020

*$p < .05$. **$p < .01$.

There was also a significant difference between semesters for the final project technical document component after controlling for SAT composite and SAT writing scores, $F(1,297) = 7.16$, $p = .008$, $\eta^2 = .024$. This significant difference indicates that students in the fall 2013 semester ($M = .94$, $SD = .11$)

earned higher scores on the final project planning component than those in the fall 2012 semester (*M* = .89, *SD* = .15). Neither of the covariates were significant.

Related to course grade, there was a significant difference between the fall 2012 and fall 2013 semesters, F(1,297) = 6.17, $p = .014$, $\eta^2 = .020$. This significant difference indicates that students in the fall 2013 semester (*M* = .90, *SD* = .11) earned higher course grades than those in the fall 2012 semester (*M* = .86, *SD* = .12). SAT composite was a significant covariate in the model (F(1,297) = 4.90, $p = .028$, $\eta^2 = .016$), but SAT writing was not.

Figure 2 summarizes the results of analyses related to research question one. The final project planning component, final project technical document component, and course grade variables were all significantly higher in fall 2013 than in fall 2012 after controlling for SAT composite and SAT writing scores.

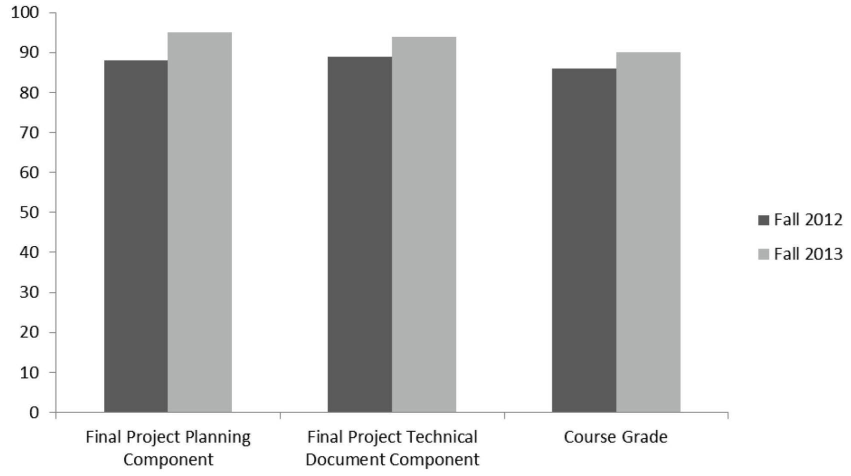


Figure 2. Percentage scores differences in final project planning component, final project technical document, and course grade between the fall 2012 and fall 2013 semesters.
$^*p < .05$. $^{**}p < .01$.

Research Question 2: Relationship Between Formative Peer Feedback and Classroom Perceptions

ANCOVA procedures were used to examine differences in student perceptions of the classroom experience while controlling for SAT composite and SAT writing scores (see Table 8). Specifically, students' perceptions of the learning climate, competence, and doubt were compared between the fall 2012 and fall 2013 semesters. Related to the learning climate, there was a significant difference between semesters when controlling for SAT composite and SAT writing scores, F(1,76) = 11.98, $p < .001$, $\eta^2 = .136$. This significant difference indicates that students in the fall 2013 semester ($M = 5.82$, $SD = .90$) perceived a more student-centered learning environment than those in the fall 2012 semester ($M = 4.85$, $SD = 1.49$). Neither of the covariates were significant.

Table 8
Results of ANCOVAs to Examine Differences in Student Perception Variables in Fall 2012 and Fall 2013 While Controlling for SAT Composite and Writing Scores

Learning climate ANCOVA	*df*	*F*-value	*p*-value	Partial-η^2
Model	3	4.31	.007	.145
Control variables				
SAT composite	1	.171	.681	.002
SAT writing	1	.399	.530	.005
Learning climate*	1	11.98	.001	.136

Competence ANCOVA	*df*	*F*-Value	*p*-value	Partial-η^2
Model	3	2.79	.046	.099
Control variables				
SAT composite	1	.06	.813	.001
SAT writing	1	.27	.602	.004
Competence*	1	7.52	.008	.090

Doubt ANCOVA	*df*	*F*-Value	*p*-value	Partial-η^2
Model	3	.96	.417	.036
Control variables				
SAT composite	1	.32	.573	.004
SAT writing	1	.16	.69	.002
Doubt	1	2.82	.097	.036

$*p < .01$

The difference between fall 2012 and fall 2013 was also significant for competence when controlling for SAT composite and SAT writing scores, F(1,76) = 7.52, $p = .008$, $\eta^2 = .090$. This significance indicates that students in the fall 2013 semester ($M = 5.05$, $SD = .1.25$) perceived a higher level of competence than those in the fall 2012 semester ($M = 4.05$, $SD = 1.72$). Neither of the covariates were significant.

ANCOVA results indicated that there was not a significant difference between students' perceptions of doubt in fall 2012 and fall 2013 after controlling for SAT composite and SAT writing scores. Neither of the covariates were significant.

Figure 3 summarizes the results related to research question two. Students in the fall 2013 semester perceived a more student-centered learning environment and more competence than did students in the fall 2012 semester after controlling for SAT composite and SAT writing scores. Differences in doubt between the semesters were not significant.

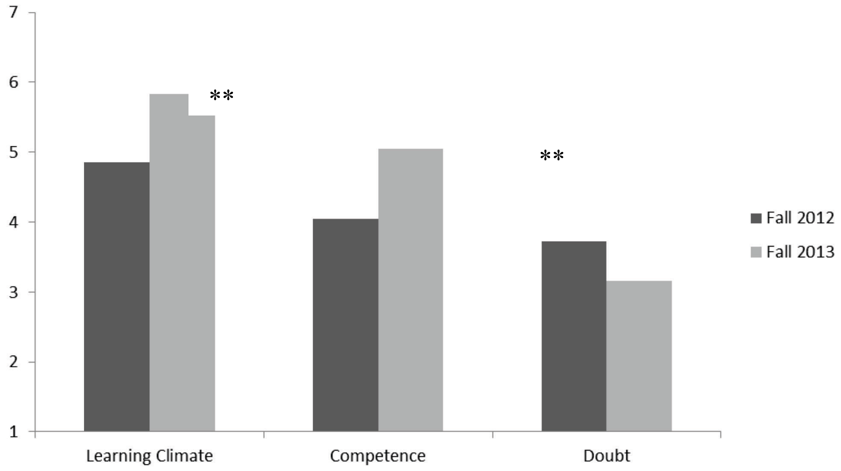


Figure 3. Differences in learning climate, competence, and doubt between the fall 2012 and fall 2013 semesters.
**$p < .01$.

Discussion

Teamwork is an essential skill in negotiating life in the 21st century at work and in social settings. As students practice working in groups, they develop the ability to negotiate, share responsibilities, and communicate and can tackle a broader range of challenges. When formative peer evaluation was implemented, students earned higher grades on the final project and in the course and perceived a more student-centered learning environment with an increased feeling of competence. We do need to acknowledge that instructor growth may have some impact on interpreting the findings of this work. It is possible that instructor growth may account for some improvements in the student experience documented here.

Improvements in learning climate (more student centered) and competence as well as reductions in doubt have been attributed to increased student persistence (Freeman et al., 2014). If more students persist as a result of the improved experience in the fall 2013 semester, two outcomes may be worth considering. First, as Freeman et al. (2014) suggested, struggling students are more likely to drop courses than high-achieving students. In our study, fewer low-achieving students may have dropped out in the treatment group as a result of the improved learning climate, higher competence, and reduced doubt. This may have depressed final project and course grade scores during the fall 2013 semester, causing the increase documented here to be artificially low and underrepresenting the benefits shown in this study. Second, a longitudinal study may help to uncover the impact on long-term college persistence as it is related to developing a sense of connectedness through improved team-based projects. Peer evaluation used as a formative tool may have the potential to sustain a longer term impact as students engage more successfully with their peers, build competence, and reduce doubt.

Teamwork can be frustrating for high-achieving students when other members of their team will receive equal credit without contributing at the same level. Peer team member evaluation holds students accountable, which improves the experiences of the students who want grades to be representative of effort and contribution. Peer evaluation also serves to motivate students who otherwise might not participate. Educators may consider using peer evaluation as both a feedback and accountability mechanism for students.

These results suggest that our field should consider including both formative and summative peer evaluation in educational experiences to foster student skill in teamwork as well as improve the success of learning experiences. Instructors interested in implementation strategies may find Mentzer's (2014) article in the *Technology and Engineering Teacher* journal to be helpful.

Peer evaluation is meant to provide meaningful feedback to learners in a confirmatory, suggestive, or corrective manner (Topping, 2009). Topping (2009) argued that the amount of feedback supplied to an individual is greater than if assessed by a singular source, suggesting that feedback from multiple peers and the instructor is more valuable and potentially more accurate than feedback from the instructor only. When a group of students is working closely on a task, the feedback is more individualized when assessing each other (Brutus & Donia, 2010; Topping, 2009). Additionally, when group members recognize that they will be held accountable for the quality of their work by their peers, more attention to detail and understanding of the task is discussed among the group (Cestone et al., 2008). In a study by Reese-Durham (2005), it was reported that the quality of the learning output improved with formative peer evaluation as compared to previous classes. Teamwork skills such as communication and acceptance of criticism can also be developed through peer assessment by educating students on how to honestly and professionally rate team participation (Topping, 1998). In addition, results of peer evaluation can serve as documentation of student growth over time as evidence of student effectiveness in team environments, which is increasingly critical for meeting graduation requirements and programmatic accreditation (Loughry, Ohland, & Woehr, 2014).

Although assessing individual performance in groups can be beneficial, it is prudent to cover the practical issues that can arise and suggestions for mitigating them. The preparedness of the students, with respect to working in teams and evaluating peers, is critical to the success of the assessment process (Kennedy, 2005; Vickerman, 2009). In an attempt at peer assessment in a computing course, Kennedy (2005) implied that the failure of the assessment and negative perception of the process was due to the lack of understanding about teamwork and how to effectively rate peers. Students were reluctant to judge peers, causing tension among the groups. Kaufman, Felder, and Fuller (2000) provided a list of concerns with peer evaluations, such as collusion among team members, inflating self-ratings, and evaluating on personal prejudices. Kaufman et al. (2000) suggested that these concerns can be managed with a primer for students on how to complete peer evaluations objectively and the skills needed for effective teamwork. Vickerman (2009) and Chen and Lou (2004) also suggested that issues with peer evaluations can be mitigated with clear instructions on how the peer evaluations will be used in the course as well as a validated assessment tool. King and Behnke (2005) voiced concerns with grading by incorporating peer-rating data. They argued that by allowing peers to assess individual contributions to a group assignment, the instructor relinquishes full control of the grade to the team and thus may have an issue with defending a grade if challenged. It was concluded by King and Behnke (2005) that the instructor should just assign one grade to the entire group to avoid this issue. Counter to this concern, Chen and Lou (2004) suggested that "group members spend a substantial amount of time working with each other [on group assignments] and, thus, are in a good position to recognize and assess their peers' efforts and [the individual] contributions" made by each member of the team (p. 276).

Formative peer assessment provides feedback, and students can alter their performance before the evaluative assessment is administered. Brooks and Ammons (2003) implemented assessments multiple times in a course, but the peer evaluations were utilized as summative assessments at the end of each short-term team project in the course. Whether the peer evaluations are formative, summative, or a combination of both, when a grade is assigned based on the outcome of the evaluation, the implementation process is similar (Cestone et al., 2008). Cestone et al. (2008) suggested that student expectations be communicated early in the course, along with how grades will be impacted. It is also recommended that learners are prepared for how to participate in peer evaluations as well as how to interpret feedback. When determining the method in which a peer evaluation instrument will be used, the validity of the chosen evaluation instrument and the behaviors that are to be measured are important factors to consider, especially when the results will be factored into student grades (Baker, 2008).

Limitations

This study had a few limitations that should be considered regarding generalization to other educational environments. Evaluation of the final project included three main components which were a planning document, a technical document, and a multimedia presentation in video form. The rubric for the video assessment in the fall 2012 semester had a typo which artificially inflated that component of the final project for only that semester. Thus, the comparison between semesters represents only two of three components of the final project rather than the entire project. Further, the grade inflation on the video assessment in 2012 would not have created more than a 1% inflation for some students in the fall 2012 semester. The results of this work show that the fall 2013 semester course grades were significantly higher, but this may slightly underrepresent the overall impact of the treatment.

Another limitation of this study was that measures of student learning were limited to course assignments, which were not subjected to rigorous validity and reliability measures. However, the assignments and rubrics used were intentionally codeveloped by a team of four faculty members and two instructional developers to align with the objectives of the course. The instructor of the course initiated the study collaboratively with instructors from other sections of the course and the university's center for learning and teaching support team. The external members of the research team served to minimize the potential for instructor bias because the course sections studied were not theirs. Although instructor-led studies of courses potentially introduce bias, the study was conceptualized after the conclusion of the semesters in which data were collected, minimizing the impact of evaluation bias on student submissions. An additional limitation related to the instructor is that although he was an experienced faculty member, this study was set in the second and third year the course was offered at the university. This was also the first and second year that this faculty member was the instructor of this course. Therefore, instructor growth during his first and second year instructing this particular course may account for some impact on student experience.

Measures of team member contribution were self-reported by students. Students completed the rater calibration function in CATME to help support their calibration with the instrument. Although these reliability and validity safeguards were in place, the actual contribution was not measured. Self-reported and peer-reported contribution were measured, which can be problematic and biased as suggested by Haidt (2012) and Oakley (2002). On the other hand, Fehr and Gächter (2000) and Henrich and Boyd (2001) suggested that students are very willing to punish noncooperating students (in this case punishment comes in the form of a poor peer evaluation). Further, Henrich and Boyd (2001) suggested there may be a tendency for cooperation to potentially stabilize as students copy the most successful students' behaviors.

Finally, conclusions about the learning climate, competence, and doubt measures were based on data from voluntarily participating students. During the fall 2013 semester, significant differences existed between students who choose to respond and those who did not. Differences discovered included SAT composite scores and ethnicity. These differences should be considered when generalizing the findings in that students' responses were biased toward students who had lower composite SAT scores and students who identified as White, as compared to other ethnicities.

Further Research

Future research could provide additional support for this study's hypothesis by employing a randomized control treatment in an experimental design. Research validated instruments could be used to measure student learning instead of instructor-generated assignments and assessment rubrics. This study purposefully relied on student perceptions of learning climate, competence, and doubt, which are related to student persistence, rather than direct measures of actual competence, for example. Additional research may holistically consider relatedness and student autonomy, which are aspects of self-determination theory that were not directly measured in this study. Further, trends in student contribution and their potential changes across time in a repeated measures design may shed light on how students develop teamwork skills and what "dosage" of peer feedback is appropriate for causing changes. Other measurable indicators of team success might illustrate a larger perspective including overall satisfaction with the course, ability to collaborate with students from other cultures, communication skills, ability to reflect, and ability to respond positively to criticism.

References

Baker, D. F. (2008). Peer assessment in small groups: A comparison of methods. *Journal of Management Education*, *32*(2), 183–209. doi:10.1177/1052562907310489

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice-Hall.

Black, A. E., & Deci, E. L. (2000). The effects of instructors' autonomy support and students' autonomous motivation on learning organic chemistry: A self-determination theory perspective. *Science Education*, *84*(6), 740–756. doi:10.1002/1098-237X(200011)84:6<740::AID-SCE4>3.0.CO;2-3

Brooks, C. M., & Ammons, J. L. (2003). Free riding in group projects and the effects of timing, frequency, and specificity of criteria in peer assessments. *Journal of Education for Business*, *78*(5), 268–272. doi:10.1080/08832320309598613

Brutus, S., & Donia, M. B. L. (2010). Improving the effectiveness of students in groups with a centralized peer evaluation system. *Academy of Management Learning & Education*, *9*(4), 652–662. doi:10.5465/AMLE.2010.56659882

Cestone, C. M., Levine, R. E., & Lane, D. R. (2008). Peer assessment and evaluation in team-based learning. *New Directions for Teaching and Learning*, *2008*(116), 69–78. doi:10.1002/tl.334

Chen, Y., & Lou, H. (2004). Students' perceptions of peer evaluation: An expectancy perspective. *Journal of Education for Business*, *79*(5), 275–282. doi:10.3200/JOEB.79.5.275-282

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159. doi:10.1037/0033-2909.112.1.155

The College Board. (2009). *ACT and SAT® concordance tables*. Retrieved from https://research.collegeboard.org/publications/content/2012/05/act-and-sat-concordance-tables

Deci, E. L., & Ryan, R. M. (1985). *Intrinsic motivation and self-determination in human behavior*. New York, NY: Plenum Press. doi:10.1007/978-1-4899-2271-7

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry*, *11*(4), 227–268. doi:10.1207/S15327965PLI1104_01

Deci, E. L., Ryan, R. M., & Williams, G. C. (1996). Need satisfaction and the self-regulation of learning. *Learning and Individual Differences*, *8*(3), 165–183. doi:10.1016/S1041-6080(96)90013-8

Elliott, N., & Higgins, A. (2005). Self and peer assessment—Does it make a difference to student group work? *Nurse Education in Practice*, *5*(1), 40–48. doi:10.1016/j.nepr.2004.03.004

Fehr, E., & Gächter, S. (2000). Cooperation and punishment in public goods experiments. *The American Economic Review*, *90*(4), 980–994. doi:10.1257/aer.90.4.980

Fellenz, M. R. (2006). Toward fairness in assessing student groupwork: A protocol for peer evaluation of individual contributions. *Journal of Management Education*, *30*(4), 570–591. doi:10.1177/1052562906286713

Fraenkel, J. R., & Wallen, N. E. (2009). *How to design and evaluate research in education* (7th ed.). New York, NY: McGraw-Hill.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences of the United States of America*, *111*(23), 8410–8415. doi:10.1073/pnas.1319030111

Gay, L. R., Mills, G.E., & Airasian, P. (2009). *Educational research: Competencies for analysis and applications* (9th ed.). Upper Saddle River, NJ: Pearson Education.

Goldfinch, J., & Raeside, R. (1990). Development of a peer assessment technique for obtaining individual marks on a group project. *Assessment & Evaluation in Higher Education*, *15*(3), 210–231. doi:10.1080/0260293900150304

Haidt, J. (2012). *The righteous mind: Why good people are divided by politics and religion*. New York, NY: Vintage Books.

Henrich, J., & Boyd, R. (2001). Why people punish defectors. Weak conformist transmission can stabilize costly enforcement of norms in cooperative dilemmas. *Jornal of Theoretical Biology*, *208*(1), 79–89. doi:10.1006/jtbi.2000.2202

Holland, N., & Feigenbaum, L. (1998). Using peer evaluations to assign grades on group projects. *Journal of Construction Education*, *3*(3), 182–188. Retrieved from http://www.ascjournal.ascweb.org/journal/1998/no3/Fall%201998,%20Vol.%203,%20No.%203,%20pp.%20182-188.pdf

Jassawalla, A., Sashittal, H., & Malshe, A. (2009). Students' perceptions of social loafing: Its antecedents and consequences in undergraduate business classroom teams. *Academy of Management Learning & Education*, *8*(1), 42–54. doi:10.5465/AMLE.2009.37012178

Johnson, D. W., Johnson, R. T., & Smith, K. A. (1998). Cooperative learning returns to college: What evidence is there that it works? *Change: The Magazine of Higher Learning*, *30*(4), 26–35. doi:10.1080/00091389809602629

Kao, G. Y.-M. (2013). Enhancing the quality of peer review by reducing student “free riding”: Peer assessment with positive interdependence. *British Journal of Educational Technology*, *44*(1), 112–124. doi:10.1111/j.1467-8535.2011.01278.x

Kaufman, D. B., Felder, R. M., & Fuller, H. (2000). Accounting for individual effort in cooperative learning teams. *Journal of Engineering Education*, *89*(2), 133–140. doi:10.1002/j.2168-9830.2000.tb00507.x

Kench, P. L., Field, N., Agudera, M., & Gill, M. (2009). Peer assessment of individual contributions to a group project: student perceptions. *Radiography*, *15*(2), 158–165. doi:10.1016/j.radi.2008.04.004

Kennedy, G. J. (2005). Peer-assessment in group projects: Is it worth it? In A. Young & D. Tolhurst (Eds.), *Proceedings of the 7th Australasian conference on computing education* (Vol. 42, pp. 59–65). Darlinghurst, Australia: Australian Computer Society.

King, P. E., & Behnke, R. R. (2005). Problems associated with evaluating student performance in groups. *College Teaching*, *53*(2), 57–61. doi:10.3200/CTCH.53.2.57-61

Levesque-Bristol, C., Knapp, T. D., & Fisher, B. J. (2010). The effectiveness of service-learning: It's not always what you think. *Journal of Experiential Education*, *33*(3), 208–224. doi:10.1177/105382590113300302

Loughry, M. L., Ohland, M. W., & Moore, D. D. (2007). Development of a theory-based assessment of team member effectiveness. *Educational and Psychological Measurement*, *67*(3), 505–524. doi:10.1177/0013164406292085

Loughry, M. L., Ohland, M. W., & Woehr, D. J. (2014). Assessing teamwork skills for assurance of learning using CATME team tools. *Jornal of Marketing Education*, *36*(1), 5–19. doi:10.1177/0273475313499023

Maiden, B., & Perry, B. (2011). Dealing with free-riders in assessed group work: Results from a study at a UK university. *Assessment & Evaluation in Higher Education*, *36*(4), 451–464. doi:10.1080/02602930903429302

Mentzer, N. (2014). Holding students accountable in team design projects. *Technology and Engineering Teacher*, *74*(3), 14–20.

Millis, B. J. (2010). Why faculty should adopt cooperative learning approaches. In B. Millis (Ed.), *Cooperative learning in higher education: Across the disciplines, across the academy* (pp. 1–9). Sterling, VA: Stylus.

National Research Council. (2011). *Assessing 21st century skills: Summary of a workshop*. Washington, DC: National Academies Press. doi:10.17226/13215

Oakley, B. (2002). It takes two to tango: How “good” students enable problematic behavior in teams. *Journal of Student Centered Learning*, *1*(1), 19–27.

Ohland, M. W., Bullard, L., Felder, R., Finelli, C., Layton, R., Loughery, M., . . Woehr, D. (2005). CATME. West Lafayette, IN: Purdue University.

Ohland, M. W., Loughry, M. L., Woehr, D. J., Bullard, L. G., Felder, R. M., Finelli, C. J., . . . Schmucker, D. G. (2012). The comprehensive assessment of team member effectiveness: Development of a behaviorally anchored rating scale for self and peer evaluation. *Academy of Management Learning & Education*, *11*(4), 609–630. doi:10.5465/amle.2010.0177

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education*, *93*(3), 223–231. doi:10.1002/j.2168-9830.2004.tb00809.x

Reese-Durham, N. (2005). Peer evaluation as an active learning technique. *Journal of Instructional Psychology*, *32*(4), 338–345.

Slavin, R. E. (1991). Synthesis of research on cooperative learning. *Educational Leadership*, *48*(5), 71–82. Retrieved from http://www.ascd.org/ASCD/pdf/journals/ed_lead/el_199102_slavin.pdf

Smith, K. A., Sheppard, S. D., Johnson, D. W., & Johnson, R. T. (2005). Pedagogies of engagement: Classroom-based practices. *Journal of Engineering Education*, *94*(1), 87–101. doi:10.1002/j.2168-9830.2005.tb00831.x

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics* (5th ed.). Boston, MA: Pearson/Allyn & Bacon.

Tessier, J. T. (2012). Effect of peer evaluation format on student engagement in a group project. *The Journal of Effective Teaching*, *12*(2), 15–22. Retrieved from http://www.uncw.edu/jet/articles/Vol12_2/Tessier.pdf

Topping, K. (1998). Peer assessment between students in colleges and universities. *Review of Educational Research*, *68*(3), 249–276. doi:10.3102/00346543068003249

Topping, K. J. (2009). Peer assessment. *Theory Into Practice*, *48*(1), 20–27. doi:10.1080/00405840802577569

Vickerman, P. (2009). Student perspectives on formative peer assessment: An attempt to deepen learning? *Assessment & Evaluation in Higher Education*, *34*(2), 221–230. doi:10.1080/02602930801955986

Warner, R. M. (2013). *Applied statistics: From bivariate through multivariate techniques* (2nd ed.). Thousand Oaks, CA: Sage.

Williams, G. C., & Deci, E. L. (1996). Internalization of biopsychosocial values by medical students: A test of self-determination theory. *Journal of Personality and Social Psychology*, *70*(4), 767–779. doi:10.1037/0022-3514.70.4.767

About the Authors

Nathan Mentzer (nmentzer@purdue.edu) is Associate Professor in the Engineering/Technology Teacher Education Program at Purdue University, jointly appointed in Technology Leadership and Innovation and Curriculum and Instruction.

Dawn Laux (dlaux@purdue.edu) is a Clinical Assistant Professor in the Department of Computer and Information Technology (CIT) at Purdue University.

Angelika Zissimopoulos (zissimopoulos@uchicago.edu) is Associate Director for STEM education at the University of Chicago's Chicago Center for Teaching.

K. Andrew R. Richards (karichards2@ua.edu) is Assistant Professor of Physical Education in the Department of Kinesiology at the University of Alabama.

Appendix: Questions Included on the Student Perceptions Survey Learning Climate, Competence, and Doubt Scale Items

All items measured on a 7-point, Likert-type scale ranging from strongly agree to strongly disagree.

Learning Climate Questionnaire

1. My instructor provided me with choices and options on how to complete the work.
2. My instructor understood my perspective.
3. My instructor encouraged me to ask questions.
4. My instructor listened to how I would like to do things.
5. My instructor tried to understand how I saw things before suggesting a new way to do things.
6. My instructor stimulated my interest in the subject.
7. My instructor made sure I really understood the goals of the course and what I needed to do.

Competence and Doubt

1. Competence
    a. People in this course told me I was good at what I was doing.
    b. I was able to learn interesting new skills in this course.
    c. Most days, I felt a sense of accomplishment from being in this course.
2. Doubt
    a. I did not feel very competent in this course.
    b. In this course, I did not get much of a chance to show how capable I was.
    c. When I was in this course, I often did not feel very capable.

Examining Elementary School Students' Transfer of Learning Through Engineering Design Using Think-Aloud Protocol Analysis

Todd Kelley and Euisuk Sung

Abstract

The introduction of engineering practices within the *Next Generation Science Standards* provides technology educators with opportunities to help STEM educators infuse engineering design within a core curriculum. The introduction of teaching engineering design in early elementary grades also provides opportunities to conduct research investigating how young students use engineering design as a way to solve problems. There is a need for research to assess how students experience engineering design as a pedagogical approach to learning science. This article will feature research on elementary students' cognitive strategies used during engineering-design science activities. We adopted the concurrent think-aloud (CTA) protocol analysis method to capture how students conceptualize design and enhance science learning. During the 2012–2013 school year, we video recorded 66 CTA sessions, and this study examines six of those sessions. NVivo (Version 10) was used to code each video using common cognitive strategies categorized by Halfin (1973). Research findings indicate that participants increased the amount of time spent on mathematical thinking by 34% when given a math-specific design task. Pre- and post-tests showed that participants gained significant science content knowledge. However, we also confirmed that participants struggled with applying accurate mathematical and scientific knowledge to solving the given design problem.

Keywords: concurrent think-aloud protocol; design cognition; transfer of learning

Design is a core component of technology education (Lewis, 2005). Engineers, designers, and others in technology design and create solutions to given problems. Therefore, technology educators have been implementing the engineering-design approach as an effective way to teach technology. Although technology education is putting greater emphasis on engineering design (Hill, 2006; Lewis, 2005; Wicklein, 2006), recently, K–12 science education in the United States has proposed the teaching of engineering practices alongside the teaching of science practices. For example, the *Framework for K-12 Science Education* (National Research Council [NRC], 2012) includes engineering-design learning standards. The framework provides a strong platform for teaching engineering and technology contexts to enhance students' science learning. The document states:

> Engineering and technology provide a context in which students can test their own developing scientific knowledge and apply it to practical problems; doing so enhances their understanding of science—and, for many, their interest in science—as they recognize the interplay among science, engineering, and technology. We are convinced that engagement in the practices of engineering design is as much a part of learning science as engagement in the practices of science [(National Academy of Engineering and National Research Council, 2009)]. (p. 12)

Many states, including Massachusetts and Minnesota, have created academic standards requiring students to engage in the engineering-design process and to explore the nature of technology and engineering practices within science standards (Robelen, 2013). Conceptually, the driving force behind these educational reforms is the emphasis on students developing the abilities to define problems by asking questions, create and apply models, generate plans, engage in design challenges, and apply evidence-based scientific knowledge to create and select the best possible solution to a problem (NRC, 2012).

With the introduction of the *Next Generation Science Standards* to the elementary science classroom, technology educators can use their long history of design study in the secondary grade level to investigate the use of engineering design with elementary students. This will provide technology educators with a better understanding of how young students solve problems using the engineering-design approach. In addition, technology educators have shown that engineering design not only enhances STEM teaching and learning but also helps students develop cognitive capabilities by practicing engineering design as a problem-solving strategy (Lammi & Becker, 2013).

One measure used to investigate students' cognitive approaches is the think-aloud protocol. Atman and Bursic (1998) employed the think-aloud protocol method as an evaluation tool to assess students' design and problem-solving capacity. They used it to understand how undergraduate engineering students solved open-ended, ill-defined engineering-design problems. Similar to Atman and Bursic's studies, this study used a concurrent think-aloud (CTA) protocol in an elementary setting to inform technology education and STEM education about how elementary students solve design problems.

As a part of Science Learning through Engineering Design (SLED), a Math Science Targeted Partnership (MSP) funded by the National Science Foundation (NSF), we conducted two studies in which we collected data from CTA sessions to measure students' problem-solving ability. In the first study, data were collected on Cohort 1 in the 2011–2012 school year. In the second study, which is the subject of this article, data were collected on Cohort 2 in the 2012–2013 school year.

In the original study of Cohort 1, we collected data from 33 CTA sessions to measure the students' problem-solving ability in the 2011–2012 school year. Key features of engineering-design thinking often require many cognitive strategies; however, in the findings from Cohort 1, students showed limited use or no use of these strategies. The Cohort 1 findings revealed that the students spent very little time in computing (4%), managing (1%), testing (3%), and predicting results (4%). Students spent almost half of their time generating ideas (47%). CTA sessions from Cohort 1 indicate that student teams (triads) did not emphasize the use of computing (CO) and testing (TE) during the protocol sessions. Additionally, the cognitive strategy interpreting data (ID) was missing from all the protocol sessions. Even though mathematical reasoning skills such as computing, testing, and interpreting data are the key elements of engineering design, the results indicate that students were not using these skills. The results of the Cohort 1 study are compared with those of Cohort 2 in the Results section.

Purpose of the Study

The purpose of this study was to investigate how triads of students collaboratively developed solutions and applied scientific and mathematical concepts to inform their solution to engineering-design challenges. The questions guiding this study included the following:

1. How do Grade 5 students conceptualize and learn design?
2. Which aspects of the engineering-design process do students tend to emphasize?
3. Which aspects of the engineering-design process do students tend to overlook?
4. To what extend do students apply scientific concepts and mathematical reasoning when engaging in an engineering-design transfer problem?

Theoretical Perspective

The theoretical perspective for studying participants' cognitive strategies through design is based upon the construct of *transfer of learning* (Bransford, Brown, & Cocking, 1999). Transfer of learning suggests that students can transfer their prior knowledge, skills, and experiences to new situations. When students are presented with new opportunities that are similar to pre-existing experiences, learning transfer can occur. Learning transfer is an indicator of understanding. Royer (1986) further describes the concept of transfer of learning: "Used as an index of understanding is equivalent to the idea that the ability to *transfer* learned information is evidence that understanding is present" (p. 95). In this study, we carefully crafted transfer problems that were similar in structure and scope to those presented to the students during a prior learning experience in order to assess a near transfer of learning (Thorndike, & Woodworth, 1901; Bransford, et al., 1999). We observed and coded student dialogue to determine if students transferred what they had learned during the SLED activities to the transfer problems. Specifically, we were looking for students to transfer key engineering and science practices, scientific concepts, and the use of mathematical reasoning.

Literature Review

A CTA protocol is a procedure that allows a researcher to study the verbal report of one individual or group of individuals speaking their thoughts while engaging in an assigned task or problem. Recently, the CTA method has been applied to a wide variety of contexts, such as studying human operations of process controlling systems (Sanderson, Verhage, & Fuld, 1989), cognitive studies on writing (Ransdell, 1995) and reading (Pressley & Afflerbach, 1995). CTA protocols are endorsed as a promising tool to capture cognitive and metacognitive thinking in engineering education research (Atman & Bursic, 1998). Multiple CTA studies have investigated engineering-design approaches within engineering education (Atman, Chimka, Bursic, & Nachtmann, 1999; Atman, Cardella, Turns, & Adams, 2005; Gainsburg, 2015) and team-based engineering design and problem solving (Mentzer, 2014; Stempfle & Badke-Schaub, 2002).

However, investigating the cognition of designers during design is challenging. Ericsson and Simon (1993) suggest that CTA methods may provide the most authentic approach to achieve a record of cognitive activity during design because the designer is allowed to perform in his or her natural state of mind not altered by outside influences beyond verbalizing thoughts. Unlike structured elicitation approaches to cognitive investigations, CTA investigation seeks to place the participant in his or her most natural state of design thinking during the protocol sessions (van Someren, Barnard, & Sandberg, 1994).

Some questions have arisen regarding CTA as a proper method to capture all aspects of design cognition. Lloyd, Lawson, and Scott (1995) reported that CTA methods may accurately capture short-term thought processes but fail to capture long-term states of memory. However, allowing designers to express ideas graphically allows for both short-term and long-term cognition (Ullman, Wood, & Craig, 1990). In addition, the CTA method requires participants to use their own language and to approach the assigned task as they would naturally solve it. Furthermore, some researchers questioned the validity of CTA data from young children. However, van Someren, Barnard, and Sandberg (1994) found that

> In our experience, the quality of verbalizations is not strongly associated with other properties that can easily be observed or measured. One possible exception is age. Young children usually find it difficult to think aloud. It is not clear if this is due to their verbalization skills, to the content of their thought processes or to the general difficulty of concentrating on a problem-

> solving task. (p. 35–36)

In a usability study, Donker and Markopoulos (2002) stated: “We expected methods like think-aloud that require high verbalization skills to be less effective for younger children or children with fever verbalization skills. Our expectations were not confirmed” (p. 314). We acknowledge these possible limitations of CTA protocols and, therefore, provided participants with the opportunity to create design sketches during the protocol sessions and to allow participants to work collaboratively and in their most natural state.

Research Design

Context of the Study

This study is part of an NSF-funded MSP entitled SLED (for more information, see https://stemedhub.org/groups/sled). The collaborative partnership is made up of four colleges within a large, research-intensive university and four school corporations located in the north-central Midwest. The primary goal of the SLED project is to improve achievement in Grades 3–6 students’ science learning through an engineering-design pedagogical approach. Over the course of 5 years, approximately 100 preservice teachers, 200 in-service teachers, and 5,000 students in Grades 3–6 will participate in the partnership.

This research study was drawn from two SLED partnership schools. School Site 1 was located in an emerging urban school district, and School Site 2 was located in a rural fringe school district (see Table 1 for demographics).

Table 1
Demographics of School Sites 1 and 2

Category	School Site1	School Site 2
Enrollment	552	124
Ethnicity		
White/Caucasian	56%	76.6%
Hispanic	27.7%	12.1%
Black/non-Hispanic	10.1%	4.8%
Asian	0.4%	0.0%
Multiracial	5.1%	5.6%
American Indian	0.5%	0.8%
Free or reduced-price lunch	71.9%	43.6%

Student Design Activities

In the second year of the project, the design team developed two math-embedded SLED activities to provide students' mathematical reasoning practice. These activities were also designed to address science standards. The activities were (a) the CO_2 Device activity in which student designed a device utilizing a balloon filled with carbon dioxide and (b) the Recycling Paper activity. Table 2 gives an overview of the design activities (see Appendices A and B for the design activity prompts). The series of science lessons implemented to support the engineering-design tasks was between five to seven 45-minute lessons delivered by SLED teachers. These science inquiry lessons contained the science content knowledge required to successfully complete the engineering-design tasks. These lessons targeted students' misconceptions regarding conservation of mass, which have been documented by Driver (1983) and Driver, Squires, Rushworth, and Wood-Robinson (1994).

Table 2
Overview of the Two New SLED *Design Activities for the Grade 5 Conservation of Mass Focused Design Tasks*

Title	CO_2 Device	Recycling Paper
Description	The CO_2 device activity required students to design a device utilizing a balloon filled with carbon dioxide generated from mixing vinegar and baking soda.	The recycling paper activity involved students calculating the volume and mass of an irregular material (pile of shredded paper) or mixture of paper and water (sludge) while designing a process to make recycled paper.

Participants

During the 2012–2013 school year (Cohort 2), we collected data from a total of 66 CTA sessions. Analysis of data from the 66 sessions provided general design patterns of the cognitive approach that students took in the engineering-design challenges. Data from six sessions were further analyzed to understand how students used cognitive strategies to solve math-embedded design problems.

We used *criterion sampling* to select cases that satisfied a specific criterion (Gall, Gall, & Borg, 2007). Participants for the think-aloud protocols were purposefully selected by the SLED teachers. Teacher recommendations were based upon (a) the students' ability to express themselves verbally, (b) their ability to successfully function as contributing members of a design team, (c) their assent to participate in the study, and (d) parental consent for the students to participate. Triads of student design teams were formed for each SLED classroom participating in the research. Welch (1999) suggests that pairing or grouping student participants allows for the design process to emerge naturally because most design efforts occur in groups of two or more people working together. Table 3 lists the total classroom size and genders of the three students selected as part of the triad for the six case studies. For example, Classroom 1 had a total of 54 students, and one male student and two female students were selected to form a triad.

Table 3
Think-Aloud Participants: Classroom Size and Student Gender Demographics of Triads

	School Site 1			School Site 2		
School	Classroom 1	Classroom 2	Classroom 3	Classroom 4	Classroom 5	Classroom 6
Classroom size	54	55	48	59	30	29
Student gender	1 M, 2 F	2M, 1F	2M, 1F	1M, 2F	2M, 1F	2M, 1F

Data Collection

Concurrent think-aloud protocol. The study employed the CTA protocol to capture students' cognitive thinking processes and thoughts. After each participant classroom completed the SLED design activity, we selected a triad of students to participate in the CTA protocol. According to the Ericson and Simon's (1993, p. 18) suggestion for CTA data collection, we provided students with two guidelines: (a) explain their thoughts directing their attention to the problem-solving procedure and (b) utilize their prior knowledge from the classroom-based design activity to the transfer problem presented in the protocol session.

Transfer problem. The transfer problem was a key instrument used to provide each triad with the opportunity to study design problems similar to the SLED design activities. As Cross (1994) suggested, transfer problems consist of three parts: (1) a goal, (2) constraints to address, and (3) design criteria to gauge the final design solution against. In this study, we focused on creating authentic engineering-design problems that required the use of science concepts embedded within the task. The problem scenarios were created based on situations that students might encounter in their daily lives or on designing products that were familiar to them. One transfer problem, Scotty's Scooters in Appendix C, was created for both the Recycling Paper and the CO_2 Device tasks because they addressed the same science concept, conservation of mass.

SLED knowledge assessments. To investigate the gap between knowing and applying scientific knowledge, we adopted a set of pre- and post-knowledge tests. Using an approach similar to Singer, Marx, Krajcik, and Chambers (2000) and Fortus, Dershimer, Krajcik, Marx, and Mamlok-Naaman (2004), we constructed a multiple-choice test that contained items of low, medium, and high cognitive demand to assess students' preexisting knowledge and to measure gains in knowledge. As Fortus et al. (2004) described, in order to get accurate indication of student's growth in knowledge from the SLED activities, researchers must first determine what students already know about the science. Pretest assessments were administered at the start of the academic year, and posttests were administered within 10 days of completing the SLED activity. Because one of the participants was absent when the pretest assessment was administered, pre- and post-test scores were only available for 17 participants.

Data Analysis

Think-aloud protocol analysis. The study adopted Halfin's (1973) codes to analyze the think-aloud data. These codes were created during Halfin's Delphi study that researched commonly used cognitive strategies by successful professional scientists, engineers, and inventors. Seventeen cognitive strategies were generated, and detailed descriptions were developed from the research and validated by 28 panel members. One advantage to using Halfin's codes for this analysis is that it provides problem-solving processes as well as comprehensive cognitive strategies usually used in design activities. Halfin's coding scheme allowed us to investigate students' abilities to apply their design and problem-solving capabilities to transfer problems (Hill, 1997; Kelley, 2008; Kelley, Capobianco, & Kaluf, 2015; Wicklein, 1996).

Interrater reliability of think-aloud analysis. Several steps were followed to ensure interrater reliability when analyzing the video data. First, two researchers carefully reviewed the coding scheme and definitions created by Halfin (1973, pp. 135–204) and mapped students' dialogues to these codes. Seven codes were determined to be outside the parameters of the protocol sessions, so these codes were removed from the coding list for the purpose of this research.[1] As a result, we utilized 10 of the 17 codes developed by Halfin (1973). The 10 codes used in this study are described in Appendix D. Second, sample video clips were viewed by the two researchers together, and their interpretations of the selected segments were discussed in order to reach coding consensus. Finally, the two researchers independently coded the video segments, and their analyses were compared. The kappa coefficient for interrater reliability was calculated. Hruschka et al. (2004) suggested that at least 20% of the data set

---

[1] Due to the time limitations for the protocol sessions, participants were not able to construct models or conduct experiments.

results should be compared between two independent researchers. In this study, we analyzed one third of the CTA sessions to ensure interrater reliability. Each video from the six CTA sessions was segmented into three parts, and one segment from each session was analyzed for interrater reliability. To achieve acceptable levels of intercoder reliability, we followed Hruschka et al.'s iterative coding method (p. 311), and a Kappa coefficient of 0.91 was calculated using NVivo (Version 10) with 99.45% agreement.

SLED knowledge assessments analysis. In order to measure that participants successfully gained scientific and mathematical knowledge through the SLED engineering-design lessons, we compared pre- and post-test scores using a paired sample *t*-test using SAS (Version 9.4), a statistical analysis software.

Results

Concurrent Think-Aloud Protocols

Data from 66 concurrent think-aloud protocols were collected during the 2012–2013 school year (Cohort 2). The mean percentages for the coded sessions are displayed in Figure 1.

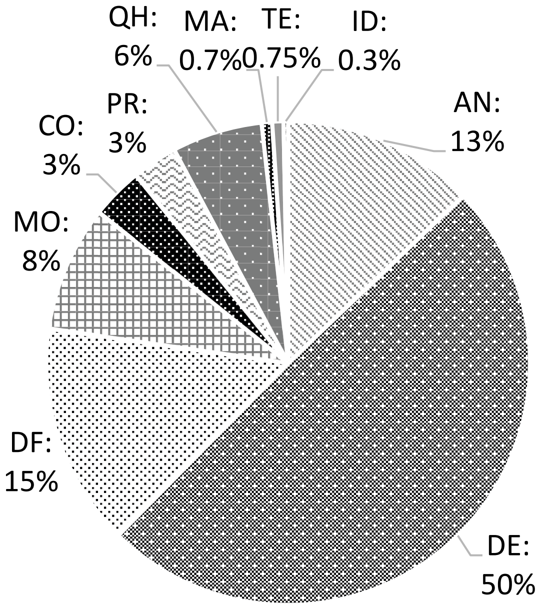


Figure 1. Result of total group mean percentages per code in Cohort 2.

Based upon the coded data for Cohort 2, we found that:

a) Participants continued to effectively define the problem and identify constraints and criteria when compared to the results from Cohort 1.
b) Students spent, on average, 50.4% of their time designing (DE), 14.4% of the time analyzing (AN), and 32.4% of the time defining the problem (DF). These percentages were comparable to the Cohort 1 findings.
c) Eleven sessions involved student dialogues that included numerical data, estimating, and mathematical predictions compared to zero sessions from Cohort 1. One reason is that design activities such as the CO_2 Device and Recycling Paper activities contain numerical data, estimations, volume, or surface area within the design brief. We also noticed that the overall length of several protocol sessions that included computing dialogue. In some cases, this was due to students focusing on computing numbers instead of designing solutions.

We further investigated how students engaged in math-embedded design tasks to determine if learning transfer occurred accurately and if students demonstrated proficiency in the key science standards. Six CTA sessions were selected from the CO_2 Device and Recycling Paper activities to further investigate the dialogue of triads within the time they spent computing. For School Site 1, CTA sessions from the CO_2 Device activity were chosen for all three classrooms (Classrooms 1, 2, and 3). For School Site 2, a CTA session form the Recycling Paper activity was chosen for one classroom (Classroom 4), and CTA sessions from the CO_2 Device activity were chosen for the other two classrooms (Classrooms 5 and 6). Figure 2 shows the coded analysis of each CTA protocol session as a percentage of time; the segment representing computational thinking is labeled CO (dark shading with dots). The six sessions selected showed that students spent 11% to 46% of their time on computational thinking (Figures 2).

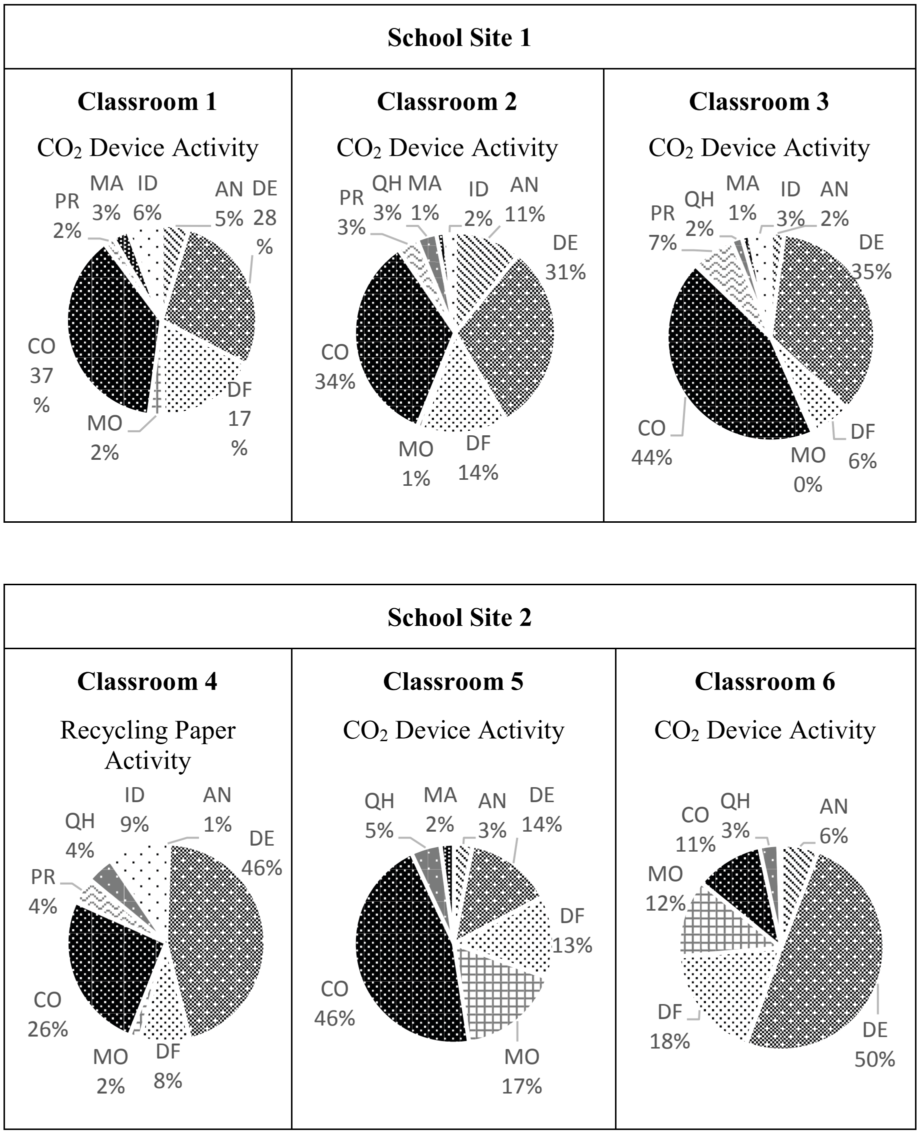


Figure 2. Percent of time spent on each cognitive strategy from School Sites 1 and 2.

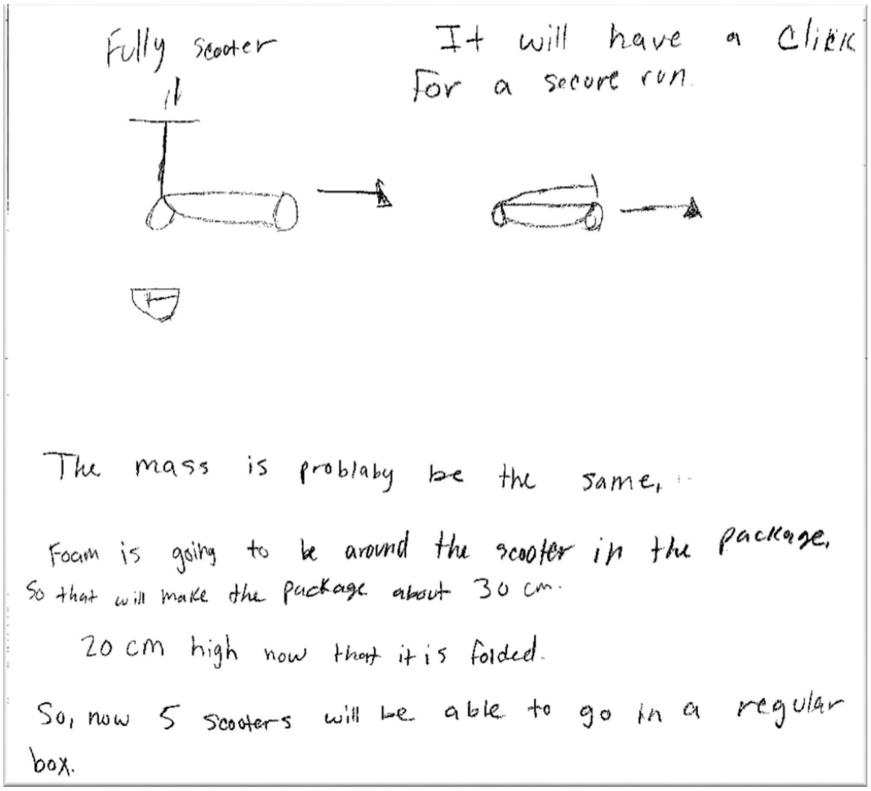
Science and engineering-design knowledge test. Seventeen participants took pre- and post-test exams to measure knowledge gained by participating in the engineering-design activity. A paired-sample *t*-test was performed to determine if these gains were statistically significant. The mean scores for the pretest and posttest and the results of the paired *t*-test are shown in Table 4. The paired *t*-test indicates that the sample means from pre- to post-test are significantly different at the $p < 0.0002$ level.

Table 4
Paired t-test Result from Knowledge Test Scores

	Pretest		Posttest		95% CL for mean difference			
n	*M*	*SD*	*M*	*SD*		DF	*t*	*p*
17	9	1.90	11.94	1.72	1.85, 3.78	16	4.88	< 0.0002

Applying science and math concepts to engineering-design task. The primary science concept being taught during the Recycling Paper and CO_2 Device design tasks was conservation of mass. In order to assess students' ability to apply the science concept to engineering-design tasks, we included a prompt in the transfer problem asking "What is the mass of the re-designed scooter?" We analyzed the computing (CO) segments of the CTA sessions for the triad's discussion regarding conservation of mass. Two of the six triads (Classrooms 1 and 2) correctly answered that the mass is the same, three triads (Classrooms 3, 4, and 5) tried to determine a new mass, and one triad (Classroom 6) did not address the question regarding conservation of mass. In order to illustrate this, we include the dialogue and sketches for two of the triads here: one triad who answered the question correctly, and one who did not. The dialogue from the triad from Classroom 1, who correctly answered the question regarding conservation of mass, appears below, and their sketch for their solution is shown in Figure 3.

Student A: What is the mass?
Student B: The scooter mass is …
Student C: Wait… the mass does not change.
Student A: Yes, mass does not change. It is gonna [*sic*] be the same the scooter mass.
Student B: [what about] not the tires?
Student A: No, the tires are the part of the scooter. It won't change



It will have a ClikK For a secure run.

The mass is problaby be the same,

Foam is going to be around the scooter in the package,
So that will make the package about 30 cm.
20 cm high now that it is folded.
So, now 5 scooters will be able to go in a regular box.

Figure 3. Sketch from the Classroom 1 triad.

Although the triads in Classrooms 1 and 2 answered the question correctly, three triads forgot that the mass does not change even when the scooter is collapsed or disassembled. The triad in Classroom 5 drew the sketch shown in Figure 4, which illustrates their calculations, and their dialogue from that session appears below.

Student X:	We need to figure out what the mass could be. … Old one was 70 cm, 80 cm, and 15 cm. So, we do, 55 times 40 and 15… [Calculating numbers, they multiplied height by width and depth]. The scooter … Yes I got 30,000 pound?
Student Y:	Pound? It is mass.
Student X:	It would be gram?
Student Y:	No, kilogram? 30,000 kg.
Student X:	That’s heavy. [sigh]

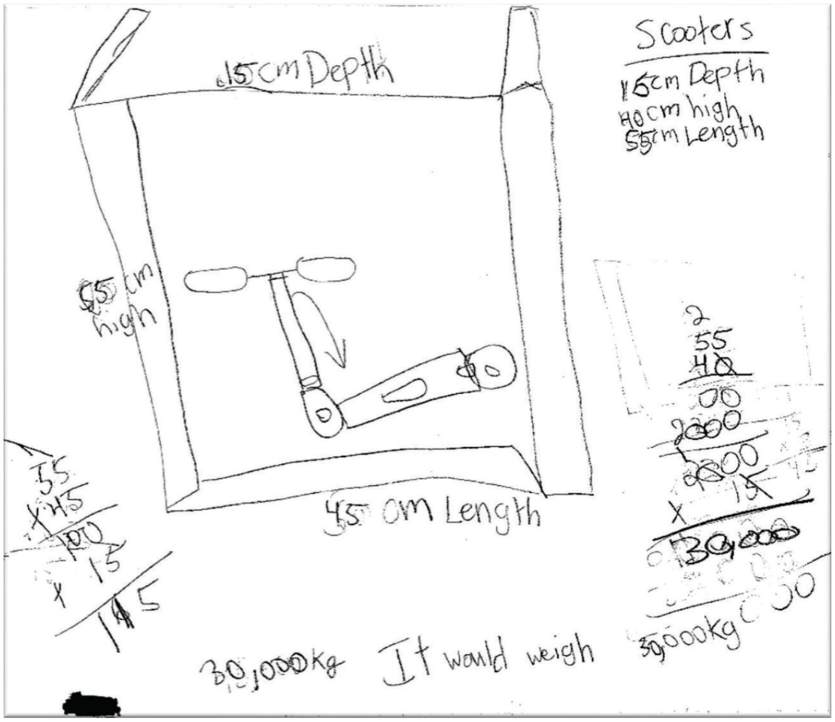


Figure 4. Sketch from the Classroom 5 triad.

The dialogue from the students Classroom 5 showed three types of mathematical and science errors. First, the students failed to recall the concept that the mass does not change even though the physical appearance of the object has changed. Second, to determine the mass of the redesigned scooter, they drew a box around the scooter and multiplied the dimensions of the box. This indicates that they did not understand the difference between the concept of mass and the concept of volume. Third, the value calculated for the mass was incorrect (it contained mathematical errors).

Discussion

The results from the math-embedded tasks demonstrated that students spent additional time engaged in computational thinking during the protocol sessions. However, it also revealed that some students still struggled to accurately transfer science concepts especially conservation of mass. One triad from School Site 1 and two triads at School Site 2 (Classrooms 4, 5, and 6) attempted to calculate a new mass for the disassembled scooter, which showed that they did not recognize that mass is conserved. Two of the three triads at School Site 1

(Classrooms 1 and 2) did correctly identify that mass was conserved when the scooter was disassembled. These results differ from the knowledge test results which indicated gains for all students from pre- to post-test. The results indicate that students were successful at identifying the concept of conservation of mass on a multiple-choice test but most of the students were unable to transfer it to a new situation. The results should be used by stakeholders within STEM education who seek to improve learning through engineering to help students use numerical data to inform their design decisions. Furthermore, using CTA protocols as a form of assessment for design thinking and problem solving revealed gaps in understanding that were not evident from the pre-and post-test knowledge assessments. We believe that using CTA protocols effectively assesses students' abilities to apply or transfer this knowledge to different situations.

Limitations

We acknowledge that there are some limitations to this research. First, we acknowledge that the criterion sampling approach may not provide sampling that best represents the average ability of the student body from each classroom due to potential bias of the teacher when selecting participants for this study. Second, the concurrent think-aloud methodology is a qualitative approach to study individual cases; therefore, these findings cannot be generalized to the entire population. We acknowledge that additional attention should be given to using alternative data methods such as open-response questions within knowledge tests in addition to the think-aloud protocol in order to strengthen the assessment of students' knowledge of science content.

Conclusions and Implications

The purpose of this study was use a CTA protocol methodology in order to classify participants' cognitive approaches to problem solving while engaged in an engineering-design task. Verbal data collected from each CTA session were categorized and organized using Halfin's (1973) codes to help us identify strategies of problem-solving and design-thinking skills. Additionally, we sought to locate within the protocol places where the transfer of learning of science concepts were present and to assess the accuracy of this transfer. The findings from this study revealed that participants were able to apply numerous cognitive strategies while creating design solutions and working in triads. This research confirmed results from previous studies finding that students were able to navigate through the design process moving from the problem space to solution space (Kruger & Cross, 2006) and not getting "stuck" in either space (Kelley, Capobianco, & Kaluf, 2015). Results from the six case studies revealed that students increased the time spent on computational thinking when given math-embedded design tasks.

Although SLED teachers used techniques such as Predict, Observe, Explain (POE) investigations suggested by educational researchers to help overcome misconceptions regarding the law of conservation of mass (Dial, Riddley, Williams, & Sampson, 2009), misconceptions remained for some students. It is not enough for students to know basic science, math, and engineering practices; it is important for students to know how to apply their knowledge and skills to solve real-world problems. We believe that the findings from this study provide strong rationale to use CTA protocol methods to assess student's abilities to apply their knowledge, skills, and practice to transfer problems set in scenarios with real-world contexts.

Elementary science teachers using engineering design as an approach to improve science learning should provide additional opportunities for students to improve their ability to transfer science and mathematical reasoning beyond the initial design tasks. Some suggest that mathematical reasoning needs to move beyond traditional classroom practices (Lesh & Yoon, 2004), requiring students to consider different approaches to thinking when problems are posed or requiring them to transfer their learning to real-world problems (Chamberlin & Moon, 2005). Elementary teachers could also use *Model Eliciting Activities* (Diefes-Dux, Moore, Zawojewski, Imbrie, & Follman (2004) to help students' practice applying mathematical thinking and spatial reasoning to solve problems in a similar way to the transfer problem used in this research study. Additional research needs to be conducted to better understand the results from this study. The findings from this study help to shed new light on (a) the complexities of knowledge transfer, (b) the limits of students' mathematical reasoning, and (c) how the engineering-design approach to teaching science provides new challenges and new opportunities to promote STEM education.

Secondary technology educators must be prepared for students to enter their classrooms with preexisting knowledge of and experience with the engineering-design process due to the *Next Generation Science Standards*. Additional technology educators should seize the opportunity to put students in new and novel situations that require them to use their math and science knowledge while engaging in engineering design. We hope that technology educators will use these research findings to adapt and refine their own engineering-design curriculum. Technology educators can leverage the new opportunities of engineering design within science education to reinforce the application of science and mathematical thinking in technology education classrooms; this is one way to continue to position technology education within STEM education.

Acknowledgements

This article is based upon work supported by the National Science Foundation under Grant No. (DUE 0962840). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

Atman, C. J., & Bursic, K.M. (1998). Verbal protocol analysis as a method to document engineering student design processes. *Journal of Engineering Education*, *87*(2), 121–132. doi:10.1002/j.2168-9830.1998.tb00332.x

Atman, C. J., Chimka, J. R., Bursic, K. M., & Nachtmann, H. L. (1999). A comparison of freshman and senior engineering design processes. *Design Studies*, *20*(2), 131–152. doi:10.1016/S0142-694X(98)00031-3

Atman, C. J., Cardella, M. E., Turns, J., & Adams, R. (2005). Comparing freshman and senior engineering design processes: An in-depth follow-up study. *Design Studies*, *26*(4), 325–357. doi:10.1016/j.destud.2004.09.005

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academy Press. doi:10.17226/9853

Chamberlin, S. A., & Moon, S. M. (2005). Model-eliciting activities as a tool to develop and identify creatively gifted mathematicians. *The Journal of Secondary Gifted Education*, *17*(1), 37–47. doi:10.4219/jsge-2005-393

Cross, N. (1994). *Engineering design methods: Strategies for product design* (2nd ed.). Chichester, England: Wiley & Sons.

Dial, K., Riddley, D., Williams, K., & Sampson, V. (2009). Addressing misconceptions: A demonstration to help students understand the law of conservation of mass. *The Science Teacher*, *76*(7), 54–57.

Donker, A., & Markopoulos, P. (2002). A comparison of think-aloud, questionnaires and interviews for testing usability with children. In X. Faulkner, J. Finlay, & F. Détienne (Eds.), *People and computers XVI—Memorable yet invisible: Proceedings of HCI 2002* (pp. 305–316). London, United Kingdom: Springer-Verlag. doi:10.1007/978-1-4471-0105-5_18

Diefes-Dux, H. A., Moore, T., Zawojewski, J., Imbrie, P. K., & Follman, D. (2004, October). A framework for posing open-ended engineering problems: Model-eliciting activities. In *Frontiers in Education, 2004. FIE 2004. 34th Annual* (pp. F1A-3). IEEE.

Driver, R. (1983). *The pupil as scientist?* Milton Keynes, England: Open University Press.

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making sense of secondary science: Research into children's ideas*. Abingdon, England: Routledge.

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis: Verbal reports as data*. Cambridge, MA: MIT Press.

Fortus, D., Dershimer, R. C., Krajcik, J., Marx, R. W., & Mamlok-Naaman, R. (2004). Design-based science and student learning. *Journal of Research in Science Teaching*, *41*(10), 1081–1110. doi:10.1002/tea.20040

Gainsburg, J. (2015). Engineering students' epistemological views on mathematical methods in engineering. *Journal of Engineering Education*, *104*(2), 139–166. doi:10.1002/jee.20073

Gall, M. D., Gall, J. P., & Borg, W. R. (2007). *Educational research: An introduction* (8th ed.). Boston, MA: Pearson Education.

Halfin, H. H. (1973). *Technology: A process approach*. (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 7323867)

Hill, R. B. (1997). The design of an instrument to assess problem solving activities in technology education. *Journal of Technology Education*, *9*(1), 31–46. doi:10.21061/jte.v9i1.a.3

Hill, R. B. (2006). New perspectives: Technology teacher education and engineering design. *Journal of Industrial Teacher Education*, *43*(3), 45–63. Retrieved from http://scholar.lib.vt.edu/ejournals/JITE/v43n3/pdf/hill.pdf

Hruschka, D. J., Schwartz, D., St. John, D. C., Picone-Decaro, E., Jenkins, R. A., & Carey, J. W. (2004). Reliability in coding open-ended data: Lessons learned from HIV behavioral research. *Field Methods*, *16*(3), 307–331. doi:10.1177/1525822X04266540

Kelley, T. R. (2008). Cognitive processes of students participating in engineering-focused design instruction. *Journal of Technology Education*, *19*(2), 50–64.

Kelley, T. R., Capobianco, B. M., & Kaluf, K. J. (2015). Concurrent think-aloud protocols to assess elementary design students. *International Journal of Technology and Design Education*, *25*(4), 521–540. doi:10.1007/s10798-014-9291-y

Kruger, C., & Cross, N. (2006). Solution driven versus problem driven design: Strategies and outcomes. *Design Studies*, *27*(5), 527–548. doi:10.1016/j.destud.2006.01.001

Lammi, M., & Becker, K. (2013). Engineering design thinking. *Journal of Technology Education*, *24*(2), 55–77. doi:10.21061/jte.v24i2.a.5

Lesh, R., & Yoon, C. (2004). Evolving communities of mind—In which development involves several interacting and simultaneously developing strands. *Mathematical Thinking and Learning*, *6*(2), 205–226. doi:10.1207/s15327833mtl0602_7

Lewis, T. (2005). Coming to terms with engineering design as content. *Journal of Technology Education*, *16*(2), 37–54. doi:10.21061/jte.v16i2.a.3

Lloyd, P., Lawson, B., & Scott, P. (1995). Can concurrent verbalization reveal design cognition? *Design Studies*, *16*(2), 237–259. doi:10.1016/0142-694X(94)00011-2

Mentzer, N. (2014). Team based engineering design thinking. *Journal of Technology Education. 25*(2), 52–72. doi:10.21061/jte.v25i2.a.4

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press. doi:10.17226/13165

NVivo qualitative data analysis Software (Version 10) [Computer software]. (2012). Melbourne, Australia: QSR International.

Pressley, M., & Afflerbach, P. (1995). *Verbal protocols of reading: The nature of constructively responsive reading*. Hillsdale, NJ: Erlbaum.

Ransdell, S. (1995). Generating thinking-aloud protocols: Impact on the narrative writing of college students. *American Journal of Psychology*, *108*(1), 89–98. doi:10.2307/1423102

Robelen, E. W. (2103). Engineering building a foundation in K-12 curricula. *Education Week*, *32*(26), 1, 18–19.

Royer, J. M. (1986). Designing instruction to produce understanding: An approach based on cognitive theory. In G. D. Phye & T. Andre (Eds.), *Cognitive classroom learning: Understanding, thinking, and problem solving* (pp. 83–113). Orlando, FL: Academic Press.

Sanderson, P. M., Verhage, A. G., & Fuld, R. B. (1989). State-space and verbal protocol methods for studying the human operator in process control. *Ergonomics*, *32*(11), 1343–1372. doi:10.1080/00140138908966911

SAS (Version 9.4) [Computer software]. (2012). Cary, NC: SAS Institute.

Singer, J., Marx, R. W., Krajcik, J. S., & Chambers, J. C. (2000). Designing curriculum to meet national standards. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA. Retrieved from http://www.umich.edu/~hiceweb/papers/2000/designing_curriculum_to_meet/singer_NARST2000_doc.pdf

Stempfle, J., & Badke-Schaub, P. (2002). Thinking in design teams—An analysis of team communication. *Design Studies*, *23*(5), 473–496. doi:10.1016/S0142-694X(02)00004-2.

Thorndike, E. L. and Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions, *Psychological Review* 8: Part I, pp. 247–261.

Ullman, D. G., Wood, S., & Craig, D. (1990). The importance of drawing in the mechanical design process. *Computers & Graphics*, *14*(2), 263–274. doi:10.1016/0097-8493(90)90037-X

van Someren, M. W., Barnard, Y. F., & Sandberg, J. A. C. (1994). *The think-aloud method: A practical guide to modelling cognitive processes*. London, England: Academic Press.

Welch, M. (1999). Analyzing the tacit strategies of novice designers. *Research in Science & Technical Education*, *17*(1), 19–34. doi:10.1080/0263514990170102

Wicklein, R. C. (1996). Processes of a technologist: Key curriculum component for technology education. Unpublished manuscript.

Wicklein, R. C. (2006). Five good reason for engineering design as the focus for technology education. *The Technology Teacher*, *65*(7), 25–29.

About the Authors

Todd Kelley (trkelley@purdue.edu) is Associate Professor in the Engineering/Technology Teacher Education Program in the Department of Technology Leadership and Innovation at Purdue University.

Euisuk Sung (sunge@purdue.edu) is a PhD Candidate in the Engineering and Technology Teacher Education Program in the Department of Technology Leadership and Innovation at Purdue University.

APPENDIX A

Design Task 1: Recycling Paper

SLED
Science Learning through
Engineering Design

Recycling Paper for Your School

The greater Lafayette area is facing the problem of increased paper waste. The city of Lafayette is interested in recycling the paper waste. They need your help to design a strainer system for the recycling plant that will produce very thin recycled paper.

Criteria

- Paper produced should be as thin as possible
- Paper should have equal or consistent thickness throughout the paper
- There should not be any holes on the paper
- Paper should be at least 3”x 5”
- Use 2.5 liters of water

Constraints

- You can only use the materials, tools, and paper available to you in the class
- Paper blending has to be done only by your teacher

Deliverables

- A dry recycled paper that has dimensions of 3 inches by 5 inches.

*The design task was developed by Şenay Purzer, Venkatesh Merwade, Brad Harriger, David Eichinger, and Erin Doherty.

APPENDIX B
Design Task 2: CO_2 Device

An employee of the Indiana Sand Dunes Chemical Company noticed that a byproduct (a substance made during a reaction, but not used) of the chemical process he was developing was a gas. In fact, the employee noted that a lot of this gas was formed after combining two reactants, vinegar and baking soda. The gas, carbon dioxide, was enough to inflate a balloon. The Indiana Sand Dunes Chemical Company is convinced that the production of the gas can be used to make a useful product and they are asking you to help them design a product that people would want to buy and use. Your team is limited to one balloon filled with gas.

You may use the following materials to generate the amount of gas necessary for your device:

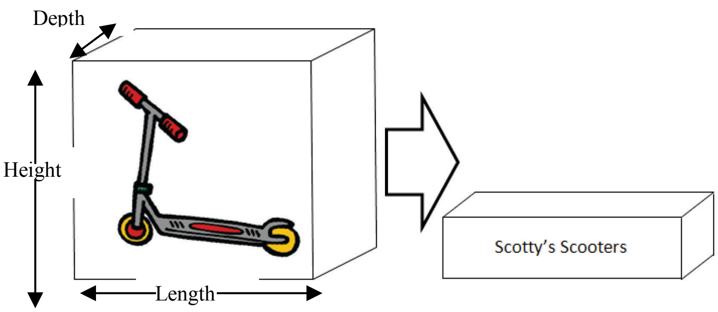
- One 16 - 24oz empty plastic drink bottle (avoid wide-necks)
- 12" helium quality balloon
- 200mL distilled white vinegar
- 3 level teaspoons (or 1 level tablespoon) Baking Soda (15 – 20g)
- Bag clip

* The design task was developed by Kari Clase, Melissa Colonis, John Grutzner, Bryan Hubbard, Alyssa Panitch, and Nancy Tyrie.

APPENDIX C

SLED
Science Learning through
Engineering Design

Transfer Problem: Scotty's Scooters



The Problem

The owner, Scotty, has a brand new line of scooters that he has designed and must package for shipment. However, storage at *Scotty's Scooters* is limited. Scotty realizes that fully assembled packaged scooters take up too much space. A re-design of the scooters is necessary to allow them to collapse or break apart to fit in smaller boxes. Scotty has asked for your design team to help in re-designing his scooter so that it will collapse and fit in the smallest packaging as possible.

Scotty is looking for the following re-design features:

- The scooter design must collapse or break apart.
- All pieces MUST be in the shipping package.
- The package must take up as little storage space as possible.

Scooter Facts:

- The size of the fully assembled scooter has a length of 70 cm, a height of 80 cm, and a depth of 15 cm.
- The scooter's mass is 3.5 kg.
- The fully assembled scooter fits in a box 75 cm long x 90 cm high x 20 cm deep.

Scotty's questions about your re-design:

- What is the size of the box to hold the re-designed (collapsed) scooter?
- What is the mass of the re-designed scooter?

- How much space can you save with the re-designed scooter?

Your Task

Describe how you would re-design a scooter that will collapse or break apart to create smaller shipping packages.

- Please describe aloud how you would start the design task - where would you begin?
- How would you design to include all the features listed above?
- How would you answer Scotty's questions?

APPENDIX D

Cognitive Processes Identified by Halfin's (1973) Study of High-level Designers

(10 of the 17 total codes that emerged in the CTA sessions)

Proposed mental methods		Definition
Analyzing	AN	The process of identifying, isolating, taking apart, breaking down, or performing similar actions for the purpose of setting forth or clarifying the basic components of a phenomenon, problem, opportunity, object, system, or point of view.
Computing	CO	The process of selecting and applying mathematical symbols, operations, and processes to describe, estimate, calculate, quantity, relate, and/or evaluate in the real or abstract numerical sense.
Defining problem(s)	DF	The process of stating or defining a problem which will enhance investigation leading to an optimal solution. It is transforming one state of affairs to another desired state.
Designing	DE	The process of conceiving, creating inventing, contriving, sketching, or planning by which some practical ends may be effected, or proposing a goal to meet the societal needs, desires, problems, or opportunities to do things better. Design is a cyclic or iterative process of continuous refinement or improvement.
Interpreting data	ID	The process of clarifying, evaluating, explaining, and translating to provide

		(or communicate) the meaning of particular data.
Managing	MA	The process of planning, organizing, directing, coordinating, and controlling the inputs and outputs of the system.
Modeling	MO	The process of producing or reducing an act, or condition to a generalized construct which may be presented graphically in the form of a sketch, diagram, or equation; presented physically in the form of a scale model or prototype; or described in the form of a written generalization.
Predicting	PR	The process of prophesying or foretelling something in advance, anticipating the future on the basis of special knowledge.
Questions/hypotheses	QH	Questioning is the process of asking, interrogating, challenging, or seeking answers related to a phenomenon, problem, opportunity element, object, event, system, or point of view.
Testing	TE	The process of determining the workability of a model, component, system, product, or point of view in a real or simulated environment to obtain information for clarifying or modifying design specifications.

Scope of the JTE

The *Journal of Technology Education* provides a forum for scholarly discussion on topics relating to technology and engineering-related education. Manuscripts should focus on technology and engineering-related education research, philosophy, and theory. In addition, the *Journal* publishes book reviews, editorials, guest articles, comprehensive literature reviews, and reactions to previously published articles.

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.

Editorial/Review Process

Manuscripts that appear in the *Articles* section have been subjected to a blind review by three or more members of the Editorial Board. This process generally takes from six to eight weeks, at which time authors are notified of the status of their manuscript. Book reviews, editorials, and reactions are reviewed by the Editor.

Manuscript Submission Guidelines

One paper copy of each manuscript and an electronic version in Microsoft Word format should be submitted to:

Chris Merrill, JTE Editor
Department of Technology
Illinois State University
215 Turner Hall
Normal, IL 61790-5100

1. Overseas submissions in Microsoft Word format may be sent electronically via the Internet (to cpmerri@ilstu.edu) to expedite the review process.
2. All manuscripts must be double-spaced and must adhere to the guidelines published in *Publication Guidelines of the American Psychological Association* (6th Edition). **Tables and figures, however, should be imbedded within the text itself rather than at the end of the document.**
3. **All figures and artwork must be scalable to fit within the JTE page size (4.5" x 7.25" column width and length) and included electronically within the document.**
4. Line drawings and graphs must be editable within Microsoft products and in vector rather than raster format when possible.
5. **Shading should not be used as a background for illustrations or graphs and within bar graphs.** If needed, fill patterns consisting of lines should be used.
6. Manuscripts for articles should generally be 15-20 pages (22,000-36,000 characters in length, with 36,000 characters an absolute maximum). Book reviews, editorials, and reactions should be approximately four to eight manuscript pages (approx. 6,000-12,000 characters).
7. Authors for whom English is not the primary language must enlist a native English editor for the manuscript prior to submission. This person and his/her email address must be identified on the title page of the manuscript.

Subscription Information

The *Journal of Technology Education* is published twice annually (Fall and Spring issues). New and renewing subscribers should copy and mail the form below:

Name (please print) ______________________________

Mailing Address (please print) ______________________________

____

Email address: ______________________Fax: __________

☐New Subscription ☐ Renewal Subscription

Make checks payable to: *Journal of Technology Education*. All checks *must* be drawn on a US bank.

Regular (USA):	$20
Regular (Canada/Overseas):	$30
Library (USA):	$30
Library (Canada/Overseas):	$40
Individual Back Issues (USA):	$10 each
Individual Back Issues (Canada/Overseas):	$15 each

Return remittance along with this form to:

Chris Merrill, JTE Editor
Department of Technology
Illinois State University
215 Turner Hall
Normal, IL 61790-5100

JTE Co-Sponsors & Membership Information

The International Technology and Engineering Educators Association (ITEEA) is a non-profit educational association concerned with advancing technological literacy. The Association functions at many levels – from international to local – in responding to member concerns. The Council on Technology and Engineering Teacher Education (CTETE), affiliated with the ITEEA, is concerned primarily with technology teacher education issues and activities. For membership information, contact: ITEEA, 1914 Association Drive, Reston, VA 22091 (703) 860-2100.

Journal of Technology Education

Editor
Chris Merrill, Illinois State University

Technical Editor
Amanda Fain, Illinois State University

Previous Editors
Mark Sanders, Virginia Polytechnic Institute and State University (1989-1997)
James LaPorte, Virginia Polytechnic Institute and State University (1997-2010)

Editorial Review Board
Vincent Childress, North Carolina Agricultural and Technical University

Rodney Custer, Black Hills State University

Jenny Daugherty, Louisiana State University

Marc deVries, Delft University of Technology, The Netherlands

Patrick Foster, Central Connecticut State University

W. Tad Foster, Indiana State University

Brenda Gustafson, University of Alberta, Canada

Ronald Hansen, University of Western Ontario, Canada

Christine Hailey, Texas State University

Oenardi Lawanto, Utah State University

Theodore Lewis, University of Trinidad and Tobago

Stephen Petrina, University of British Columbia, Canada

Philip Reed, Old Dominion University

Mary Annette Rose, Ball State University

Kay Stables, Goldsmiths University of London, England

Ken Volk, Masdar Institute of Science and Technology, Abu Dhabi

John Wells, Virginia Polytechnic Institute and State University

John Williams, University of Waikato, Hamilton, New Zealand

Electronic Access to the JTE
All issues of the *Journal of Technology Education* may be accessed on the World Wide Web at: http://scholar.lib.vt.edu/ejournals/JTE/ (Note: this URL *is* case sensitive).

Directory of Open Access Journals Statement
As an open access journal, the *JTE* does not charge fees for authors to publish or readers to access.