Contents

Positioning the T and E in STEM: A STL Analytical Content Review of Engineering and Technology Education Research

Paul A. Asunda & Jenny Quintana

Abstract

Despite the presence of the *Standards for Technological Literacy* (STL) in engineering and technology curricula and in scholarly research (e.g., Strimel & Grubbs, 2016; Kennedy, Quinn, & Lyons, 2018; Bers, Seddighin, & Sullivan, 2013; Harrison, 2011), it is now the *Framework for K-12 Science Education* (National Research Council, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013) that are recognized and critiqued by organizations such as the American Society for Engineering Education. This study utilized an analytical content review of scholarly literature published during a recent 6-year period (2011–2016) to identify how engineering and technology researchers, including STEM professionals, position the T and E in the context of the STL in engineering and technology and STEM instruction. Findings revealed that the domains of Design, The Nature of Technology, and The Designed World of the STL provide a rich platform from which researchers and educators can employ evidence-based strategies to promote successful STEM learning.

Keywords: Engineering and technology education; STEM, STEM instruction; STL standards; the T and E of STEM

In the past 100 years, the subject known as engineering and technology education at the K–12 level has gone through significant curricula changes. Since the passing of the Smith-Hughes National Vocational Education Act of 1917, the field has evolved from industrial arts to technology education and to its current name: engineering and technology education. The *Jackson's Mill Industrial Arts Curriculum Theory* introduced in 1981 by Snyder and Hales was the main benchmark for industrial arts teaching. This model revolved around "'four universal technical systems . . . communication, construction, manufacturing, and transportation'" (Snyder & Hales, 1981, p. 16; as cited in O'Riley, 1996, p. 30). In the early 90s, the International Technology Educators Association (ITEA), which was later renamed the International Technology and Engineering Educators Association (ITEEA), "updated the Jackson's Mill model, and also identified four universal content reservoirs (ITEA, 1990, p. 17): bio-related; communications; production; and, transportation" (O'Riley, 1996, p. 30). These areas were to be used to guide technology education instruction (O'Riley, 1996). Through these transitions, the meaning of engineering and technology as a school subject continues to be explored by the learning of theoretical concepts integrated with practical activities (de Vries, Custer, Dakers, & Martin, 2007).

Today the learning of engineering and technology education as a subject is an important part of our school culture. The subject lays the foundation for building a vibrant STEM workforce through collaborative problem-solving experiences that lead to the creation of solutions to tomorrow's challenges. In recent years, curricula revisions in engineering and technology education and the development of standards—including the *Standards for Technological Literacy* (International Technology Education Association [ITEA], 2007), the *Next Generation Science Standards* (NGSS Lead States, 2013), and the Common Core State Standards—to match contemporary societal needs have been accompanied by educational research, detailing the rich products of the subject, best practices, and possible future research areas in scholarly technology and engineering education journals. As such, the study of technological processes continues to provide students with opportunities to learn about the processes of design, the fundamental concepts of technology and engineering, and the limits and possibilities of technology in society.

The *Standards for Technological Literacy: Content for the Study of Technology* (STL), national standards that were originally released by ITEA in 2000, identify and define 20 standards that "every student should know and be able to do in order to be technologically literate" (ITEA, 2007, p. 14). These standards are categorized into five key domains: (a) "The Nature of Technology," (b) "Technology and Society," (c) "Design," (d) "Abilities for a Technological World," and (e) "The Designed World" (ITEA, 2007, p. 14). The standards continuously guide teachers in the development of meaningful learning experiences that integrate engineering design practices for all students through STEM courses.

Despite the presence of the STL in engineering and technology curricula and in scholarly research since their inception in 2000 (e.g., Strimel & Grubbs, 2016; Kennedy et al., 2018; Bers et al., 2013; Harrison, 2011), it is now the *Framework for K-12 Science Education* (National Research Council, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013), which emphasize integration of engineering design into K–12 science, that are recognized and critiqued by organizations such as the American Society for Engineering Education (Strimel & Grubbs, 2016). "The ITEEA community or the *Standards for Technological Literacy* are only referenced minimally" (Strimel & Grubbs, 2016, p. 22). This may indicate that there is little recognition of how engineering and technology educators deliver and position the T and E in STEM education and engineering and technology instructional practices. In this study, the term *position* is defined as how educators and professionals portray and situate the T and E in their teaching of STEM-related concepts. One way of demonstrating position of the T and E is through an analytical content review of scholarly literature from an STL perspective. This will enable articulation of how educators incorporate the standards into teaching, or how the T and E integrate with and promote the learning of STEM concepts. Analytical content reviews have been used successfully to identify research trends, best practices, and improve research in a variety of academic fields (Bryman, 2004; Titscher, Meyer, Wodak, & Vetter, 2000).

To this end, we sought to identify how engineering and technology researchers, including STEM professionals, position the T and E in engineering and technology as a subject designed to educate students in the context of STEM instruction and initiatives. We examined the primary question: How are the *Standards for Technological Literacy* integrated into STEM instructional practices and research as reported in major STEM education professional journals from the years 2011–2016?

We acknowledge that STL might have received significant focus in professional journals and reports from the National Academies in the first decade since inception, which has tapered. Nevertheless, Hutchinson and Lovell (2004) observed that "professional journals serve an important function within most disciplines. They offer a mechanism by which professionals communicate ideas, stimulate discussion (as well as controversy), and share information, often in the form of research findings" (p. 383).

> Given the key role peer-reviewed journals play in the development, promotion, and maintenance of a profession, periodic examinations of scholarly journals are a widely-reported practice across education and social science professions (Bangert & Baumberger, 2005; Elmore & Woehlke, 1998; Goodwin & Goodwin, 1985; Rojewski, 1997). (Rojewski, Asunda, & Kim, 2009, p. 57)

We also acknowledge that different learning environments may lead to different instructional practices. However, given this perspective, we anticipate that the findings of this analytical content review would accomplish two things. First, they would offer educators, researchers, practitioners, and policy makers immediate and emerging research needs toward the positioning of the T and E in teaching of engineering and technology education as an area to support STEM learning. Second, they would provide a rationale that will allow researchers and practitioners utilize STL and position particular instructional problems or projects that may support STEM learning within context of STL. As a result, this may equip educators with strategies to integrate STEM as they develop and connect STEM-rich learning environments.

Source of Literature

The primary sources of literature for this review included all research articles published in three refereed scholarly journals: the *Journal of Technology Education* (*JTE*), the *Journal of Engineering Education* (*JEE*), and the *Journal of STEM Education* (*JSTEM*), during a recent 6-year period (2011–2016). These journals were purposefully selected for their focus on STEM initiatives and engineering and technology education. Articles published in these journals have a general, comprehensive scope in engineering and technology education, engineering education, and STEM education. These three journals are respected and possess a relatively high degree of prestige in the field. All three journals are sponsored by professional associations, are governed by an external board of reviewers, and use a blind review process.

Method

A research synthesis strategy (Cooper, 1998) was adopted. This strategy supported our efforts to examine primary or original scholarship on various aspects of how the T and E is being positioned in STEM education for the purpose of describing, integrating, and synthesizing contents of this scholarship from an STL perspective. We reviewed three peer-reviewed journals producing relevant studies in engineering and technology education scholarly work: the *Journal of Technology Education* (*JTE*), the *Journal of Engineering Education* (*JEE*), and the *Journal of STEM Education* (*JSTEM*). This processes yielded 361 original articles. The population did not include marginal, gray areas of the literature, such as unpublished reports, program evaluation reports, or other non-peer-reviewed publications, because we were not interested in research practices reported in the entirety of engineering and technology education research. Rather, we were interested in research practices reported in current, peer-reviewed, mainstream STEM-related research forums. We included full papers, but excluded poster summaries, demo summaries, editorials, conference reviews, book reviews, forewords, introductions, and prologues in the sampling frame. We then adopted and incorporated aspects of Neuendorf's (2002, 2009) Integrative Model of Content Analysis as a model for carrying out the review. Neuendorf (2002) describes content analysis as consisting of the following steps: (a) developing a theory and rationale, (b) conceptualizing variables, (c) operationalizing measures, (d) developing a coding form and coding book, (e) sampling, (f) training and determining pilot reliabilities, (g) coding, (h) calculating final reliabilities, and (i) analyzing and reporting data (pp. 50–51). We describe how we adopted these steps in the following section.

Developing a Theory and Rationale

We utilized the STL as a framework. The standards identify content necessary for K–12 students, including *knowledge*, abilities, and capacities to apply both to the real world. The standards in the STL were built around a *cognitive* base as well as a doing or *activity* base. They include *assessment* criteria for specific grade levels (K–2, 3–5, 6–8, and 9–12). The STL articulate what needs to be taught in K–12 *laboratory classrooms* to enable all students to develop technological literacy (ITEA, 2007). These standards are grounded in constructivist theory (see Tobin & Tippins, 1993), which states that "knowledge is not passively received but actively built up by the cognizing subject," the learner (von Glasersfeld, 1989, p. 182).

Conceptualizing Variables and Operationalizing Measures

The STL standards are made up of five domains: The Nature of Technology (Standards 1–3), Technology and Society (Standards 4–7), Design (Standards8–10), Abilities for a Technological World (Standards 11–13), and The Designed World (Standards 14–20). The goal of these standards is to prepare students with a more conceptual understanding of technology and engineering and its place in society. As such, students are able to conceptualize and evaluate new technologies that they may have never before seen. By *doing* and *making*, children are able to become *makers* for the future.

> Students who study technology learn about the technological world that inventors, engineers, and other innovators have created. They study how energy is generated from coal, natural gas, nuclear power, solar power, and wind, and how it is transmitted and distributed. They examine communication systems: telephone, radio and television, satellite communications, fiber optics, [and] the Internet. They delve into the various manufacturing and materials-processing industries, from steel and petrochemicals to computer chips and household appliances. They investigate transportation, information processing, and medical technology. They even look into new technologies, such as genetic engineering or emerging technologies, such as fusion power that is still years or decades away. (ITEA, 2007, p. 4)

Developing a Coding Form and Coding Book

To this end, we developed a coding sheet in Excel software, similar to the one described by Hutchinson and Lovell (2004), to guide our content analysis of each article included in the three journals to be selected for review. The coding sheet included the five categories and accompanying standards in an attempt to record how scholarly work was integrating the T and E in STEM. We searched for articles within the designated years (2011–2016) and built a database for ease of managing each journal, designated year, issues, volumes and number of articles. Two researchers in STEM education were invited to be interrater reliability reviewers. The STEM researchers had participated in previous analytical reviews in STEM studies and were invited to review the coding book over a period of 2 weeks and offer suggestions. After the 2-week period, the first author read through the coding book and coding sheet together with the interrater reliability reviewers and discussed questions raised about the coding book or coding sheet. We then modified the noted inconsistencies in the coding book or coding sheet, and the two interrater reliability reviewers and the first author coded a purposive sample of 15 research articles (five articles per reviewer). These articles were not included in the final reliability subsample. We then asked the reviewers to independently code and position the T and E in the sample articles into STL standards and domains. The purposive sample consisted of STEM-related articles that the first author deemed representative of articles that incorporated elements of STL practices to be examined. The reviewers and the researchers also coded the articles. After both sets of coders had coded the articles, we came together to compare codes and discuss any noted inconsistencies. When any disagreements arose, we would try to determine the cause of the disagreement, and the first author would modify the coding book if it were cause of the disagreement. We then calculated the percent agreement for each domain, as suggested by Banerjee, Capozzoli, McSweeney, and Sinha (1999). Percent agreement reflects the number of times all three raters agreed upon an identified domain as present or absent divided by the total number of their agreements and disagreements, which is then multiplied by 100. Since three raters analyzed the transcripts, the percent agreement expected by chance was 25%. Therefore, agreement greater than 25% supported consistency among the raters. Percent agreements for each domain were: 82% for The Nature of Technology, 76% for Technology and Society, 100% for Design, 62% for Abilities for a Technological World, and 90% for The Designed World.

Sampling

Based on our search criteria, we narrowed the sample down to 361 original articles from the three peer-reviewed journals. These articles were analyzed for their content in order to identify evidence of how researchers position instances of technology and engineering practices in the context of the STL (ITEA, 2007) and its five domains in their work. We remodified the coding book and created a spreadsheet to help keep record of the page numbers, content, article title, authors' names, year, journal name, and the standards found during the examination.

Analyzing and Reporting Data

As an example, Table 1 illustrates a portion of the synthesis matrix that we developed to help organize excerpts from the articles in readiness for analysis of how the T and E was being incorporated in STEM through the STL standards (see appendices for full table). As such, each standard was a guide for classifying the articles' content into the five domains (i.e., The Nature of Technology, Technology and Society, Design, Abilities for a Technological World, and The Designed World). It is important to mention that some STL statements presented in the table do not only have evidence for exclusively one standard but have combinations of two or more. For example, the article by Reynolds, Yazdani, and Manzur (2013) included elements of design (i.e., Standard 8 and evidence of hands-on activities) and "structural components of a building, such as beams, columns, studs, and connections" (p. 14; i.e., Standard 20). Further, all evidence possible was collected from each article, whether the standard exhibited the positioning of the T and E or not. For example, Katsioloudis and Moye (2012) conducted a study "to determine the future critical issues and problems facing the K-12 technology and engineering education profession in the Commonwealth of Virginia" (p. 7), and in doing so, they underscored Standard 1 to support and justify their work.

Findings

In reference to the question guiding this study (How are the STL integrated into STEM instructional practices and research as reported in major STEM education professional journals from the years 2011–2016?), we examined 361 articles published in three peer reviewed journals: the *Journal of Technology Education* (*JTE*; six volumes, 13 issues, 59 articles), the *Journal of Engineering Education* (*JEE*; six volumes, 26 issues, 148 articles), and the *Journal of STEM Education* (*JSTEM*; seven volumes, 23 issues, 154 articles). We utilized the STL as a basis for understanding how the T and E had been positioned by researchers and scholars. We noted that in the three journals, nearly all of the 20 standards had been referenced in each journal, as presented in Table 2.

In *JEE*, Standards 8, 10, 3, 9, 4, 14, and 17 were referenced frequently, whereas Standards, 7, 12, and 18 were the least referenced. For example, Standard 8, "students will develop an understanding of the attributes of design" (ITEA, 2007, p. 91), is illustrated by Goncher and Johri (2015), who shared that constraints were a great tool to help develop student crtical thinking skills in various aspects of the design project.

Table 1
Example of Synthesis Matrix Developed to Organize Excerpts From the Articles

STL standard	STL statement	Quote from journal article	Journal
1	"A technologically literate person understands the significance of technology in everyday life and the way in which it shapes the world" (ITEA, 2007, p. 23).	"'Schools today must prepare students to understand technological innovation, the productivity of technology, the impact of technology on the quality of life, and the need for critical evaluation of the social changes resulting from technological changes . . . . (Willcox & Van Dyke, 1992, p. iii)'" (Katsioloudis & Moye, 2012, p. 7).	*Journal of Technology Education*
		"Technology—the artifacts of the human-made world" (Katehi, Pearson, & Feder, 2009; as cited in Carr, Bennett, & Strobel, 2012, p. 546). "'A Vision of Engineering Standard in terms of Big Ideas Knowledge . . . . • Technology is a fundamental attribute of human culture'" (Sneider & Rosen, 2010, p. 131; as cited in Carr et al., 2012, p. 546).	*Journal of Engineering Education*
2	"The core concepts of technology . . . are systems, resources, requirements, optimization and trade-offs, processes, and controls" (ITEA, 2007, p. 32).	"The course covers organizational structures and information management for project teams, as well as communications between project teams, clients, and government agencies. Cost estimation, scheduling, load/resource balancing, and quality management is covered" (Pence & Rowe, 2012, p. 48).	*Journal of STEM Education*
3	"Standard 3 discusses various opportunities to connect ideas and procedures that demonstrate how technologies are interrelated and combined," including "science and technology," "mathematics and technology", and "other fields of study" (ITEA, 2007, p. 44).	"Robofest games are designed in such a manner that students can learn math and science through a hands-on robotics educational experience which has direct links to concepts in physics and mathematics. For example, math and science topics in robotics include numbers and operations, algebra, calculus, geometry, trigonometry, measuring, and data analysis . . . (see detailed examples of Robofest's use of math and science in the section below)" (Chung, Cartwright, & Cole, 2014), pp. 24–25).	*Journal of STEM Education*
		"By attending to cohesion, we seek to generate insights into the process by which students come to assign meaning to representations and activities in the context of collaborative, project-based learning experiences. We also seek to develop a new perspective to advance our understanding of the challenges teachers face in their efforts to promote STEM integration, and to suggest ways instruction can become more effective"(Nathan et al., 2013, p. 85).	*Journal of Engineering Education*

On the other hand, Nathan et al. (2013) demonstrated Standard 3 by noting that "by attending to cohesion [among aspects of the classroom related to learning], we seek to generate insights into the process by which students come to assign meaning to representations and activities in the context of collaborative, project-based learning experiences" (p. 85).

Table 2
STL Standards as Referenced in JEE, JSTEM, and JTE

Standards	*JEE*	*JSTEM*	*JTE*	Frequency across journals
1	12	9	6	27
2	7	8	3	18
3	27	48	19	94
4	19	17	6	42
5	12	13	10	35
6	4	4	4	12
7	1	2	2	5
8	37	25	18	80
9	22	31	20	73
10	37	42	10	89
11	17	39	7	63
12	1	10	4	15
13	17	14	5	36
14	2	7	4	13
15	3	11	5	19
16	8	9	2	19
17	14	38	12	64
18	1	4	2	7
19	5	13	7	25
20	0	6	3	9

As such, Nathan et al. (2013) and other researchers provide perspectives to advance our understanding of the challenges that teachers face in their efforts to promote the T and E in STEM integration and to suggest ways to make instruction more effective. Standard 4 was noted 19 times. According to Jamison, Kolmos, and Holgaard (2014),

> The perception of engineering that informs these approaches [in which engineering are combined with cultural context] is that of public service, or cultural appropriation, by which technologies are diffused or implemented into particular contexts of use (Jamison & Hård, 2003). These approaches have grown out of social movements in the nineteenth and twentieth centuries that try to establish and provide a more socially relevant form of higher education, where engineering is not separated from the contextual and interdisciplinary nature of real-life problems. (p. 264)

The review also revealed that Standard 20, which calls for students to "develop an understanding of and be able to select and use construction technologies" (ITEA, 2007, p. 191), was not referenced in *JEE*. In *JSTEM*, Standards 3, 10, 11, and 17 were frequently referenced, and the least noted standards were Standards 6, 7, and 18. Chung, Cartwright, and Cole (2014) illustrated Standard 3 by sharing that

> Robofest games are designed in such a manner that students can learn math and science through a hands-on robotics educational experience which has direct links to concepts in physics and mathematics. For example, math and science topics in robotics include numbers and operations, algebra, calculus, geometry, trigonometry, measuring, and data analysis. (p. 24)

Standard 10 was noted 42 times. In reference to this standard, Ejiwale (2012) noted that

> It is important that learning activities are open-ended, giving students the freedom to explore and experiment within their own interests and learning styles, rather than just encouraging recipes to right answers. The emphasis from the outset of student learning should be based on problem solving. (p. 91)

Standard 11 was noted 39 times, and Standard 17, "students will develop an understanding of and be able to select and use information and communication technologies" (ITEA, 2007, p. 166), was noted 38 times. The least noted standard was Standard 7, "Students will develop an understanding of the influence of technology on history" (ITEA, 2007, p. 79), which was noted two times. For example, White, Wood, and Jensen (2012) posited that

> Although significant questions remain on what precise traits give a person the ability to be creative, there is general agreement that history has numerous examples of individuals who have exhibited tremendous creative accomplishments. The concept generation technique of "Historical Innovators" attempts to capture some of the principles that these

> extraordinary individuals used to accomplish their innovative feats and then apply these principles to the concept generation process. (p. 17)

Unlike *JEE*, in which Standard 20 was not noted, Standard 20 was noted six times in *JSTEM*. For example, as mentioned previously, Reynolds et al. (2013) illustrated "various structural components of a building such as beams, columns, studs, and connections" (p. 14). They also made teachers "aware of how faulty design and lack of quality control during construction could have severe detrimental effects during a wind event" (p. 14).

In *JTE*, Standards, 9, 3, and 8 were referenced frequently, and the least noted standards were Standards 7, 6, and 18. Standard 9 was noted 20 times. For example, Dixon and Johnson (2012) investigated "if there are differences in the cognitive process of engineering students and professional engineers as they use executive control processes (i.e., planning, monitoring, and evaluation) in the problem and solution spaces while solving an engineering design problem conceptually" (p. 77). Standard 3 was common across all three journals and was referenced 94 times. In other words, scholars envision a need to help students see the connection between different STEM fields. Standard 10, which was referenced 89 times, and Standard 8, which was referenced 80 times, both speak about the nature of design, and as such, the T and E is situated in Design practices. The least noted standards were Standards 7 and 18. We further categorized the articles from major STEM education professional journals from the years 2011–2016 into the five STL domains and use this classification as a guide for reporting our findings in the following sections.

2011 Journal Analysis

Table 3 presents findings from 2011 across the three journals. In 2011, out of 24 articles reviewed in *JEE*, the Design domain, which is made up of STL Standards, 8, 9, and 10, was noted 21 times. For example, researchers such as Adams et al. (2011); Capobianco, Diefes-Dux, Mena, and Weller (2011); Litzinger, Lattuca, Hadgraft, and Newstetter (2011); and Walther, Kellam, Sochacka, and Radcliffe (2011) envision design as a major element of engineering education curricula that transcends multiple fields. Embedding design as part of learning experiences of students promotes "creativity, ingenuity, communication, business, leadership, ethics, professionalism, dynamism, agility, resilience, flexibility, and lifelong learning . . . (National Academy of Engineering, 2004)" (Borrego & Bernhard, 2011, p. 18).

Table 3
Year 2011: The Five STL Domains as Referenced in JEE, JSTEM, and JTE

Journal	***n***	**The Nature of Technology**	**Technology and Society**	**Design**	**Abilities for a Technological World**	**The Designed World**
JEE	24	14	8	21	10	9
JSTEM	23	9	8	13	6	13
JTE	13	5	4	7	4	2
Total	60	28	20	41	20	24

Design is interwoven into the teaching of T and E concepts and was instrumental in devising solutions to problems. In this context, design is defined as the act of producing an item or product of need to society through a process that brings a concept from the drafting table or program into the real world (Bertola & Texeira, 2003). The authors and researchers also noted that *portfolio content reflections* and *design notebooks* were learning interventions that foster knowledge integration in STEM environments to help connect concepts that showed design evidence. The domain Nature of Technology (i.e., STL Standards, 1, 2, and 3) was referenced 14 times. For instance, Charyton, Jagacinski, Merrill, Clifton, and DeDios (2011) noted that an interdisciplinary approach increased students' creativity and innovation. In other words, such an approach provided students' with an opportunity to see how each STEM discipline enhanced the other as a consequence of developing students' ingenuity and novelty in their thinking. The least noted domain was Technology and Society, which was referenced only eight times.

In the 23 articles that we reviewed in *JSTEM*, and the domains Design and The Designed World were depicted 13 times. The Designed World consists of STL Standards 14, 15, 16, 17, 18, 19, and 20. Foutz et al. (2011) "outline[d] a strategy which uses the discipline of agricultural engineering to integrate science and math both vertically and horizontally across the curriculum" and "to explore interdisciplinary approaches for understanding STEM concepts and to develop strategies to help students understand how these concepts are used to solve real-word problems" (p. 25). Likewise, Connolly (2011) noted the use of engineering design process to inform product data management and product lifecycle management in an information systems course. The least noted domain was Abilities for a Technological World, which was noted six times.

For the 13 articles that we reviewed in *JTE*, Design as a domain was noted seven times. For example, Lee (2011) noted that "culture and design are always interwoven 'as design does not take place in isolation but is embedded in its user's culture' (Moalosi, Popovic, & Hickling-Hudson, 2010, p. 1)" (p. 46).

DeLuca and Lari (2011) reported that in the $GRID_C$ project, "students will learn how the disciplines of science and mathematics are used in the design and optimization of systems," and the project "will provide a platform for continued research and development of instructional materials that improve STEM education" (p. 15). Positioning of this standard provided students with an understanding of the influence of technology in contemporary society. The Nature of Technology was noted five times, and the least noted domain was The Designed World.

In summary, for publications in 2011, Design as a domain was noted 41 times in the three journals, followed by the Nature of Technology, which was noted 28 times. The main theme espoused in the Design domain in reference to the T and E was that design is fundamental in developing students' creativity and innovation toward addressing the needs of and solving problems in society.

2012 Journal Analysis

Table 4 presents findings from 2012 across the three journals. In 2012, out of 30 articles reviewed in *JEE*, the Design domain was noted 15 times, 23 times in *JSTEM*, and 12 times in *JTE*.

In *JEE*, Finelli et al. (2012) articulated the importance of ethical development and practices in curricular experiences that supported design. In their review of "engineering in the K–12 STEM standards," Carr, Bennett, and Strobel (2012) pointed out that teaching the T and E incorporated within a design activity built around constraints is a value generative approach to solving problems or achieving goals. Crismond and Adams (2012) noted that "design experiences are also playing a more substantive role in precollege students' STEM . . . education and career preparation" (p. 739). However, they noted that "advancements in the scholarship of design teaching and learning must therefore address two significant needs. First, the field lacks a coherent representation of design pedagogical content knowledge (Design PCK)" (p. 739), and "a second need for an integrative scholarship in engineering design is to help K–16 teachers access and interpret implications from design cognition research and render it usable for everyday classroom teaching" (p. 740). The Nature of Technology and Abilities for a Technological World were each referenced 10 times in *JEE*.

Table 4
Year 2012: The Five STL Domains as Referenced in JEE, JSTEM, and JTE

Journal	*n*	The Nature of Technology	Technology and Society	Design	Abilities for a Technological World	The Designed World
JEE	30	10	5	15	10	8
JSTEM	35	16	9	23	16	18
JTE	12	5	1	4	1	2
Total	77	31	15	42	27	28

We reviewed 35 articles in *JSTEM*, the domain Design was noted 23 times, compared to the previous year when it was noted only 13 times. Urias, Gallagher, and Wartman (2012) outlined that their *Engineering Cities* "REU experience is designed to encourage development of key skills that serve students throughout their careers" (p. 33); however, there was a need to have an assessment framework in evaluating efficacy of a given program that highlighted design practices as one of its instructional tenets. Similarly, Hagerty and Rockaway (2012) noted that the adaptation of "the entry level engineering course Statics . . . to emphasize critical thinking skills, identify a culminating design experience, and promote alternative learnings styles . . . . had a positive effect on student performance" (p. 32). The domains The Nature of Technology and Abilities for a Technological World were each mentioned 16 times. For example, the T and E in The Nature of Technology (i.e., Standards 1, 2, and 3) were captured by Franchetti, Hefzy, Pourazady, and Smallman (2012) who noted that "design capstone projects for engineering students are essential components of an undergraduate program that enhances communication, teamwork and problem-solving skills" (p. 30). In the article, they present "a general framework that can be used by students and faculty to create a strong, industry-based senior design capstone course" (p. 30). Likewise, Pence and Rowe (2012) espoused the idea of adding engineering management courses (e.g., engineering economics, project management, and systems engineering) to engineering degree programs, as they have at Vanderbilt University, to better prepare students for their careers. "Students wishing to start new businesses required a plethora of skills including defining user requirements (Systems Engineering), building rapid prototypes (Project Management), defining stakeholder response (Technology Forecasting/Marketing), and funding/implementing a business plan (Technology-Based Entrepreneurship)" (p. 49). Abilities for a Technological World were demonstrated by Ejiwale (2012), who stated that "employers are looking for employees who possess the skills that are taught in STEM programs, including creative problem solving, product building, collaborative team work, design, and critical thinking (Aleman, 1992; Darling-Hammond, 1994)" (p. 87).

JTE had 12 articles reviewed, and Design as a domain was noted only four times, a drop compared to the previous year. The least noted domains were Technology and Society and Abilities for a Technological World, which were each noted only once.

In summary, for 2012 publications, Design as a domain was noted 42 times in the three journals, followed by the Nature of Technology, which was noted 31 times. Again, the main themes positioning the T and E in STEM across the three journals in 2012 were from the Design domain. As such, design was viewed as an instructional strategy to build students' critical thinking skills and life long career abilities.

2013 Journal Analysis

Table 5
Year 2013: The Five STL Domains as Referenced in JEE, JSTEM, and JTE

Journal	*n*	The Nature of Technology	Technology and Society	Design	Abilities for a Technological World	The Designed World
JEE	27	6	4	12	4	9
JSTEM	25	9	4	9	7	7
JTE	12	4	4	5	2	6
Total	64	19	12	26	13	22

Table 5 presents findings from 2013 across the three journals. In 2013, the Design domain was noted 12 times, the Nature of Technology was noted six times, and Abilities for a Technological World was noted four times. In *JSTEM*, Design was noted nine times, and the Nature of Technology and Abilities for a Technological World were each referenced seven times. In *JTE*, Design as a domain was noted only five times. Out of 27 articles reviewed in *JEE*, for instance, Juhl and Lindegaard (2013) addressed the use of "visual representation to develop and integrate recognitions" (p. 20) and concluded that this enhanced engineering design practices. They argued that

> Representations not only communicate findings but also incorporate analysis in their creation, and facilitate what we call *collaborative design synthesis*. Successful representations present and organize recognitions so that they are recognizable across other disciplines and can be integrated into new recognitions. Representations therefore shape the collaborative base of

> design process and emphasize important competencies that can produce them. (p. 20)

We reviewed 25 articles in *JSTEM*, and the domain Design was noted nine times. Reynolds et al. (2013) shared a teacher preparation workshop that enhanced STEM high school teachers' comprehension of the impact of man-made hazards (e.g., simulated effects of extreme wind loads on structures). In the lecture portion of the project,

> a description of the various types of extreme winds and their effect on structures were shown through the use of mathematics and statistics. It was important for teachers to understand the mathematical and statistical processes involved in order to develop a lesson plan for their high school classes. (p. 12)

"Overall, the experience provided teachers with comprehensive knowledge, ranging from the nature of wind load to quantification on structures, and the method to evaluate the resulting response of structure" (p. 14). The Nature of Technology and Abilities for a Technological World were each mentioned seven times. Specifically, Hesser and Schwartz (2013) envisioned T and E positioned in both domains:

> We envision the integration of iPads as a technology that will be introduced into many facets of learning . . . . allowing an increased level of student engagement. Using the iPads, students responded to questions asked by the instructor during class and answers were monitored interactively. (p. 8)

JTE had 12 articles reviewed, and Design as a domain was noted only five times. For example, Baskette and Fantz (2013) conducted a study "designed to gauge the ability of a single-semester course to raise students' technological literacy as well as gains in student perceptions of the importance of technology education in the K–12 curriculum" (p. 3). They suggested that "understanding what technology is, and is not, is the first step in becoming technologically literate" (p. 2). "Efforts should be made to include content that emphasizes the global impact of technological literacy and the need to understand how it was developed, how it works, and how it shapes society and individuals" (p. 18). The least noted domain was Abilities for a Technological World, which was depicted only twice.

In summary, for 2013 publications, Design as a domain was noted 26 times across the three journals. The main theme situating the T and E in the Design domain was the use of simulated visuals and representations to enhance students' comprehension and level of engagement in learning key design competencies.

2014 Journal Analysis

Table 6 presents findings from 2014 across the three journals. In 2014, out of 24 articles reviewed in *JEE*, the Design domain was noted four times; this was the least referenced time throughout the review. For example, Klotz et al. (2014) posited that sustainability was "a route to broadening participation in engineering." Klotz et al. (2014), specifically mentioned that "many of NAE's Grand Challenges (NAE, 2012) for engineering do align with the outcome expectations of those students we would like to be attracting" (p. 149). "Opportunities abound to emphasize the human impact of engineering through sustainability issues" (p. 149).

Table 6

Year 2014: The Five STL Domains as Referenced in JEE, JSTEM, and JTE

Journal	*n*	The Nature of Technology	Technology and Society	Design	Abilities for a Technological World	The Designed World
JEE	24	2	4	4	1	3
JSTEM	16	9	2	8	4	3
JTE	11	3	1	4	1	6
Total	51	14	7	16	6	12

Likewise, the domain Technology and Society was depicted four times, and the least referenced was Abilities for a Technological World, which was referenced only once. In *JSTEM*, the Nature of Technology domain was noted nine times. For instance, Kapila and Iskander (2014) posited that

> As technology continues to profoundly impact our daily lives, it is essential that all students receive comprehensive, high quality education in STEM subjects because K-12 students must achieve high scores on standardized STEM courses to advance in society. Unfortunately, many science labs often make use of antiquated technology that fails to tap the potential of modern technology in order to create and deliver exciting lab content. As a result, students are turned off by science, fail to excel on standardized science exams and do not consider STEM as a career option. Integrating modern sensing technology into science labs presents one answer to the declining interest in STEM disciplines among American high school students. (pp. 49–50)

This was the first time in the review that the Nature of Technology domain had outpaced Design in the review across the three journals. Design was noted eight times.

JTE had 11 articles reviewed, and Design as a domain was noted four times. For example, in his article "A Curricular Analysis of Undergraduate Technology & Engineering Teacher Preparation Programs in the United States," Litowitz (2014) noted that design, including product design, innovation, problem solving, industrial design, and engineering design, was a frequently required technical course (pp. 76–77). The least noted domains were Abilities for a Technological World and Technology and Society, which were each depicted only once.

In summary, for 2014 publications, Design as domain was noted 16 times in the three journals, followed by the Nature of Technology, which was noted 14 times. However, researchers' depicted infusion of T and E concepts into the Nature of Technology as a vehicle in enhancing the learning of STEM concepts, especially in preparing students considering STEM careers.

2015 Journal Analysis

Table 7
Year 2015: The Five STL Domains as Referenced in JEE, JSTEM, and JTE

Journal	*n*	The Nature of Technology	Technology and Society	Design	Abilities for a Technological World	The Designed World
JEE	20	6	4	10	4	2
JSTEM	26	6	5	12	13	13
JTE	9	3	3	6	4	4
Total	55	15	12	28	21	19

Table 7 presents findings from 2015 across the three journals. In 2015, out of 20 articles reviewed in *JEE*, the Design domain was noted 10 times, the Nature of Technology was depicted six times, and the least noted was The Designed World, which was mentioned two times. With regard to the Design domain, Gilbuena et al. (2015) examined design coaching and feedback as a way to help students participating "in engineering design projects . . . to practice both professional and technical skills. Feedback on professional skills helps students recognize how to simultaneously represent themselves as legitimate members of multiple communities of practice" (p. 7). Additionally, Atadero, Rambo-Hernandez, and Balgopal (2015) examined how participation in group design projects affects "student content knowledge and intentions to persist in engineering" and noted that "there were strong positive relationships between self-efficacy and outcome expectations and between intention to persist and content knowledge" promoting students' "own abilities, goals, and success in engineering" and technology related subjects (p. 55).

In *JSTEM*, the Abilities for a Technological World domain (Standards, 11, 12, and 13) was referenced 13 times. This was the first time in the review that the domain had been ranked highly in the three journals reviewed. For example, Bowen and DeLuca (2015) examined the use of simulation and modeling in technology and engineering education classrooms and how these affected student content knowledge learning, performance, and engagement. They concluded that

> additional research needs to be conducted . . . . Specifically, the balance of the value of content knowledge and performance must be determined for effective curriculum development, and how the learning outcomes of the project are aligned with state standards, national standards, and standards for technological literacy. (p. 9)

Design was noted 12 times. For example, Huang, Mejia, Becker, and Neilson (2015) stated:

> This article investigates physics learning and teaching research and the use of engineering design in the teaching of physics. By integrating engineering into STEM, students may apply scientific ideas to solving an engineering design problem while carrying and transferring knowledge in core science areas. (p. 31)

This conclusion by Huang et al. also positioned the T and E in the Nature of Technology domain (Standard 3) as well.

JTE had nine articles reviewed, and Design as a domain was noted six times. For example, in their article "Identifying Characteristics of Technology and Engineering Teachers Striving for Excellence Using a Modified Delphi," Rose, Shumway, Carter, and Brown (2015) found that one of the characteristics deemed most important in such an instructor is one who "inspires students' curiosity, creativity, ingenuity, and innovative spirit" (p. 11). Although it was not found to be critically important, an instructor also "knows and is able to apply an engineering design process to design a potential solution" (p. 13).

In summary, for 2015 publications, the Abilities for a Technological and The Designed World domains were ranked highly. In essence, these domains situated the T and E in STEM by promoting effective curricula that enhanced student content knowledge learning, performance, and engagement.

2016 Journal Analysis

Table 8 presents findings from 2016 across the three journals. In 2016, out of 21 articles reviewed in *JEE*, the Design domain was noted seven times. For example, Litchfield, Javernick-Will, and Maul (2016) noted that “engineers must acquire increasing technical and professional skills to meet pressing global challenges” through participation in engineering service projects (p. 70).

Table 8
Year 2016: The Five STL Domains as Referenced in JEE, JSTEM, and JTE

Journal	*n*	The Nature of Technology	Technology and Society	Design	Abilities for a Technological World	The Designed World
JEE	21	3	4	7	1	2
JSTEM	30	6	5	25	5	10
JTE	5	3	1	5	2	3
Total	56	12	10	37	8	15

In *JSTEM*, the Design domain was noted 25 times. For instance, in the program described by Franchetti and Ariss (2016), “design projects involved the creation of cross-disciplinary design teams comprised of engineering students, business students, engineering faculty, business faculty, entrepreneurs, and professional engineers” (p. 29). “Collaborative and Project-Based Learning (PBL) have been shown to increase individual learning through co-construction and personal reflection [Brindley et al., 2009]” (p. 29).

In *JTE*, five articles were examined, and Design as a domain was noted five times. Wilhelmsen and Dixon (2016) investigated “engineering design constructs identified by Childress and Rhodes (2008)” and concluded that “more questions still need to be answered. For example, can an instrument be developed from the indicators that validly and reliably assesses students’ outcomes in design? What indicators should be included on such an instrument?” (p. 75).

In summary, for 2016 publications, the T and E would greatly be enhanced in STEM subjects through engineering service projects that incorporated cross-disciplinary teams. Nevertheless, a much needed area of research noted was “assessment of the outcomes” of the design process.

2011–2016 Journal Analysis

Table 9
Year 2011–2016: The Five STL Domains as Referenced in JEE, JSTEM, and JTE

Year	The Nature of Technology	Technology and Society	Design	Abilities for a Technological World	The Designed World
2011	28	20	41	20	24
2012	31	15	42	27	28
2013	19	12	26	13	22
2014	14	7	16	6	12
2015	15	12	28	21	19
2016	12	10	37	8	15
Total	119	76	190	95	120

Table 9, provides a summary of the five domains, as referenced in the 6-year review across the three journals. Researchers and scholars in the field position the T and E in Design, and they cumulatively referenced the Design domain 190 times. Specifically, as evidenced in Table 2, Standards 8, 9, and 10 were referenced 242 times in total. The Designed World follows at a distant second, having been referenced 120 times. Standards 14, 15, 16, 17, 18, 19, and 20 in this domain were referenced 156 times in total (see Table 2). The Nature of Technology was referenced 119 times, and Standards 1, 2, and 3 were referenced 139 times in total (see Table 2).

Implications for Situating the T and E through STL

These findings suggest that the T and E situated in the STL standards, specifically the domains Design, The Nature of Technology, and The Designed World in STEM coursework and engineering and technology education, provide a rich platform from which researchers and educators can employ evidence-based strategies to promote successful learning. Researchers and educators designate the Design domain by situating the T and E in STEM through projects and problems situated in a design context to introduce STEM-related content. In other words, engineering and technological design practices are accentuated through active learning strategies that seek to develop students' ingenuity and novelty that purposefully enhances their understanding of STEM concepts. Compton and Harwood (2005) describe *technology* as "purposeful intervention by design" through engineering practices. It's through these technological practices that the rich products of the designed worlds are then engineered and have impact on our lives. The findings of this study, specifically examples noted from the domains of The Nature of Technology, Design, and The Designed World, continue to support the notion that technological outcomes are engineered to enhance the capabilities of people and expand human possibilities. The Nature of Technology domain is interwoven in STEM disciplines and engineering and technology curricula, providing educators with opportunities to develop learning episodes through strategies such as linked curricula, common language and subject matter, shared teaching and learning approaches, and joint activities to enhance the learning of STEM concepts. Likewise, in order to develop an understanding of the domain The Designed World, by selecting and utilizing appropriate, medical technologies, agricultural and related biotechnologies, information and communication technologies, transportation technologies, manufacturing technologies, and construction technologies, students need to develop an understanding of the attributes of design, engineering design, the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving. Therefore, the findings of this study imply that the T and E in the domains Design and The Designed World offer students and educators alike integrated STEM experiences that perpetuate The Nature of Technology. It then may be argued that positioning of the T and E through STL continues to enhance students' and educators' abilities in relation to the technology and engineering practices that they use to understand society and historical practices that have shaped cultural, social, economic, and political effects of technology across formal and informal settings. Such experiences may help students build complex skills such as leadership, collaboration, critical thinking, communication, creativity, and the ability to solve problems using mathematical, scientific, engineering, and technological practices.

Conclusion

Wicklein (2006) suggested that

> The benefits of an engineering-design-focused curriculum for technology education are huge. If done correctly, technology education as a subject will be viewed and understood in an entirely different light. Students and parents will see a curriculum that is organized and systematic, leading to valued career options. School administrators and counselors will have a curriculum that provides multiple options for students, both college-bound and non-college-bound. Engineering educators will receive a more prepared student who understands engineering design processes from the beginning of his/her college experience. Business and industry will have more U.S. citizens entering the STEM workforce. This is a viable future for technology education; are we willing to take the challenge? (p. 29)

Findings suggest that the STL domains provide students with a vehicle to comprehend how technology integrates with engineering practices in the curricular. This analytical review has highlighted varied scholarly examples that support problem-based, hands-on learning opportunities. Positioning of the T and E in STEM-related courses and engineering and technology education affects the field as a whole. How are you positioning the T and E in your STEM instruction?

References

Adams, R., Evangelou, D., English, L., de Figueiredo, A. D., Mousoulides, N., Pawley, A. L., . . . Wilson, D. M. (2011). Multiple perspectives on engaging future engineers. *Journal of Engineering Education*, *100*(1), 48–88. doi:10.1002/j.2168-9830.2011.tb00004.x

Atadero, R. A., Rambo-Hernandez, K. E., & Balgopal, M. M. (2015). Using social cognitive career theory to assess student outcomes of group design projects in statics. *Journal of Engineering Education*, *104*(1), 55–73. doi:10.1002/jee.20063

Banerjee, M., Capozzoli, M., McSweeney, L., & Sinha, D. (1999). Beyond kappa: A review of interrater agreement measures. *The Canadian Journal of Statistics*, *27*(1), 3–23. doi:10.2307/3315487

Baskette, K. G., & Fantz, T. D. (2013). Technological literacy for all: A course designed to raise the technological literacy of college students. *Journal of Technology Education*, *25*(1), 2–19. doi:10.21061/jte.v25i1.a.1

Bers, M. U., Seddighin, S., & Sullivan, A. (2013). Ready for robotics: Bringing together the T and E of STEM in early childhood teacher education. *Journal of Technology and Teacher Education*, *21*(3), 355–377.

Bertola, P., & Texeira, J. C. (2003). Design as a knowledge agent. How design as a knowledge process is embedded into organizations to foster innovation. *Design Studies*, *24*(2), 181–194. doi:10.1016/S0142-694X(02)00036-4

Borrego, M., & Bernhard, J. (2011). The emergence of engineering education research as an internationally connected field of inquiry. *Journal of Engineering Education*, *100*(1), 14–47. doi:10.1002/j.2168-9830.2011.tb00003.x

Bowen, B., & Deluca, W. (2015). Comparing traditional versus alternative sequencing of instruction when using simulation modeling. *Journal of STEM Education*, *16*(1), 5–10. Retrieved from https://jstem.org/index.php/JSTEM/article/view/1896

Bryman, A. (2004). *Social research methods* (2nd ed.). New York, NY: Oxford University Press.

Capobianco, B. M., Diefes-Dux, H. A., Mena, I., & Weller, J. (2011). What is an engineer? Implications of elementary school student conceptions for engineering education. *Journal of Engineering Education*, *100*(2), 304–328. doi:10.1002/j.2168-9830.2011.tb00015.x

Carr, R. L., Bennett, L. D., IV, & Strobel, J. (2012). Engineering in the K–12 STEM standards of the 50 U.S. states: An analysis of presence and extent. *Journal of Engineering Education*, *101*(3), 539–564. doi:10.1002/j.2168-9830.2012.tb00061.x

Charyton, C., Jagacinski, R. J., Merrill, J. A., Clifton, W., & DeDios, S. (2011). Assessing creativity specific to engineering with the revised Creative Engineering Design Assessment. *Journal of Engineering Education*, *100*(4), 778–799. doi:10.1002/j.2168-9830.2011.tb00036.x

Chung, C., Cartwright, C., & Cole, M. (2014). Assessing the impact of an autonomous robotics competition for STEM education. *Journal of STEM Education*, *5*(2), 24–34. Retrieved from http://www.jstem.org/index.php/JSTEM/article/view/1704

Compton, V., & Harwood, C. (2005). Progression in technology education in New Zealand: Components of practice as a way forward. *International Journal of Technology and Design Education*, *15*(3), 253–287. doi:10.1007/s10798-004-5401-6

Connolly, P. E. (2011).The application of an engineering design and information systems case study in a senior level product data management course. *Journal of STEM Education*, *12*(3–4), 35–45. Retrieved from https://jstem.org/index.php/JSTEM/article/view/1489

Cooper, H. (1998). *Synthesizing research: A guide for literature reviews* (3rd ed.). Thousand Oaks, CA: Sage.

Crismond, D. P., & Adams, R. S. (2012). The Informed Design Teaching and Learning Matrix. *Journal of Engineering Education*, *101*(4), 738–797. doi:10.1002/j.2168-9830.2012.tb01127.x

DeLuca, V. W., & Lari, N. (2011). The $GRID_C$ Project: Developing students' thinking skills in a data-rich environment. *Journal of Technology Education*, *23*(1), 5–18. doi:10.21061/jte.v23i1.a.2

de Vries, M., Custer, R., Dakers, J., & Martin, G. (Eds.). (2007). *Analyzing best practices in technology education*. Rotterdam, the Netherlands: Sense.

Dixon, R. A., & Johnson, S. D. (2012). The use of executive control processes in engineering design by engineering students and professional engineers. *Journal of Technology Education*, *24*(1), 73–89. doi:10.21061/jte.v24i1.a.5

Ejiwale, J. A. (2012). Facilitating teaching and learning across STEM fields. *Journal of STEM Education*, *13*(3), 87–94. Retrieved from https://jstem.org/index.php/JSTEM/article/view/1711

Finelli, C. J., Holsapple, M. A., Ra, E., Bielby, R. M., Burt, B. A., Carpenter, D. D., . . . Sutkus, J. A. (2012). An assessment of engineering students' curricular and co-curricular experiences and their ethical development. *Journal of Engineering Education*, *101*(3), 469–494. doi:10.1002/j.2168-9830.2012.tb00058.x

Foutz, T., Navarro, M., Hill, R. B., Thompson, S. A., Miller, K., & Riddleberger, D. (2011). Using the discipline of agricultural engineering to integrate math and science. *Journal of STEM Education*, *12*(1–2), 24–32. Retrieved from https://jstem.org/index.php/JSTEM/article/view/1577

Franchetti, M., & Ariss, S. A. (2016). The implementation of senior design capstone projects combining engineering and business students. *Journal of STEM Education*, *17*(4), 29–34. Retrieved from https://jstem.org/index.php/JSTEM/article/view/2163

Franchetti, M., Hefzy, M. S., Pourazady, M., & Smallman, C. (2012). Framework for implementing engineering senior design capstone courses and design clinics. *Journal of STEM Education*, *13*(3), 30–45. Retrieved from https://jstem.org/index.php/JSTEM/article/view/1561

Gilbuena, D. M., Sherrett, B. U., Gummer, E. S., Champagne, A. B., & Koretsky, M. D. (2015). Feedback on professional skills as enculturation into communities of practice. *Journal of Enginerring Education*, *104*(1), 7–34. doi:10.1002/jee.20061

Goncher, A., & Johri, A. (2015). Contextual constraining of student design practices. *Journal of Engineering Education*, *104*(3), 252–278. doi:10.1002/jee.20079

Hagerty, D. J., & Rockaway, T. D. (2012). Adapting entry-level engineering courses to emphasize critical thinking. *Journal of STEM Education*, *13*(2), 25–34. Retrieved from https://jstem.org/index.php/JSTEM/article/view/1547

Harrison, M. (2011). Supporting the T and the E in STEM : 2004-2010. *Design and Technology Education: An International Journal*, *16*(1), 17–25. Retrieved from https://ojs.lboro.ac.uk/DATE/article/view/1591

Hesser, T. L., & Schwartz, P. M. (2013). iPads in the science laboratory: Experience in designing and implementing a paperless chemistry laboratory course. *Journal of STEM Education*, *14*(2), 5–9. Retrieved from https://jstem.org/index.php/JSTEM/article/view/1827

Huang, S., Mejia, J. A., Becker, K., & Neilson, D. (2015). High school physics: An interactive instructional approach that meets the Next Generation Science Standards. *Journal of STEM Education*, *16*(1), 31–40. Retrieved from https://jstem.org/index.php/JSTEM/article/view/1813

Hutchinson, S. R., & Lovell, C. D. (2004). A review of methodological characteristics of research published in key journals in higher education: Implications for graduate research training. *Research in Higher Education*, *45*(4), 383–403. doi:10.1023/B:RIHE.0000027392.94172.d2

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

Jamison, A., Kolmos, A., & Holgaard, J. E. (2014). Hybrid learning: An integrative approach to engineering education. *Journal of Engineering Education*, *103*(2), 253–273. doi:10.1002/jee.20041

Juhl, J., & Lindegaard, H. (2013). Representations and visual synthesis in engineering design. *Journal of Engineering Education*, *102*(1), 20–50. doi:10.1002/jee.20001

Kapila, V., & Iskander, M. (2014). Lessons learned from conducting a K-12 project to revitalize achievement by using instrumentation in science education. *Journal of STEM Education*, *15*(1), 46–51. Retrieved from https://jstem.org/index.php/JSTEM/article/view/1760

Katsioloudis, P., & Moye, J. J. (2012). Future critical issues and problems facing technology and engineering education in the Commonwealth of Virginia. *Journal of Technology Education*, *23*(2), 6–24. doi:10.21061/jte.v23i2.a.1

Kennedy, J., Quinn, F., & Lyons, T. (2018). Australian enrolment trends in technology and engineering: putting the T and E back into school STEM. *International Journal of Technology and Design Education*, *28*(2), 553–571. doi:10.1007/s10798-016-9394-8

Klotz, L., Potvin, G., Godwin, A., Cribbs J., Hazari, Z., & Barclay, N. (2014). Sustainability as a route to broadening participation in engineering. *Journal of Engineering Education*, *103*(1), 137–153. doi:10.1002/jee.20034

Lee, K. (2011). Looking back, to look forward: Using traditional cultural examples to explain contemporary ideas in technology education. *Journal of Technology Education*, *22*(2), 42–52. doi:10.21061/jte.v22i2.a.3

Litchfield, K., Javernick-Will, A., & Maul, A. (2016). Technical and professional skills of engineers involved and not involved in engineering service. *Journal of Engineering Education*, *105*(1), 70–92. doi:10.1002/jee.20109

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

Litzinger, T. A., Lattuca, L. R., Hadgraft, R. G., & Newstetter, W. C. (2011). Engineering education and the development of expertise. *Journal of Engineering Education*, *100*(1), 123–150. doi:10.1002/j.2168-9830.2011.tb00006.x

Nathan, M. J., Srisurichan, R., Walkington, C., Wolfgram, M., Williams, C., & Alibali, M. W. (2013). Building cohesion across representations: A mechanism for STEM integration. *Journal of Engineering Education*, *102*(1), 77–116. doi:10.1002/jee.20000

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

Neuendorf, K. A, (2002). *The content analysis guidebook*. Thousand Oaks, CA: Sage.

Neuendorf, K. A. (2009). Reliability for content analysis. In A. B. Jordan, D. Kunkel, J. Manganello, & M. Fishbein (Eds.), *Media messages and public health: A decisions approach to content analysis* (pp. 67–87). New York, NY: Routledge.

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

O'Riley, P. (1996). A different storytelling of technology education curriculum re-visions: A storytelling of difference. *Journal of Technology Education*, *7*(2), 28–40. doi:10.21061/jte.v7i2.a.3

Pence, K. R., & Rowe, C. J. (2012). Enhancing engineering education through engineering management. *Journal of STEM Education*, *13*(3), 46–51. Retrieved from https://jstem.org/index.php/JSTEM/article/view/1661

Reynolds, D., Yazdani, N., & Manzur, T. (2013). STEM high school teaching enhancement through collaborative engineering research on extreme winds. *Journal of STEM Education: Innovations and Research*, *14*(1), 12–19. Retrieved from http://jstem.org/index.php/JSTEM/article/view/1665

Rojewski, J. W., Asunda, P., & Kim, S. J. (2009). Trends in career and technical education research. *Journal of Career and Technical Education*, *24*(2), 57–68. doi:10.21061/jcte.v24i2.457

Rose, M. A., Shumway, S., Carter, V., & Brown, J. (2015). Identifying characteristics of technology and engineering teachers striving for excellence using a modified Delphi. *Journal of Technology Education*, *26*(2), 2–21. doi:10.21061/jte.v26i2.a.1

Smith-Hughes National Vocational Education Act of 1917, Pub. L. No. 64-347, Ch. 114, 39 Stat. 929 (1917).

Snyder, J. F., & Hales, J. A. (1981). *Jackson's Mill industrial arts curriculum theory*. Charleston, WV: West Virginia Department of Education.

Strimel, G., & Grubbs, M. E. (2016). Positioning technology and engineering education as a key force in STEM education. *Journal of Technology Education*, *27*(2), 21–36. doi:10.21061/jte.v27i2.a.2

Tobin, K., & Tippins, D. (1993). Constructivism as a referent for teaching and learning. In K. Tobin (Ed.), *The practice of constructivism in science education* (pp. 3–21). Hillsdale, NJ: Erlbaum.

Titscher, S., Meyer, M., Wodak, R., & Vetter, E. (2000). *Methods of text and discourse analysis*. Thousand Oaks, CA: Sage.

Urias, D., Gallagher, P., & Wartman, J. (2012). Critical features and value in assessing a research experience for undergraduates: The case of Engineering Cities. *Journal of STEM Education*, *13*(1), 30–42. Retrieved from https://jstem.org/index.php/JSTEM/article/view/1517

von Glasersfeld, E. (1989). Constructivism in education. In T. Husen & T. N. Postlethwaite (Eds.), *The international encyclopedia of education* (Supplementary Vol. 1, pp. 182–183). Oxford, England: Pergamon Press.

Walther, J., Kellam, N., Sochacka, N., & Radcliffe, D. (2011). Engineering competence? An interpretive investigation of engineering students' professional formation. *Journal of Engineering Education*, *100*(4), 703–740. doi:10.1002/j.2168-9830.2011.tb00033.x

White, C., Wood, K., & Jensen, D. (2012). From brainstorming to C-Sketch to principles of historical innovators: Ideation techniques to enhance student creativity. *Journal of STEM Education*, *13*(5), 12–25. Retrieved from https://jstem.org/index.php/JSTEM/article/view/1621

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

Wilhelmsen, C. A., & Dixon, R. A. (2016). Identifying indicators related to constructs for engineering design outcome. *Journal of Technology Education*, *27*(2), 57–77. doi:10.21061/jte.v27i2.a.4

About the Authors

Paul A. Asunda (pasunda@purdue.edu) is an Assistant Professor in the Department of Technology Leadership and Innovation at Purdue University.

Jenny Quintana (quintan3@purdue.edu) is a graduate student in the Department of Technology Leadership and Innovation at Purdue University.

Teaching Upcycling to Impact Environmental Attitudes

Jim Flowers, Cale Rauch, & Alexander Wierzbicki

Abstract

With the hope of positively impacting environmental attitudes, student interest in prototyping and product design were leveraged to create and deliver a course called Green Prototyping and Upcycling to undergraduates and graduate students. Pretest and posttest surveys with the Environmental Attitudes Inventory (Milfont & Duckitt, 2010) showed significant increases and showed no significant decreases in students' environmental attitudes along one or more of the 12 scales in that survey. Students' comments from their reports provided further evidence of evolving environmental attitudes. The course included several activities in which students designed and created products recycled from postconsumer materials.

Keywords: recycling, environmental attitudes, sustainability, prototyping

Within technology education, curricular attention to environmental sustainability has often focused on the impacts of technology in a somewhat reactive manner. Technological Literacy Standard 5 is "Students will develop an understanding of the effects of technology on the environment" (International Technology Education Association [ITEA], 2007, p. 65). Leaders in the field ranked highest the following "essential" goal for technological literacy: "Describe social, ethical, and environmental impacts associated with the use of technology" (Ritz, 2009, p. 59).

In other instances, there is a more proactive approach for the inclusion of environmental sustainability within technology education. Rose and Flowers (2008) described a technology education course in technology assessment that included environmental impact assessment; they suggested that the primary purpose of technology assessment was "informing [future] policy decisions" (p. 13.1187.4). Benchmarks 5G and 5H (Grades 9–12) in the *Standards for Technological Literacy* (ITEA, 2007) are proactive: "Humans can devise technologies to conserve water, soil, and energy through such techniques as reusing, reducing, and recycling," and "when new technologies are developed to reduce the use of resources, considerations of tradeoffs are important" (p. 71). Rose (2012) called for actionable environmental education: "In the face of complex environmental problems, we must learn how to facilitate a student's ability to conduct inquiry, synthesize knowledge and skills from a variety of subject areas, and make informed decisions that lead to environmentally sustainable actions" (p. 87).

In the hope of promoting attitudes in students needed for environmental stewardship, and considering the historical emphasis in the field on both technological materials and product design, it would make sense to encourage students and preservice teachers to engage in proactive activities in which they design, create, and test products that promote environmental sustainability and recycle postconsumer materials into new products. They can "identify ways in which various resources can be recycled and reused. Evaluate the viability of recycling based on economic and technological factors, spatial variables such as distance from recycling facility to markets, and possible future developments" (North American Association for Environmental Education, 2010, p. 62).

Increasing interest in rapid prototyping technologies coupled with the acknowledgement of a growing global necessity for environmental sustainability have prompted technology education faculty at a Midwestern U.S. university to create a course called Green Prototyping and Upcycling (Flowers & Gorski, 2017) in an effort to leverage student interest in prototyping technologies and to positively impact their attitudes concerning environmental sustainability. Existing technology education coursework in additive and subtractive manufacturing at this institution was felt to lack sufficient attention to environmental concerns regarding material streams and the need to develop products and processes that promote environmental sustainability. It was hoped that in this new course, educational experiences involving student product design and recycling technologies could leverage student creativity, possibly impacting the environmental attitudes of future technology and engineering teachers and others in the class. The purpose of this article is to distinguish upcycling from other forms of recycling and to describe a course in this area that was created in an attempt to impact students' environmental attitudes.

The creation of this course was prompted by the course developer's decades of experience teaching manufacturing, construction, material processing, and product design courses at the secondary and postsecondary levels in industrial arts and technology education. In these courses, there had been a focus on materials, processes, and product design and creation with little attention to the social need for a product or to the environmental costs of manufacturing it. As such, creating this course was an attempt by that faculty member to better reflect their evolving environmental ethic and not continue to promote pro-technology materialism without adequate regard to environmental and social impacts.

Literature Review

Recycling and Its Subset: Upcycling

A main focus chosen for this course was the engagement of students in upcycled product design and development, empowering them to take on the role of product designer and manufacturer rather than merely a consumer. In an effort to reduce the negative effects and growth of our material waste stream, there has been a push to suggest to consumers that they reduce, reuse, and recycle (United States Environmental Protection Agency [EPA], 2018).

> Recycling is defined as the recovery of useful materials such as paper, glass, plastic, metals, construction and demolition (C&D) [materials] and organics from the waste stream (e.g., municipal solid waste) and the transformation of that material to make new products, resulting in a reduction in the amount of virgin raw materials needed to meet consumer demand. (EPA, 2016, p. 10)

Thus, recycling entails the reprocessing or remanufacturing of the materials making up a product to create a new product and is typically done with professional manufacturing technology rather than by an end user. Recycling rates can be promoted by efforts to evolve into a stronger culture of recycling, possibly through educational interventions: "Education should emphasize the environmental benefits of recycling to encourage a culture of recycling for the environment" (Loughlin & Barlaz, 2006, p. 320).

When a product's materials are recycled to create a new product, we can compare the value of the new product to the original one to classify this as downcycling, upcycling, or neither. *Upcycling* can refer to "the creation or creative modification of any product out of used materials in an attempt to generate a product of higher quality or value than the compositional elements" (Sung, Cooper, & Kettley, 2014, p. 237). Although this is likely to suggest a comparison of the economic value between a new product and the product from which it was made, this distinction may be based on an increase or decrease in a value that is not economic. Because recycling involves remanufacturing, it can have an impact on product quality. "Repeated recycling causes fibers to become less suitable for papermaking. The fibers become less flexible and shorter than virgin fiber and do not conform as well" (Abubakr, Scott, & Klungness, 1995, p. 123). Similarly, during recycling, "when some plastics are melted and combined, the polymers in the plastic—the chains that make it strong and flexible—shorten" (McDonough & Braungart, 2002, p. 58). Thus, "most recycling is actually *downcycling*; it reduces the quality of a material over time" (McDonough & Braungart, 2002, p. 56). Due to material degradation during reprocessing, upcycling can pose a challenge. However, students charged with designing products that are examples of upcycling can find this challenge inspiring.

Teaching Recycling

For some, recycling education may be seen as important only to the extent that it increases consumer use of local materials recycling programs. Blumstein and Saylan (2007) assert that "if teaching recycling [to children] were effective, then we would expect to see a specific increase in recycling in the class where there was a lesson on recycling" (p. 976). Even when conceptual learning outcomes are studied, the value of recycling education may still be seen in terms of consumer participation. Nadi, Aghaabedi, and Radnezhad (2016) found that with a sample of sixth grade female students in Iran, recycling education "had an effect on the perception of the concept of recycling" (p. 116), among other key concepts. However, they went on to draw conclusions about the purpose of recycling education as connected with recycling behaviors rather than only with conceptual learning outcomes:

> Therefore, educating people in this regard will have to follow the following objectives:
> - Promoting public awareness on solid waste management and recycling.
>   - Changing consumption patterns in society.
>   - Encouraging producing less garbage.
> - Performing the project of separating wet, dry, and burial garbage.
> - Improving the city's environment and public health conditions. (Samiifard, 2008; as cited in Nadi, Aghaabedi, & Radnezhad, 2016, p. 118)

Several examples of recycling education go beyond addressing the appropriate diversion of waste stream materials to engage students in both design-related and manufacturing-related content. Brusic (2014) suggested that teachers "explain to students how we live in a 'throwaway' society" (p. 12). In her "creative upcycling design brief," she outlined an activity for elementary grade teachers that would challenge their students to "create a useful and appealing product by transforming and combining throwaway goods in unique and creative ways" (p. 13). There have been numerous examples of upcycling education in higher education in which students are challenged to design products to be made from postconsumer materials and then to make those products, including the following:

- The British Council's (2015) Upcycling Design Workshop of Industry Leftovers Event (six UK Universities travelled to Wuxi China to attend a collaborative upcycling design workshop);
- The University of Sydney's (2018) Upcycled Glass course, which "examines conceptual and practical applications of up-cycled and found glass through contemporary art and design" ("2000 level units of study: Selective," para. 14); and
- Fashion and textiles students' upcycling of postconsumer shirts into newly designed clothing (University of Wolverhampton, 2016).

However, this raises a question as to whether a single college course is sufficient for a meaningful change in students related to environmental sustainability.

Ryu and Brody (2006) studied changes in ecological footprint (EF) throughout a graduate course on sustainability and found that:

> Graduate level education can significantly increase sustainable behavior as measured by their [students'] EF. Findings support the effectiveness of PBL [problem-based learning] techniques in teaching the principles of sustainable development and the ability of a single course to change student consumptive patterns in a period of only three months. (p. 169)

Ecological footprint analysis (EFA) uses results from a 27-item survey on respondents' demographics and reported behaviors related to four elements: food, mobility, housing, and goods and services (Center for Sustainable Economy, n.d.).

Studying actual behaviors (as opposed to reported behaviors) can be problematic because these behaviors occur at times and locations where there is no direct observation by researchers. Instead, conclusions may be drawn regarding some outcomes of sustainability education by surveying self-reported behaviors (as in the EFA) and self-reported environmental attitudes. "Environmental attitudes are a psychological tendency that is expressed by evaluating perceptions of or beliefs regarding the natural environment, including factors affecting its quality, with some degree of favour or disfavour" (Milfont, 2007, p. 12).

Milfont and Duckitt (2010) proposed the Environmental Attitudes Inventory as an "attempt to develop a tool for measuring the overall structure of EA [environmental attitudes]" (p. 88). The assessment consists of 120 items with 10 items for each of 12 scales; the shortened form, the EAI-S, consists of 72 items. All items use a 7-point Likert scale ranging from 1 (*strongly disagree*) to 7 (*strongly agree*). Within each scale or factor, five of the items are phrased so that 7 is associated with positive environmental attitudes, and five others are worded so that 7 is associated with negative environmental attitudes. "The twelve factors were established through confirmatory factor analyses, and the EAI scales are shown to be unidimensional scales with high internal consistency, homogeneity and high test-retest reliability, and also to be largely free from social desirability" (Milfont & Duckitt, 2010, p. 80).

Methodology

A university-wide elective course called Green Prototyping and Upcycling was developed and offered at a Midwest U.S. university in the spring semesters of 2015, 2016, and 2017 with the same instructor. Pretest and posttest surveys as well as student reports provided data on their environmental attitudes.

Subjects

Subjects included students of different levels, from freshman to doctoral-level students, across a broad range of majors (including technology and engineering teacher education) in the three sections agreeing to participate (16, 11, and 10 students). This study went through the university's Institutional Review Board approval for human subjects research.

Treatment

The semester-long course had each student participate in four hands-on projects with written reports through which they studied "the life cycle of the material and learn[ed] about material streams and environmental responsibility" (Flowers & Gorski, 2017, p. 9) in addition to their creative design work.

- Upcycling with a Laser: Each student designed and created a higher value product using a 150-watt CO_2 laser cutter or engraver and postconsumer materials they found.
- Upcycling with a Vacuum Former: Each student designed and created a higher value product using a vacuum former, finding postconsumer thermoplastic sheet stock and designing or finding a model over which to thermoform that material into a useful product.
- Design for Sustainability: Each student designed and created a 3D prototype for a product that in some way promotes environmental sustainability, and then the student justified how the product promotes sustainability. Students were provided instruction on and were free to use filament-based, powder-based, or resin-based 3D printers, laser cutters or engravers, and a wide variety of power and hand tools.
- Recycling PostConsumer Plastic into 3D Printer Filament: Working in a team of about six, students found, collected, identified, and researched a postconsumer thermoplastic. They granulated it, dried it, performed a melt-flow index test on it, and attempted to extrude their plastic into viable 3D printer filament. They then used a filament-based 3D printer and experimented with parameters in an attempt to produce viable objects.

With no technical course prerequisites, much of the instruction in the class addressed the technical nature of materials and processes and required student experimentation. Additional instruction was provided on life cycle analysis, material streams, design for sustainability, and similar areas.

Data Collection and Analysis

This study examined changes to students' reported environmental attitudes from the beginning to the end of this course. Pretest and posttest data were collected using the Environmental Attitudes Inventory (EAI), which consists of 120 items and uses a 7-point Likert scale. The EAI was administered on the first day of class and again on the last class day as a course assignment with full credit for all who completed it. EAI pretest and posttest responses were compared according to the 12 EAI scales. During analysis, responses to "reversed coded items," as identified by Milfont and Duckitt (2010, pp. 91–92), were flipped on the 7-point Likert scale so that higher numbers always indicated values aligned with positive environmental attitudes. The critical level of significance ($p = .05$) was divided by 12 using a Bonferoni approach to control Type I error, resulting in a two-tailed critical value of $p = 0.004$. Nonparametric procedures were used.

With students' permission, additional data were collected from their assignment reports. Comments from students' reflections in these reports were studied to look for evidence of changes in a student's understanding during the course and were reviewed to identify common themes.

Results

EAI Data Analysis

For the 2015 course offering, data from the 120 EAI items were recorded from the pretest and posttest for all students. Student identifiers were not included, so paired analysis was not possible. For data from the 16 students who had taken both surveys, a Mann–Whitney *U* test was performed. As shown in Table 1, although there were increases in the means for each of the 12 scales, only the increase for Scale 6 was significant, and Scale 6 had the highest mean in the posttest. There were no significant decreases for any scale.

Table 1

Increases in Means for 2015 Data Aggregated by EAI Scale

		M				
Scale	***n***	**Pretest**	**Posttest**	**Increase**	***U***	**Two-sided sig**
1	160	5.56	5.61	0.013	13,029	0.773
2	160	5.58	5.83	0.244	14,145	0.090
3	160	5.20	5.44	0.244	14,652	0.020
4	160	4.46	4.52	0.056	13,188	0.634
5	159	3.72	3.86	0.138	13,190	0.479
6	160	5.52	6.06	0.538	16,457	0.000*

7	160	4.33	4.38	0.056	13,049	0.760
8	159	5.08	5.09	0.013	12,890	0.832
9	160	5.20	5.53	0.331	14,444	0.039
10	160	4.95	5.04	0.094	13,410	0.450
11	158	5.79	5.90	0.111	13,527	0.252
12	160	3.91	4.30	0.394	14,612	0.026

* Significant with Mann–Whitney *U* test at $p = .004$

In the second year, data from the 2016 pre- and post-tests were paired for each of the 11 students in this class. Using the same two-tailed critical value of $p = 0.004$, a Wilcoxon signed ranks test was performed. As shown in Table 2, significant increases were seen in Scales 1, 7 and 8. Two scales showed decreases, though not at the level of significance used.

Table 2
Increases in Means for 2016 Data from Paired Pre- and Post-Tests by EAI Scale

		M				
Scale	***n***	**Pretest**	**Posttest**	**Increase**	**Z**	**Two-sided sig**
1	110	5.78	5.99	0.21	2.956	0.003*
2	110	5.59	5.66	0.07	0.467	0.641
3	109	5.27	5.45	0.18	2.648	0.008
4	107	4.49	4.42	-0.07	0.381	0.704
5	110	4.05	4.33	0.27	2.414	0.032
6	108	5.48	5.75	0.27	2.824	0.004
7	108	3.95	4.47	0.52	3.231	0.001*
8	110	5.27	5.56	0.29	3.108	0.002*
9	109	5.22	5.00	-0.22	1.76	0.078
10	109	4.69	4.87	0.18	1.601	0.109
11	110	5.84	5.96	0.13	1.442	0.149
12	110	4.32	4.58	0.26	1.909	0.056

* Significant with Wilcoxon signed-rank test at $p = .004$

The paired data from 10 subjects in 2017, the third year, produced significant increases in Scales 1, 2, 4, 6, 7, 8, and 9 using the same two-tailed critical value of $p = 0.004$ with a Wilcoxon signed-rank test (see Table 3). A different scale than in 2016 showed a decrease, but again this was not significant.

Table 3
Increases in Means for 2017 Data from Paired Pre- and Post-Tests by EAI Scale

		M				
Scale	***n***	**Pretest**	**Posttest**	**Increase**	**Z**	**Two-sided sig**
1	100	5.98	6.26	0.28	3.313	0.001*
2	100	5.84	6.37	0.53	4.508	0.000*
3	100	5.83	5.9	0.07	2.002	0.045
4	100	4.53	5.12	0.59	3.37	0.001*
5	100	3.89	3.57	-0.32	-2.093	0.036
6	100	6.11	6.46	0.35	3.207	0.001*
7	100	4.55	5.12	0.57	3.664	0.000*
8	99	5.25	5.76	0.51	3.275	0.001*
9	100	5.73	6.08	0.35	3.326	0.001*
10	100	5.31	5.46	0.15	0.933	0.351
11	100	6.23	6.35	0.12	1.16	0.246
12	100	4.54	4.72	0.18	1.502	0.133

* Significant with Wilcoxon signed-rank test at $p = .004$

The 12 scales in the EAI (Milfont & Duckitt, 2010) are as follows, with descriptions provided for those scales associated with significant changes from pretest to posttest in at least one of the years: (1) *enjoyment of nature*, (2) *support for interventionist conservation policies*, (3) *environmental movement activism*, (4) *conservation motivated by anthropocentric concern*, (5) *confidence in science and technology*, (6) *environmental fragility*, (7) *altering nature*, (8) *personal conservation behavior*, (9) *human dominance over nature*, (10) *human utilization of nature*, (11) *ecocentric concern*, and (12) *support for population growth policies* (pp. 89–90).

Scale1: Enjoyment of nature. This construct was defined as the "belief that enjoying time in nature is pleasant and preferred to spending time in urban areas, versus belief that enjoying time in nature is dull, boring and not enjoyable, and not preferred over spending time in urban areas" (p. 89). There were significant increases from pre- to post-test on this scale in 2016 and 2017.

Scale 2: Support for interventionist conservation policies. This construct was defined as "support for conservation policies regulating industry and the use of raw materials, and subsidizing and supporting alternative ecofriendly energy sources and practices, versus opposition to such measures and policies" (p. 89). There was a significant increase in 2017 on this sale.

Scale 4: Conservation motivated by anthropocentric concern. This construct was defined as "support for conservation policies and protection of the environment motivated by anthropocentric concern for human welfare and gratification, versus support for such policies motivated by concern for nature and the environment as having value in themselves" (p. 90). For this scale, there was a significant increase in 2017.

Scale 6: Environmental fragility. This construct was defined as the

> belief that the environment is fragile and easily damaged by human activity, and that serious damage from human activity is occurring and could soon have catastrophic consequences for both nature and humans, versus belief that nature and the environment are robust and not easily damaged in any irreparable manner, and that no damage from human activity that is serious or irreparable is occurring or is likely. (p. 90)

There were significant increases in 2015 and 2017 for this scale.

Scale 7: Altering nature. This construct was defined as the

> belief that humans should and do have the right to change or alter nature and remake the environment as they wish to satisfy human goals and objectives, versus belief that nature and the natural environment should be preserved in its original and pristine state and should not be altered in any way by human activity or intervention. (p. 90)

For Scale 7, there were significant increases in 2016 and 2017.

Scale 8: Personal conservation behavior. This construct was defined as "taking care to conserve resources and protect the environment in personal everyday behaviour, versus lack of interest in or desire to take care of resources and conserve in one's everyday behaviour" (p. 90). There were significant increases in 2016 and 2017 for Scale 8.

Scale 9: Human dominance over nature. This construct was defined as the "belief that nature exists primarily for human use, versus belief that humans and nature have the same rights" (p. 90). On Scale 9, there was a significant increase in 2017.

Each year did produce a significant increase in at least one scale, and there were no significant decreases. Several of the scales showed increases in more than one year. Still, it seems likely that the individual student's relationship with the curricular content and activities, as experienced through that student's creative product design, reading, troubleshooting, experimentation, and reflection, may be responsible for shifts seen from one year to the next. Year-to-year differences would therefore be expected in future offerings of this course, and results related to specific EAI scales cannot be generalized to those future offerings. Larger sample sizes may lead to results that are more generalizable.

Student Comments

Changes to students' reported environmental attitudes could also be seen in the reports they submitted that were associated with each project.[1] Unlike data from the EAI, students' reflections sometimes suggested causal relationships between course experiences and changes in their understanding or environmental attitudes. In general, most reflections by students on their assignment reports were technical in nature rather than reflections on their learning about or their relationship with environmental sustainability. The new technical content had been demanding and intriguing and, therefore, seemed to be central to what many students primarily gained from these activities. However, several comments did indicate impacts on their environmental attitudes.

One of the major shifts illustrated in student projects and reports was the change in their perceptions of "trash." One student, Tyler Carey, wrote: "I learned that even though some things may look like trash, with a lot of hard work, they can be redeemed into usable items." Brian Symanski stated that there was "very little difference" between his upcycled product and one that could be bought for over $100.

One student pointed out some societal factors that impact material use. To some, the end-goal may not be worth the effort based on time, money, or potential needs. Philip Borkowski summarized: "It has become too common of a task in our society to run to [local hardware stores] to pick up building supplies when we might be able to obtain what we need for free." He wrote,

> I found that it all comes to what you value . . . when using materials in ways that they are not intended to be used, there is an extra amount of labor

[1] Permission to use information contained in students' project reports was given on a student-by-student basis. Some granted permission under the condition that their name would be associated with content from their reports; others granted permission electing to have their names omitted.

> involved. Problems could also arise more frequently when reusing materials.

This shows growing insight into understanding the complex nature of technical issues and of attitudes related to promoting environmental sustainability.

A graduate student charged with making good use of relevant literature (e.g., Szaky, 2015), reflected on his experiences recycling plastic into 3D printer filament:

> I feel challenged to design a practical and useful product or service utilizing these processes to get more value out of the throwaway objects we encounter every day. The major challenge lies in having to segregate plastics by manufacturer and even by the batches of plastics used by each manufacturer. As Tom Szaky notes, “If plastic products were consistent in their resin composition, color, transparency, weight and size, we probably wouldn’t be having this conversation, as everything could be recycled together” (Szaky, 2015). This challenge seems to be a chief obstacle in the way of utilizing recycled goods as means of recycling products in the 21st century (Szaky, 2015).

One problem encountered by many students who worked in teams to attempt to extrude postconsumer plastic into viable 3D printer filament emerged because the students found postconsumer plastic products to use in this assignment that had originally been injection molded. These often were made from injection-grade rather than extrusion-grade plastic, and therefore tended to have low viscosity when melted, frustrating some attempts to extrude the plastic into viable filament. Grace Douglas wrote: “The project was challenging and enlightening. This project made me realize how many different polymers are used in our day to day lives; however, many of these polymers cannot be successfully extruded.”

The idea that material choice was critical surfaced in other activity reports, for example, when Michelle Loconte reflected on her design for a bird feeder made from postconsumer materials:

> I realized early on that by choosing litter as my main material I risked the uncertainty of materials . . . their unknown compound origins. This choice forced me to be conscious of my overall usage because of the uniqueness of each item.

In some instances, students' experiences in this class were the beginning of initiatives that could grow after the course ends:

> When I first introduced my idea, I was told that I should get it patented. After creating a prototype and physically seeing how the product works and how it will impact social and environmental systems, I may have to look into it more. (Phoebe Sherer)

One (anonymous) student mentioned learning a great deal about how energy can be saved around a home, writing the following reflection about the product the student designed: "There are definitely flaws with the design, but I can confidently say that I can use the concepts of this project and incorporate them into another product that will promote sustainability." Kandice Grimme, who designed and prototyped a compost bin, reported that she hadn't known it was possible for her to design and create a compost bin. She stated,

> In the future, I would like to build one that could be insulated to prevent the unpleasant smell. This definitely taught me that there are even more ways I can proactively engage in environmental sustainability besides just recycling and conserving energy.

Conclusions and Recommendations

In each of the 3 years that a course in Green Prototyping and Upcycling was offered to undergraduate and graduate students, students' environmental attitudes for at least one EAI scale showed a significant increase. Although there was no scale that showed a significant increase in all 3 years, there were four scales that showed a significant increase over 2 years: enjoyment of nature, environmental fragility, altering nature, and personal conservation behavior. Seven of the 12 scales showed an increase in at least one of the 2 years. There were no significant decreases in any scale in any year. Many student comments addressed technical learning associated with materials and processes, and other comments described changes in their environmental attitudes due to course experiences.

These students likely are not representative of students at this institution because this elective course likely appealed to some students who were predisposed to sustainability efforts. "Students enrolled in the biological and environmental sciences would be more pro-environmental in their attitudes than those enrolled in other science-based discipline" (Sutton & Gyuris, 2015, p. 28). This, coupled with the small sample size, confounds the ability to generalize to a broader population.

Although the EAI is a powerful tool, this particular context involved student creativity and students' interaction with technologies, two areas not addressed by the EAI. An instrument with greater focus on material streams, creative design, technological processes, and related environmental attitudes and behaviors would be a welcome addition.

Changing societal values toward greater environmental stewardship is a huge undertaking involving a variety of initiatives and spanning decades. Teachers can play a role here, especially technology teachers. Even if existing programs of study do not contain coursework related to environmental sustainability, teachers at the primary, secondary, and postsecondary levels can infuse sustainability into current course offerings. In some instances, experimental new courses, such as the one discussed here, or new programs could be offered. Such courses or programs would be likely to impact not only the students of those courses but others who may in turn be impacted by those students.

References

Abubakr, S. M., Scott, G. M., & Klungness, J. H. (1995). Fiber fractionation as a method of improving handsheet properties after repeated recycling. *TAPPI Journal*, *78*(5), 123–126.

Blumstein, D. T., & Saylan, C. (2007). The failure of environmental education (and how we can fix it). *PLoS Biology*, *l5*(5), 973–977. doi:10.1371/journal.pbio.0050120

British Council. (2015). Upcycling design workshop of industry leftovers. Retrieved from https://www.britishcouncil.org/education/ihe/opportunities/upcycling-industry-leftovers-workshop

Brusic, S. A. (2014). Transform me! Promoting children's creativity through newfangled upcycling. *Children's Technology and Engineering*, *19*(1), 11–15.

Center for Sustainable Economy. (n.d.). Ecological footprint quiz. Retrieved from http://myfootprint.org/en/

Flowers, J., & Gorski, A., (2017). Upcycle! *Technology and Engineering Teacher*, *76*(6), 8–12.

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

Loughlin, D. H., & Barlaz, M. A. (2006). Policies for strengthening markets for recyclables: A worldwide perspective. *Critical Reviews in Environmental Science and Technology*, *36*(4), 287–326. doi:10.1080/10643380600566952

McDonough, W., & Braungart, M. (2002). *Cradle to cradle: Remaking the way we make things*. New York, NY: North Point Press.

Milfont, T. L. (2007). *Psychology of environmental attitudes: A cross-cultural study of their content and structure* (Doctoral thesis, The University of Auckland, New Zealand). Retrieved from https://researchspace.auckland.ac.nz/handle/2292/1712

Milfont, T. L., & Duckitt, J. (2010). The environmental attitudes inventory: A valid and reliable measure to assess the structure of environmental attitudes. *Journal of Environmental Psychology*, *30*(1), 80–94. doi:10.1016/j.jenvp.2009.09.001

Nadi, M. A., Aghaabedi, E, & Radnezhad, H. (2016). Effectiveness of teaching recycling on the perception concept of recycling in sixth grade female students. *Journal of Earth, Environment and Health Sciences*, *2*(3), 116–121. doi:10.4103/2423-7752.199287

North American Association for Environmental Education. (2010). *Excellence in environmental education: Guidelines for learning (K–12)*. Washington, DC: Author. Retrieved from https://cdn.naaee.org/sites/default/files/learnerguidelines_new.pdf

Ritz, J. M. (2009). A new generation of goals for technology education. *Journal of Technology Education*, *20*(2), 50–64. doi:10.21061/jte.v20i2.a.4

Rose, M. A., (2012). EnviroTech: Student outcomes of an interdisciplinary project that linked technology and environment. *The Journal of Technology Studies*, *38*(2), 80–89. doi:10.21061/jots.v38i2.a.3

Rose, M., & Flowers, J. (2008). Technology assessment: A graduate course to build decision-making skills. In *Proceedings of the 2008 Conference of the American Society for Engineering Education* (pp. 13.1187.1–13.1187.11). Washington, DC: American Society for Engineering Education. Retrieved from https://peer.asee.org/3217

Ryu, H.-C., & Brody, S. D. (2006). Examining the impacts of a graduate course on sustainable development using ecological foot print analysis. *International Journal of Sustainability in Higher Education*, *7*(2), 158–175. doi:10.1108/14676370610655931

Sung, K., Cooper, T., & Kettley, S. (2014). Individual upcycling practice: Exploring the possible determinants of upcycling based on a literature review. In *Sustainable Innovation 2014: Cities & regions as catalysts for smart & sustainable innovation* (pp. 237–244). Farnham, England: University for the Creative Arts Farnham, The Centre for Sustainable Design.

Sutton, S. G., & Gyuris, E. (2015). Optimizing the environmental attitudes inventory: Establishing a baseline of change in students' attitudes. *International Journal of Sustainability in Higher Education*, *16*(1), 16–33. doi:10.1108/IJSHE-03-2013-0027

Szaky, T. (2015, April 22). The many challenges of plastic recycling. *Waste Not: Sustainable Brands Issue in Focus*. Retrieved from http://www.sustainablebrands.com/news_and_views/waste_not/tom_szaky/many_challenges_plastic_recycling

United States Environmental Protection Agency. (2016). *Advancing sustainable materials management: 2016 Recycling Economic Information (REI) Report methodology*. Washington, DC: Author. Retrieved from https://www.epa.gov/sites/production/files/2017-06/documents/final_epa_2016_rei_methodology_0.pdf

United States Environmental Protection Agency. (2018). Reduce, reuse, recycle. Retrieved from https://www.epa.gov/recycle

University of Sydney. (2018). Interdisciplinary studies handbook 2018: Visual arts description. Retrieved from http://sydney.edu.au/handbooks/interdisciplinary_studies/units_of_study/tables_pz/visual_arts_descriptions.shtml

University of Wolverhampton. (2016, May 17). Fashion students cotton on to upcycling trend. Retrieved from https://www.wlv.ac.uk/about-us/news-and-events/latest-news/2016/may-2016/fashion-students-cotton-on-to-upcycling-trend.php

About the Authors

Jim Flowers (jcflowers1@bsu.edu) is Professor in the Department of Educational Studies at Ball State University.

Cale Rauch (cbrauch@bsu.edu) is a former Graduate Research Assistant in Department of Family, Consumer, and Technology Education at Ball State University.

Alexander Wierzbicki (anwierzbicki@bsu.edu) is a former Graduate Research Assistant in Department of Family, Consumer, and Technology Education at Ball State University.

Research Evidence of the Impact of Engineering Design on Technology and Engineering Education Students

Jenny Daugherty, Raymond Dixon, & Chris Merrill

Abstract

Within the technology education classroom, engineering design has been targeted as key to improving learning, enhancing interest in STEM careers, and positively impacting students. The purpose of this research review was to determine whether the research evidence bears these claims. Four scholarly journals that focus on technology and engineering education research were reviewed resulting in the identification of 25 empirical research studies from the past decade. Across all of the studies, data had been collected from a total of 6,397 technology and engineering education students to analyze: (a) how students design, (b) student learning outcomes, and (c) student interests and perceptions. Just over half of the studies used qualitative methods to explore how small samples of students engage in engineering design. Although the overall research evidence of the impact of engineering design on technology and engineering students is sparse, there are some important descriptive findings relating to how engineering design can impact student learning and how students allocate their time and access information while designing.

Keywords: Engineering design; Engineering and technology education; Research; Student learning

Several science, technology, engineering, and mathematics (STEM) reports, mostly supported by the National Research Council and the National Academies, have focused on the inclusion of engineering at the K–12 level. For example, in the report *Engineering in K–12 Education: Understanding the Status and Improving the Prospects*, the committee argued that “K–12 engineering education may improve student learning and achievement in science and mathematics; increase awareness of engineering and the work of engineers; boost youth interest in pursuing engineering as a career; and increase the technological literacy of all students” (Katehi, Pearson, & Feder, 2009, p. 1). In 2010, the National Academy of Engineering’s Committee on Standards for K–12 Engineering Education explored the need for K–12 engineering standards. The following year, another committee outlined criteria for identifying effective STEM schools and programs (National Research Council, 2011). In 2014, yet another committee explored “integrated STEM education,” finding that “far from being a single, well-defined experience, integrated STEM education includes a range of different experiences that involve some degree of connection" (Honey, Pearson, & Schweingruber, 2014, p. 2).

The concerns—and, some might argue, rhetoric—articulated in these reports tend to center on the need for the United States to remain globally competitive by producing future innovative thinkers and designers. STEM education, it is argued, is the avenue by which students will gain the knowledge needed for the global economy. The reports argue that the current educational system is lacking in rigor, particularly in mathematics and science, in preparing students for STEM-based careers. For example, the reports point to lagging test scores, such as the National Assessment of Educational Progress results, to make their case. Although much of the emphasis in these reports is on mathematics and science, technology and engineering have been offered as opportunities for improving these areas by providing authentic contexts, making the learning more relevant to students. This is seen most recently with the inclusion of engineering concepts and practices in the *Next Generation Science Standards* (NGSS Lead States, 2013). Integrating STEM, it is argued, "can enhance motivation for learning and improve student interest, achievement, and persistence" (Honey et al., 2014, p. 1). It is believed that these outcomes will create better prepared students for college and the workplace.

Within the technology education classroom over the past decade or so, engineering education in general and, more specifically, engineering design have been offered as keys to improving teaching and learning (Daugherty & Custer, 2012; Denson & Lammi, 2014; Lewis, 2005; Wicklein, 2006; Wilhelmsen & Dixon, 2016). This is reflected by both the *Standards for Technological Literacy* (STL) including engineering design in its standards (International Technology Education Association [ITEA], 2007) and the International Technology and Engineering Education Association, the professional association for the discipline, including engineering in its name. Pinelli and Haynie (2010) outlined three reasons for including engineering in the K–12 curriculum: (a) "to support the engineering pipeline" by getting more students interested in engineering careers (p. 60), (b) "to enhance and enrich the teaching and learning of STEM" (p. 61), and (c) "to create a technologically literate citizenry and society" (p. 62).

With the numerous claims and hopes offered, what evidence exists to support these claims? Does the research support these assertions? In particular, is engineering design as impactful in the technology and engineering education classroom as the rhetoric suggests? The purpose of this study was to examine the research evidence on the impact of engineering design on technology and engineering education students. In order to address this purpose, the research questions for this study were as follows.

1. What research has been published in academic, peer-reviewed journals that provides empirical data on the impact of engineering design on technology and engineering education students in the United States?
2. What research topics exploring the impact of engineering design on technology and engineering education students have been published?
3. How is engineering design impacting student learning?

Engineering Design

Although K–12 engineering education is broader than engineering design, the focus of this study is on understanding the research evidence measuring the impact of engineering design. However, defining engineering design is as difficult as defining technology or engineering because there is no single, agreed upon definition. Often engineering design is described as a problem-solving process with specific steps identified. For example, Gomez, Oakes, and Leone (2012), in an engineering textbook, described engineering design as a problem-solving process. Perhaps closest to a definitive definition is the one offered by the Accreditation Board for Engineering and Technology's Engineering Accreditation Commission (2015) in their 2016–2017 criteria for accrediting programs, which defined *engineering design* as

> the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs. (p. 4)

Within the K–12 engineering and technology education literature, a few definitions of engineering design exist. Within the STL (ITEA, 2007) and in *Engineering in K–12 Education: Understanding the Status and Improving the Prospects* (Katehi et al., 2009), engineering design is described as an approach to solving technologically related problems. Wicklein and Thompson (2008) offered that "engineering design is an orderly, structured, problem-solving activity or process through which changes can lead toward a required result" (p. 58). And Gattie and Wicklein (2007) defined engineering design by citing Ullman's (2003) definition, as a

> process that centers around four (4) representations used to describe technological problems or solutions: (1) **Semantic** – verbal or textual explanation of the problem, (2) **Graphical** – technical drawing of an object, (3) **Analytical** – mathematical equations utilized in predicting solutions to technological problems, (4) **Physical** – constructing technological artifacts or physical models for testing and analyzing (International Technology Education Association, 2000; Ulman [*sic*], 2003). (Gattie & Wicklein, 2007, p. 10).

Across these descriptions, the consistent element of engineering design is that it is a systematic process for solving problems. However, as Lewis (2005) pointed out, although there is some agreement about the cognitive activity of engineering design, “there are nuances in how it is conceptualized” (p. 40) in the technology education classroom. Unfortunately, researchers often fail to articulate these nuances or operationalize the definition of engineering design being explored in their studies. As Flowers (2010) pointed out, “too often, our literature discusses *the model* or *the process* were there was no initial introduction of *a model* or *a process*” (p. 16). The assumption being that there is one engineering design process in K–12 technology education. This is not a safe assumption because of the variety of engineering design models and approaches identified in the literature and because the inclusion of or emphasis on certain steps or stages of the process vary. This is important to note when considering the research exploring the impact of engineering design on engineering and technology education students.

Method

A search and content analysis of empirical studies from four peer-reviewed academic research journals that publish research on K–12 technology and engineering education was conducted. These journals were: the *Journal of Technology Education* (*JTE*), the *Journal of Technology Studies* (*JOTS*), the *Journal of Pre-College Engineering Education Research* (*JPEER*), and the *Journal of Engineering Education* (*JEE*). Although there are other journals and conferences where researchers share their work in this domain, these four journals were believed to be the more prominent journals that would contain studies that examine the impact of engineering design on U.S. students because of their focus and audience.

As discussed previously, engineering design’s prominence in technology and engineering education is reflected in the inclusion of engineering design in four STL standards. The most recent edition of the STL, published in 2007, was assumed to have spurred research on engineering design; thus, volumes from 2007–2017 of the selected journals were analyzed.[1] The title and abstract (if available) of each article published in the volumes of the journals were reviewed, and if an abstract was not included, the article itself was analyzed for inclusion in the review. Articles were included in the review if they:

- included empirical data collected quantitatively, qualitatively, or with mixed methods;
- focused on technology and engineering education students;

[1] Two of the journals, *JPEER* and *JOTS*, did not span all years included in this study. The first issue of *JPEER* was published in 2011. At the time of this study, *JOTS* had not yet published any issues in 2017.

- were situated in the United States; and
- examined the impact of engineering design.

Although there were studies exploring engineering design in other contexts (i.e., science classrooms or other countries), focusing on elementary age students, or investigating topics related to engineering (i.e., visualization or computer-aided drafting), such studies were excluded because they stray from the purpose of this study, which was to determine the research evidence concerning the impact of engineering design on technology and engineering students. The studies had to include an explicit examination of "engineering design" and a focus on "technology and engineering education" students or "STEM" students. The studies that met the identified criteria were analyzed based on their method for data collection, number of participants, grade level, and findings. Although participant data is important because it enables researchers and readers to appropriately interpret the data, draw conclusions, and determine implications, several of the studies did not specify the demographic characteristics of the participants.

A content analysis was conducted for each of the studies that met the above criteria. "Content analysis is a detailed and systematic examination of the contents of a particular body of material for the purpose of identifying patterns, themes, or biases" (Leedy & Ormrod, 2016, p. 275). For the purpose of this study, the research studies were reviewed, and the method of data collection and number of research participants were documented for each study. Then, the studies were examined to identify consistent research topics on which they focused. The topics that emerged were used to categorize the studies according to their focus. For consistency, one of the researchers of this study categorized all of the studies. To establish interrater reliability, each of the two coresearchers checked a different 10% of the categories. Thus, 20% of the codes were checked and aligned with the established categorizing scheme.

Results

Research Question 1: Research on the Impact of Engineering Design

Based on the method established for this study, 25 research studies were identified in the four journals. *JPEER* had the most studies with 10, *JTE* had eight studies, *JEE* contained five studies, and *JOTS* had two studies. Across the 25 studies, 17 focused on high school level students, six included middle school students, one included both middle and high school students, and one did not report grade level. One study collected data from first-semester college students asking them information about their high school experiences and was thus coded as including high school students.

Across 24 of the 25 research studies (one did not report the number of research participants), data were collected from 6,397 students. One of the studies collected test score data from 2,530 students and another from 1,835 students, skewing the total number of students studied across the articles. For example, 76% of the studies had less than 200 students in their samples, and 56% of the studies had less than 50 students. Because very few reported the students' ethnicity or other student demographics, this cannot be reported. In lieu of reporting the research participants' demographics, researchers often shared the school district demographics as an apparent proxy for this data. Some of the studies reported the gender of the participants, and a few others provided percentages of males and females for control and experimental groups but did not report the number within these subgroups, so the number of female and male participants could not be determined.

In terms of the research methods used in the 25 studies, there was not uniformity in describing the research design. Some researchers identified both the research design and the data collection methods, whereas others chose to only identify the methods used. For example, in some of the studies that analyzed and reported qualitative data, the researchers identified the method for data collection (i.e., interviews) but did not describe a particular qualitative research design (i.e., case study), or the researchers used inconsistent terms (i.e., verbal protocol analysis). The authors for this study first used the terminology used by the researcher or researchers and then grouped similar methods together to determine which method (quantitative, qualitative, or mixed methods) was used most frequently in the research.

The most frequently used research methods were qualitative. Twelve studies relied on qualitative data; some identified a specific qualitative research design, and others simply described qualitative data collection methods and analysis. For example, researchers in one study described their design as collecting ethnographic student reflections, and in another, researchers identified their study as a focus group study. Although identified differently within the studies, 11 of the qualitative studies collected verbal data either by video or audio (or both) of small samples of students engaged in design. In five of these studies, researchers described their approach as verbal protocol analysis or think-aloud protocol analysis. Researchers in one study described collecting video data of small group discussions. In one study, researchers described conducting discourse analysis, and in another study, researchers described conducting collaborative video analysis using grounded theory. Two studies described the method used as exploratory triangulation mixed methods using function–behavior–structure ontology collecting verbal data. In addition to individual interviews and observations of group meetings, verbal protocols were also collected in an ethnographic study.

Researchers in seven of the studies identified mixed methods as the research design. Two of the studies used a quasiexperimental or "educational design experiment" that included a pretest and posttest, no control group, and follow-up interviews. Two studies described the method used as exploratory triangulation mixed methods using function–behavior–structure ontology. One study's researchers described the method as a combined quantitative pre-/post-test and interviews; another study used an embedded design mixed-methods framework with a two-group posttest; and another study's researchers described using surveys, questionnaires, and focus groups to collect data.

Of the 25 studies examining the impact of engineering design, six of the studies used quantitative research designs or methods. Four of the studies described specific statistical methods, including longitudinal multilevel modeling, multiple linear regression, multilevel statistical modeling, and regression and mediation analyses to analyze the quantitative data collected. In one study, researchers reported descriptive statistical results from a survey, and in another study, researchers reported descriptive statistical results from a questionnaire. These six studies accounted for the larger sample sizes, ranging from 41 to 2,530 students included in the sample sizes.

Research Question 2: Research Topics

The research topic categories emerged from the stated purpose of each of the studies. After reviewing each of the studies thoroughly, consistent research topics were identified within the larger goal of examining the impact of engineering design on technology and engineering education students. The topics that emerged were: (a) how students design, (b) student learning outcomes, and (c) student interests and perceptions. The studies classified under the first topic, how students design, investigated student design strategies, typically through think-aloud or verbal protocol analysis. For the second topic, student learning outcomes, these studies examined the impact of engineering design on student learning outcomes measured primarily using test scores. Studies classified under the last topic, student interests and perceptions, largely captured students' interests in engineering careers or their perceptions about specific engineering programs or their engineering design experiences.

Table 1 includes the number of studies by research topic within each of the journals. Almost half of the studies (12) explored how students design. These studies aimed to capture technology and engineering students' thought processes as they engaged in engineering design. Seven of the studies focused on measuring student learning outcomes as a result of an engineering design curricular program or experience. Six of the studies explored the impact of engineering design experiences on students' interests and perceptions—often, either their perceptions of engineering as a career or of the engineering program itself.

Table 1
Research Topics of the Studies

Purpose	JTE	JOTS	JPEER	JEE	Total
How students design	5	0	4	3	12
Student learning outcomes	3	0	3	1	7
Student interests and perceptions	0	2	3	1	6
Total	8	2	10	5	25

Research Question 3: Impact of Engineering Design on Students

The third research question under investigation in this study focused on how engineering design was impacting students. The studies were analyzed to better understand the research evidence concerning the impact of engineering design on technology and engineering education students. Below are the combined findings from the studies that were grouped together by the three categories that emerged based on the research topics of the studies: (a) how students design, (b) student learning outcomes, and (c) student interests and perceptions.

How students design. Most of the 12 studies that explored how students engage in design examined student cognition during engineering design activities to inform curriculum and instruction. Student engagement in design can be tied to student learning; however, most of the studies examined small samples of high school students outside the context of the classroom environment as they interact with the process of engineering design and with each other. Many of the studies make reference to the intention of identifying the gaps between novice and expert engineering designers and equipping students with the knowledge, skills, and abilities needed to advance toward expertise.

Mentzer is a researcher or coresearcher on five of the 12 studies; thus, his work greatly impacts this area of research. Three of his studies focused on information access and time allocation while students are engaged in the design process. In terms of information access, Pieper and Mentzer (2013) analyzed videos from 12 high school students engaged in an engineering design problem who had different information sources available. They found that “on average, participants spent 38.8% of their total time accessing information” (p. 86), primarily from Internet-based sources, which was significantly more than college-level engineering students and expert engineers in previous studies. Another Mentzer (2014a) study compared two groups of high school students (30 students in each group) engaged in “a design problem in a three-hour design experience” in which “one group has access to the internet while the other does not" (p. 31). Mentzer found that "the most commonly requested piece of information related to cost of materials" (p. 31). He also found that "students with access to the internet spent substantially more time in the design process," although "most of the difference in design session duration was explained by the additional time allocated to gathering information" (p. 39). In another study, Mentzer and Fosmire (2015) used verbal protocol analysis of video and audio recordings to measure "the information gathering behaviors of [19] high school students who had taken engineering design courses as they solved a design problem" (p. 22). As in the previous study, Mentzer and Fosmire found that students spent the most time searching for material costs; however, they also spent time searching for information concerning construction techniques or processes and information related to the solution being considered. "The high school students understood the need for information, . . . but their skill in locating high-quality information was relatively poor" (p. 22).

Two of the other studies that Mentzer was involved in focused on how students allocate their time when engaged in engineering design. Mentzer's (2014b) study examined 17 design teams comprised of 47 high school students as they engaged in an engineering design activity. In comparison to experts, the high school teams spent less time working on the problem and modeling but spent more time communicating. Finally, Mentzer, Becker, and Sutton's (2015) study compared the design processes of high school students, "freshmen who have taken one engineering course and seniors who have taken a series of engineering courses" (p. 417), to expert engineers. Using verbal protocol analysis, 59 "students from four states were asked to think aloud in a three-hour design task that was audio and video recorded" (p. 417). The researchers found that the "students and experts alike spent a large portion of their time modeling" (p. 417)—unlike the students in Mentzer's (2014b) study. However, the "students spent significantly less time in the process of information gathering" and thinking about the problem from the client's perspective than experts (Mentzer, Becker, & Sutton, 2015, p. 417). Also, "freshmen spent significantly less time in the idea generation process than seniors and experts" (p. 417).

The comparison of different groups of students was also an element of Kelley's (2008) verbal protocol study that compared the impact of Project Lead the Way (PLTW) and the National Center for Engineering and Technology Education's (NCETE) engineering-design focused instruction on how seven (three PLTW and four NCETE) students engaged in an ill-defined problem-solving activity. Kelley found that both groups of students used similar strategies but spent varying time developing solutions. The study published by Wells et al. (2016) also used verbal protocol analysis to compare the design cognition of high school students who have had a pre-engineering course experience, high school students who have not, and undergraduate engineering students as part of a larger longitudinal study; they found no significant differences in the design cognition of these different groups.

The following two studies sought to understand student design cognition in groups using verbal data without a comparison group. Lammi and Becker (2013), for example, used verbal protocol analysis and the Function–Behavior–Structure framework, as well as interviews and the artifacts of the design process, to examine 12 high school students' cognitive processes while working in pairs on an engineering design challenge. They found that structure was the most prevalent element and that the lowest was function. Valtorta and Berland's (2015) study used discourse analysis of video data that captured 31 high school students working on a unit in an engineering course over 15 class sessions. They sought to determine if students applied STEM concepts when engaged in engineering design. Valtorta and Berland

> found that students successfully applied math and science concepts to their engineering design work without teacher prompting when the concepts were familiar. However, explicit teacher prompting and instruction regarding the integration of less familiar concepts did not seem to facilitate student use of those concepts. (p. 15)

Two other studies used verbal data to understand the role of culture on how students engage in engineering design. Wilson-Lopez, Mejia, Hasbún, and Kasun's (2016) ethnographic study relied on verbal data, interviews, and observations of seven groups of 25 Latina/o high school students as they engaged in engineering design. Wilson-Lopez et al. found that the students' "familial, community, and recreational funds of knowledge" were connected to their understanding and approach to engineering design (p. 278). Schnittka and Schnittka's (2016) study explored "how cultural gender norms are navigated within informal K-12 engineering contexts . . . . [using discourse analysis to analyze] video of single- and mixed-gender collaborative groups participating in . . . a design-based, environmentally themed afterschool program" (p. 1).

> Discrepancies were found regarding functional and cultural characteristics of groups based on gender composition. Single-gender groups adhered more closely to social gender norms . . . . In contrast, characteristics of interactional styles within mixed gender groups strayed from social gender norms. (Schnittka & Schnittka, 2016, p. 1)

The only research study exploring how students design that did not analyze verbal data was Menekse, Higashi, Schunn, and Baehr's (2017) study of "366 youths on 61 K-8 robotics teams that participated in a FIRST LEGO League Championship. Regression and mediation analyses were conducted to explore the relation between effective team collaboration and team performance" (p. 1). They found that "Collaboration Quality was a good predictor of robotics team performance across all measures" (p. 1). In other words, they found that how students collaborated during design impacts how they performed in the competition.

Student learning outcomes. Of the seven studies published exploring the impact of engineering design on student learning outcomes, four used mixed methods, and three were quantitative. The majority of the studies found that engineering design via a unit, course, program, or curriculum positively impacted some facet of student learning, but the results were mixed. For example, Merrill, Custer, Daugherty, Westrick, and Zeng's (2008) study was designed to measure student learning of engineering concepts via a unit of instruction with an engineering design challenge. Using a quasiexperimental design, 114 high school students engaged in the unit of instruction designed to teach three engineering concepts: constraints, optimization, and predictive analysis (COPA). Using a pre-/post-test design, the researchers found statistically significant gain scores. Although, "mean score gains . . . were modest, they did indicate significant improvement in understanding of COPA concepts" (p. 62).

Berland et al.'s (2013) mixed-methods study sought to determine the impact of an engineering design course in seven high schools with 106 students. The researchers found mixed results in that students' understanding of engineering increased, but it did so inconsistently and without much detail. And Svarovsky's (2011) mixed-methods study investigated the impact of a 60-hour program called *Digital Zoo* on 10 middle school female students using a pre-/post-test and interviews. The researcher found that the program enabled students "to develop each of the five epistemic frame elements—engineering skills, knowledge, identity, values, and epistemology" (p. 19).

Two of the studies explored the impact of PLTW curriculum on student learning. Tran and Nathan (2010) used multilevel statistical modeling to explore the relationship between PLTW course enrollment and student achievement on the state math and science standardized test scores of 140 high school students with a matched comparison group of 70 students. The results indicated that

> While students gained in math and science achievement overall from eighth to tenth grade, students enrolled in *PLTW* foundation courses showed significantly smaller math assessment gains than those in a matched group that did not enroll, and no measurable advantages on science assessments, when controlling for prior achievement and teacher experience. (p. 143)

Dixon and Brown (2012) also investigated the impact of PLTW on student learning, finding mixed results. Their study was designed to compare PLTW students with students who have not taken PLTW courses in terms of their ability to "transfer mathematics, science, and design concepts from one situation to another" (p. 3). They "found significant relationships between the number of PLTW courses students took and students' performance in design score and total score. Also, there was no significant difference in mathematics and science performance between PLTW and non-PLTW students" (p. 10).

The last two studies in this category were a bit different than the others but still examined the impact of engineering design on student learning by correlating data. Mentzer and Becker (2010) investigated the possible correlation between the prior academic achievement of 41 high school students, as determined by student GPA in science, mathematics, communication courses, and "their experience during an engineering design challenge, as measured by an achievement test" (p. 27). They found that "student achievement was significantly correlated to science GPA, but not significantly [correlated] to mathematics or communication GPA" (p. 37). The study by Crotty et al. (2017) correlated "different approaches to integrating engineering practices in science, technology, engineering, and mathematics (STEM) curriculum units . . . with student outcomes on engineering assessment items" (p. 1). They found that when and how engineering design was placed in the curriculum impacted students' performance on the assessments.

> Including engineering at the beginning of a STEM unit to frame the learning and provide context for the unit with engineering being revisited and used as a project at the end produced stronger engineering understandings for students compared to when engineering was used solely as a culminating project. (p. 9)

Student interests and perceptions. The last topic of research examining the impact of engineering design on technology and engineering education students included six studies that explored students' interests and perceptions. Two of the studies sought to understand students' perceptions of engineering design in general. Four of the studies captured the students' perceptions after experiencing a specific engineering program or experience: one using surveys, one using surveys and a focus group, on using only a focus group, and one using an ethnographic approach. The studies were designed to capture the students' perceptions of the program or experience itself as well as its impact on their interests in engineering or STEM.

Sirinterlikci, Zane, and Sirinterlikci (2009) described the results of a survey administered to elementary and middle students involved in the TOYchallenge competition, finding that "some of the student survey responses reflected positive attitudes toward the engineering process, albeit their lack of interest in pursuing the field as an adult" (p. 20). Using mixed methods, Blanchard et al. (2015) surveyed nearly 2,000 middle school students and conducted a focus group of 19 students who had participated in *Beyond Blackboards*, "an inquiry-centered, after-school program designed to enhance middle school students' engagement with engineering through design-based experiences" (p. 1).

Students reported that as a result of their participation, their interest in engineering careers and their interest in pursuing a 4-year degree increased.

Denson, Lammi, White, and Bottomley (2015) convened a focus group "to further understand the student experience and ascertain the perceived value of an informal learning environment for students engaged in an engineering design challenge" during a summer camp (p. 40). The eight high school students who participated in the study reported that they perceived "the benefits of the summer camp to include the use of mathematical modeling (application of math and science), a field experience, and teamwork" (p. 43). Carroll (2014) reported on an ethnographic study that involved 4 months of data collection in an urban afterschool program in which university students worked with 36 middle school students "engaged in design thinking and STEM activities" (p. 17). The researcher concluded that design thinking permeated the experience for both the university and middle school students, informing how the students approached mentoring, "how to create user-centered learning experiences, and how to share their experiences" (p. 29).

Although Ing, Aschbacher, and Tsai's (2014) longitudinal study sought to examine the possible gender differences in students' interests in careers in engineering and science. They surveyed 482 students over 3 years (Grades 7–9) "to explore gender differences in engineering and science career preferences" (p. 1). The findings indicated that "females were far more likely to express interest in a science career (31%) than an engineering career (13%), while the reverse was true for males (58% in engineering, 39% in science)" (p. 1). Additionally, "females were less interested in designing and inventing, solving problems, and using technology" than males (p. 1).

Seeing self-efficacy as an important indicator of students electing to major in STEM subjects, Fantz, Siller, and DeMiranda (2011) surveyed 332 first-semester college students about their precollegiate experiences, including "pre-engineering classes, multi-day programs, engineering hobbies, working in an engineering environment, extra-curricular engineering programs, and single-day field trips" that included exposure to engineering design (p. 604). The results indicated that that there were "significant differences in self-efficacy . . . between groups of students who had pre-engineering classes and engineering hobbies versus students who did not have these experiences" (p. 604).

Discussion

Overall, the research evidence of the impact of engineering design on technology and engineering students is sparse. In over a decade of time, only 25 studies in four journals with a total of only 6,397 students has been published. In addition, the majority of the studies used qualitative or mixed methods to collect data from purposively selected small samples, mostly of high school students. This prevents the generalization of findings about how students design, the impact of engineering design on student learning, and its impact on their interests and perceptions. Despite the limitations of this body of research, there are some descriptive findings explored in these studies that are worth further discussion.

With almost half of the studies seeking to understand how students engage in engineering design, this is a prominent topic in the research, and verbal protocol analysis is a prominent method used. Although these studies seek to explore student cognition, the studies exploring how students engage in the design process were often conducted outside of the classroom learning environment. However, by understanding how students design (i.e., how they allocate time, apply STEM concepts, or collaborate), the intent of these studies is to inform and improve engineering design-based curriculum and instruction in the classroom. This also appears to be the case for those studies exploring how particular curricula (e.g., PLTW vs. NCETE), access to information, and cultural and gender norms impact students' ability to design. How and to what extent these findings are informing curriculum and instruction is an important question.

In terms of student learning outcomes, a few of the seven studies reported some positive impacts, but several documented minimal or mixed results. Nevertheless, it is challenging to identify any consistent findings across the studies because the research contexts, designs, and outcomes measured varied greatly. The context of engineering design varied across the studies, whether it was embedded in a unit of instruction, a course, or an entire curriculum. The study designs also varied from using pre- and post-test data in a quasiexperiment to correlating variables to determine possible relationships between them. Variables such as exposure to a type of curriculum, academic history, and standardized test scores were used to determine possible correlations. The outcomes being measured across the seven studies also varied from measuring the impact of engineering design on students' understanding of engineering, student achievement on state mathematics and science standardized test scores, and students' ability to transfer mathematics, science, and design concepts. It appears that the targeted outcome of engineering design on student learning includes several dimensions or aspects of learning and that the evidence of impact is scant to nonexistent.

As several of the researchers noted, it is important to understand how students' exposure to engineering design impacts their perceptions because their self-efficacy and interest levels can impact their future engagement in engineering. The majority of these studies were more evaluative in nature, collecting student perception data as a result of their involvement in an engineering design-oriented program or experience. The other two sought to explore students' future interests in STEM and possible gender differences or as a result of exposure to engineering education. These types of studies are particularly important for engineering and technology education because it is largely an elective in the K–12 classroom. Staying attuned to students' interests and perceptions is key to orienting the curriculum to draw the most number of students possible. In addition, one of the primary motivators for focusing on STEM education is to motivate students to major in and pursue careers in STEM. The role of engineering design in accomplishing this goal is important to study, but clarity in what is being measured and what is being reported is crucial to draw broader conclusions.

Conclusion

The purpose of this study was to understand the research evidence regarding the impact of engineering design on technology and engineering education students. Admittedly, the research footprint is not very extensive because it has only been a decade or so since the field has been actively engaged in researching the impact of engineering design in the technology and engineering education classroom. In terms of many scholarly endeavors, this area of research is in its infancy. Further, the limits of the design of this study, including the identification of studies from only four journals in the past decade, further narrows the scope of analysis. Publications from other research journals, proceedings from conferences such as the American Society for Engineering Education annual conference, and dissertations might contain further research on the impact of engineering design on students.

Another potential limitation of this research review, and perhaps in the framing of the purpose of this study, is the assumption that the research community and practitioners (e.g., teachers, curriculum developers, and professional development providers) are all approaching engineering design in a similar way; that there is an “engineering design process” in technology and engineering education. As discussed above and indicated by the variety of curricular approaches and experiences in the studies reviewed, perhaps there is not one (and should not be one) engineering design process. Flowers (2010) cautioned against the dogmatic use of the definite article in phrases such as *the engineering design process* and suggested that “one solution to the problems mentioned concerning definite article usage and the bigger issue of dogma is to question our assumptions, even at the expense of our comfort” (p. 18). If the points of comparison are to be fair, a more thorough review of how researchers, teachers, and students are defining or approaching engineering design would help. In other words, a more nuanced understanding of how engineering design is being implemented in classrooms, how students are experiencing engineering design, and the outcomes of those experiences is needed.

There are certainly lessons to be learned in terms of how engineering design can impact student learning, students’ perceptions of engineering and STEM careers, and how students approach the design process. Obviously, there is considerably more work that needs to be done to provide the kind of evidence needed to be able to determine the impact of engineering design experiences on dimensions such as learning, interest, and creativity. As Katehi, Pearson, and Feder (2009) stated,

> Meaningful improvements in the learning and teaching of engineering—and movement toward integrated STEM education—will not come easily or quickly. Progress will be measured in decades, rather than months or years. The necessary changes will only happen with a sustained commitment of financial resources, the support of policy makers and other leaders, and the efforts of many individuals in and outside K–12 schools. (p. 14)

The lack of strong research evidence on the impact of engineering design in technology and engineering education points to the need for more concentrated efforts in this regard. The National Academy of Engineering and National Research Council reports identified in this study offer guidance for next steps and point to needed areas of research that would help inform the collective efforts of engineering and technology education. Given that the STL were published over a decade ago and that technology and engineering education has charted the course toward engineering design, it would seem like an opportune time to develop a focused and strategic research agenda that would help inform the collective efforts of researchers and scholars to be able to better answer questions concerning the evidence of impact. Expanding the number of student research participants, diligently reporting the demographics of those students, following rigorous research design methods, clearly describing those methods and the engineering design approaches and experiences that students are engaged in, and documenting the outcomes (whether on learning, interest, or some other dimension) are crucial steps forward.

References

Accreditation Board for Engineering and Technology, Engineering Accreditation Commission. (2015). *Criteria for accrediting engineering programs: Effective for reviews during the 2016-2017 accreditation*. Retrieved from http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2016-2017/

Berland, L. K., Martin, T. H., Ko, P., Peacock, S. B., Rudolph, J. J. & Golubski, C. (2013). Student learning in challenge-based engineering curricula. *Journal of Pre-College Engineering Education Research*, *3*(1), 53–64. doi:10.7771/2157-9288.1080

Blanchard, S., Judy, J., Muller, C., Crawford, R. H., Petrosino, A. J., White, C. K.; Lin, F.-A., & Wood, K. L. (2015). *Beyond Blackboards*: Engaging underserved middle school students in engineering. *Journal of Pre-College Engineering Education Research*, *5*(1), 1–14. doi:10.7771/2157-9288.1084

Carroll, M. P. (2014). Shoot for the moon! The mentors and the middle schoolers explore the intersection of design thinking and STEM. *Journal of Pre-College Engineering Education Research*, *4*(1), 14–30. doi:10.7771/2157-9288.1072

Crotty, E. A., Guzey, S. S., Roehrig, G. H., Glancy, A. W., Ring-Whalen, E. A., & Moore, T. J. (2017). Approaches to integrating engineering in STEM units and student achievement gains. *Journal of Pre-College Engineering Education Research*, *7*(2), 1–14. doi:10.7771/2157-9288.1148

Daugherty, J. L., & Custer, R. L. (2012). Secondary level engineering professional development: Content, pedagogy, and challenges. *International Journal of Technology and Design Education*, *22*(1), 51–64. doi:10.1007/s10798-010-9136-2

Denson, C. D., & Lammi, M. (2014). Building a framework for engineering design experiences in high school. *Journal of Technology Education*, *26*(1), 75–87. doi:10.21061/jte.v26i1.a.5

Denson, C., Lammi, M., White, T. F., & Bottomley, L. (2015). Value of informal learning environments for students engaged in engineering design. *Journal of Technology Studies*, *41*(1), 40–46. doi:10.21061/jots.v41i1.a.5

Dixon, R. A., & Brown, R. A. (2012). Transfer of learning: Connecting concepts during problem solving. *Journal of Technology Education*, *24*(1), 2–17. doi:10.21061/jte.v24i1.a.1

Fantz, T. D., Siller, T. J., & DeMiranda, M. A. (2011). Pre-collegiate factors influencing the self-efficacy of engineering students. *Journal of Engineering Education*, *100*(3), 604–623. doi:10.1002/j.2168-9830.2011.tb00028.x

Flowers, J. (2010). *The* problem in technology education (a definite article). *Journal of Technology Education*, *21*(2), 10–20. doi:10.21061/jte.v21i2.a.2

Gattie, D. K., & Wicklein, R. C. (2007). Curricular value and instructional needs for infusing engineering design into K-12 technology education. *Journal of Technology Education*, *19*(1), 6–18. doi:10.21061/jte.v19i1.a.1

Gomez, A. G., Oakes, W. C., & Leone, L. L. (2012). *Engineering your future: A project-based approach* (3rd ed.). St. Louis, MO: Great Lakes Press.

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

Ing, M., Aschbacher, P. R., &Tsai, S. M. (2014). Gender differences in the consistency of middle school students' interest in engineering and science careers. *Journal of Pre-College Engineering Education Research*, *4*(2), 1–10. doi:10.7771/2157-9288.1090

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

Kelley, T. R. (2008). Cognitive processes of students participating in engineering-focused design instruction. *Journal of Technology Education*, *19*(2), 50–64. Retrieved from http://scholar.lib.vt.edu/ejournals/JTE/v19n2/pdf/kelley.pdf

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

Leedy, P. D., & Ormrod, J. E. (2016). *Practical research: Planning and design* (11th ed.). New York, NY: Pearson Education.

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

Menekse, M., Higashi, R., Schunn, C. D., & Baehr, E. (2017). The role of robotics teams' collaboration quality on team performance in a robotics tournament. *Journal of Engineering Education*, *106*(4), 564–584. doi:10.1002/jee.20178

Mentzer, N. (2014a). High school student information access and engineering design performance. *Journal of Pre-College Engineering Education Research, 4*(1), 31–42. doi:10.7771/2157-9288.1074

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

Mentzer, N., & Becker, K. (2010). Academic preparedness as a predictor of achievement in an engineering design challenge. *Journal of Technology Education*, *22*(1), 22–42. doi:10.21061/jte.v22i1.a.2

Mentzer, N., Becker, K., & Sutton, M. (2015). Engineering design thinking: High school students' performance and knowledge. *Journal of Engineering Education*, *104*(4), 417–432. doi:10.1002/jee.20105

Mentzer, N. & Fosmire, M. J. (2015). Quantifying the information habits of high school students engaged in engineering design. *Journal of Pre-College Engineering Education Research*, *5*(2), 22–34. doi:10.7771/2157-9288.1108

Merrill, C., Custer, R. L., Daugherty, J., Westrick, M., & Zeng, Y. (2008). Delivering core engineering concepts to secondary level students. *Journal of Technology Education*, *20*(1), 48–64. doi:10.21061/jte.v20i1.a.4

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. (2011). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: National Academies Press. doi:10.17226/13158

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

Pieper, J., & Mentzer, N. (2013). High school students' use of paper-based and internet-based information sources in the engineering design process. *Journal of Technology Education*, *24*(2), 78–95. doi:10.21061/jte.v24i2.a.6

Pinelli, T. E., & Haynie, W. J., III. (2010). A case for the nationwide inclusion of engineering in the K-12 curriculum via technology education. *Journal of Technology Education*, *21*(2), 52–68. doi:10.21061/jte.v21i2.a.4

Schnittka J., & Schnittka C. (2016). "Can I drop it this time?" Gender and collaborative group dynamics in an engineering design-based afterschool program. *Journal of Pre-College Engineering Education Research*, *6*(2), 1–24. doi:10.7771/2157-9288.1120

Sirinterlikci, A., Zane, L., & Sirinterlikci, A. L. (2009). Active learning through toy design and development. *Journal of Technology Studies*, *35*(2), 14–22. doi:10.21061/jots.v35i2.a.2

Svarovsky, G. N. (2011). Exploring complex engineering learning over time with epistemic network analysis. *Journal of Pre-College Engineering Education Research*, *1*(2), 19–30. doi:10.5703/1288284314638

Tran, N. A., & Nathan, M. J. (2010). Pre-college engineering studies: An investigation of the relationship between pre-college engineering studies and student achievement in science and mathematics. *Journal of Engineering Education*, *99*(2), 143–157. doi:10.1002/j.2168-9830.2010.tb01051.x

Ullman, D. G. (2003). *The mechanical design process* (3rd ed.). New York, NY: McGraw-Hill.

Valtorta, C. G., & Berland, L. K. (2015). Math, science, and engineering integration in a high school engineering course: A qualitative study. *Journal of Pre-College Engineering Education Research*, *5*(1), 15–29. doi:10.7771/2157-9288.1087

Weber, K. (2012). Gender differences in interest, perceived personal capacity, and participation in STEM-related activities. *Journal of Technology Education*, *24*(1), 18–33. doi:10.21061/jte.v24i1.a.2

Wells, J., Lammi, M., Gero, J., Grubbs, M. E., Paretti, M., & Williams, C. (2016). Characterizing design cognition of high school students: Initial analyses comparing those with and without pre-engineering experiences. *Journal of Technology Education*, *27*(2), 78–91. doi:10.21061/jte.v27i2.a.5

Wicklein, R. C., & Thompson, S. A. (2008). The unique aspects of engineering design. In R. L. Custer & T. L. Erekson (Eds.), *Engineering and technology education: 57th Yearbook of the Council on Technology Teacher Education* (pp. 57–76). Woodland Hills, CA: Glencoe/McGraw Hill.

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

Wilhelmsen, C. A., & Dixon, R. A. (2016). Identifying indicators related to constructs for engineering design outcome. *Journal of Technology Education*, *27*(2), 57–77. doi:10.21061/jte.v27i2.a.4

Wilson-Lopez, A., Mejia, J. A., Hasbún, I. M., & Kasun, G. S. (2016). Latina/o adolescents' funds of knowledge related to engineering. *Journal of Engineering Education*, *105*(2), 278–311. doi:10.1002/jee.20117

About the Authors

Jenny Daugherty (jdaugherty@lsu.edu) is Director, of the Leadership Development Institute and Jones S. Davis Distinguished Associate Professor in the School of Leadership & Human Resource Development at Louisiana State University.

Raymond Dixon (rdixon@uidaho.edu) is Department Chair and Associate Professor in the Department of Curriculum & Instruction at Idaho State University.

Chris Merrill (cpmerri@ilstu.edu) is Professor of Technology and Engineering Education in the Department of Technology at Illinois State University.

Special Note: Because Chris Merrill is serving as the Editor of the *Journal of Technology Education*, Dr. Rodney Custer served as the Editor for this particular manuscript, chose his own reviewers that were not known to the editor, and handled all aspects of the review and acceptance cycle.

The Impacts of Integrating Introductory Composition, Communication, and Design Thinking Courses

Amelia Chesley, Michael W. Coots, Andrew Jackson, Sarah Knapp, Nathan Mentzer, & Dawn Laux

Abstract

Much recent STEM research indicates that course integration improves the student learning experience and fosters stronger connections among concepts and skills; this study attempts to evaluate whether or not students learn the design process more fully in the integrated version of a required first-year course, Design Thinking in Technology. Drawing from an ongoing assessment of an Integrated First-Year Experience at Purdue University, this article reports on the challenges of teaching design thinking and analyzes whether students in an interdisciplinary course integration can demonstrate the work of their design processes more completely and effectively compared to students in a non-integrated version of the course. We employ a modified version of the Engineering Design Process Portfolio Scoring Rubric (EDPPSR) as a method of evaluating students' design portfolios. Our initial and follow-up analyses show that students in both versions of the course struggle to complete design journal assignments satisfactorily. We assess and analyze the impact of STEM-humanities integration on students' abilities to document and contextualize the design process using journals, and also offer discussion and suggestions about our findings.

Keywords: design thinking, STEM integration, interdisciplinary pedagogy, design portfolios, first-year programs

Design thinking has the potential to be an umbrella skill encompassing several other valued skills, such as creativity, critical thinking, innovation, empathy, collaboration, information literacy, and audience awareness. Educators and employers see these skills and abilities as crucial tools for the 21st century. The Partnership for 21st Century Skills Report indicates that employers place increasing importance on creativity and innovation (Casner-Lotto & Barrington, 2006). Creative thinking and critical thinking have long been common terms in conversations about what college graduates most need as they transition into the workforce; "design thinking" is a relatively new addition to such discussions. "Design thinking" involves a strategic, practical process of conceiving and actualizing solutions to problems. Design thinking is not something only designers can engage in, and its process can become a powerful agent of change, especially when used in collaboration and with dialogue among multiple stakeholders (Brown, 2009). Tom and David Kelley (2013) also cite the strong potential for design thinking and empathy, creative thinking, and iterative approaches it encourages to make the world a better place. Critical design thinking skills and processes can be difficult to teach, especially in ways that adequately reflect the interdisciplinary nature of how those skills and processes are used in real-world businesses and industry. Finding opportunities to foster these skills is important for preparing students to recognize, value, and transfer design thinking across disciplines.

In the Polytechnic Institute at Purdue University, educators have introduced a STEM Integration model for their first-year gateway course, Design Thinking in Technology. This integration effort was motivated by a perceived need to more clearly demonstrate the value of critical communication in combination with design thinking, and to teach these skills in a holistic, connected, interdisciplinary context. Much recent STEM research (Bannerot, Kastor, & Ruchhoeft, 2010; Guthrie et al., 2012; Honey, Pearson, & Schweingruber, 2014; Kellam et al., 2013; Rhee et al., 2014) indicates that course integration has the potential to improve student learning. We hypothesize that an integrated program will help students recognize the importance of design and demonstrate this learning more concretely as a result of seeing both communication and composition principles at work within the design process, and vice versa. In this integrated model, instructors from the Polytechnic Institute join with instructors from the College of Liberal Arts to teach integrated sections of their courses and create an atmosphere where empathetic audience awareness, design thinking, and communication skills are valued and taught as cohesive, interlocking, iterative practices that students will need to succeed in their future lives and careers.

This study attempts to quantitatively evaluate whether or not students in the integrated version of the Design Thinking course learned to articulate the design process more fully. Using the Engineering Design Process Portfolio Scoring Rubric (EDPPSR) to analyze students' final design journals in both integrated and non-integrated sections, we measure whether the Integrated First-Year Experience had the intended effect on students' abilities to document and demonstrate their understanding and experience of a team-based design process. In the article that follows, we first review existing literature about both design and STEM course integration, then describe our data collection and analysis. We then offer further discussion points and exploration of our results, and finally push for future research and assessment of technology students' design abilities.

Literature Review

This course integration was developed and implemented specifically to demonstrate the interconnectedness of design thinking, critical problem-solving skills, and strong communication skills in both oral and written modes. Though design thinking and many other 21st-century skills are increasingly prized by employers, they can be difficult to teach and assess. The Integrated First-Year Experience described below seeks to address this difficulty and bring additional support to the challenges of teaching and learning design.

Many course integration programs in STEM fields are generally geared toward developing and increasing 21st-century competencies, fostering readiness for the STEM workforce, and generating student interest and engagement (Honey, Pearson, & Schweingruber, 2014). Wang, Moore, Roehrig, and Park (2011) explained, “STEM integration is a curricular approach that combines the concepts of STEM in an interdisciplinary teaching approach.” A variety of integration programs have been discussed and studied in existing literature, many within STEM disciplines and some involving broader collaborations (See Bannerot, Kastor, & Ruchhoeft, 2010; Guthrie et al., 2012; Rhee et al., 2014). Explicit connections are commonly made in the contexts of engineering and technology, which are known for design activities (Grubbs & Strimel, 2016); such “technological and engineering contexts bring attention to the increasingly important role that STEM plays in our society and emphasize how STEM affects our everyday existence” (De La Paz, 2013). Often these integrations involve specialized capstone or “cornerstone” courses taught at either the beginning or end of a student’s undergraduate career. Conversely, Kellam et al. (2013) described integration among design, engineering, and social science courses threaded through four years of their engineering program, reporting that the main goal of the program, “is for students to develop a deep understanding of the larger socio-technical systems in which engineering is situated” (p. 8). They hope that “students will develop an understanding of the interrelationships between engineering, the social sciences, and the humanities” (p. 9).

The goals of our Integrated First-Year Experience are similar. In creating an integrated, interdisciplinary course for teaching design alongside both introductory composition and communication skills, we are working to jointly foster opportunities for learning and practicing innovation. The tools and skills of the design process ideally come together in this integration with the tools and skills of communicating orally and in writing, drafting, revision, following conventions, thinking rhetorically, understanding audiences, conducting and citing research, and so on. As students practice using these skills and tools in concert, instructors from all three disciplines (design thinking, English and oral communications) involved are available and prepared to encourage and advise them.

Design and design skills are inherently difficult to teach, due to the unique epistemology of design— “we come to know through active and purposeful construction of new knowledge” (Rowland, 2004, p. 43) and only a small part of design knowledge can be readily shared. Several design theories describe an epistemology which requires that knowledge is constructed by experience. Knowledge that is learned through experience and constructed through continual practice can also be described as a *tacit-knowledge* or *knowing-in-action* (Schön, 1995). As Schön (1995) described, an expert who tries to teach their craft or practice must reflect on specific situations and contexts to describe how they would approach them. It is in this highly contextualized, individual manner that design knowledge is created, through reflection on the practice and the process. Schön described this as either *reflection-in-action* or *reflection-on-action*, and such reflection is crucial to design. Reflection is also important within the relationship between problems and solutions; well-designed solutions align with the problem as stated at the beginning of the process. Here, as well, the nature of design is contextualized and difficult to isolate. The iterative process of reflecting and aligning problem and solution gives credence to the concept of problem and solution co-evolution (Rittel & Webber, 1984). Essentially, when working with a complex design problem, also called a wicked problem, the designer is looking to define the problem in a specific context. The process of defining the problem, researching, reflecting, ideating, and reflecting builds an understanding of the context in which the problem is situated.

Designers, no matter their discipline, need to reflect-in-action and reflect-on-action, define problems and solutions simultaneously, and organize their thoughts before acting. Experience in design education is intended to scaffold the adoption of such designerly ways of thinking (Cross, 1982). After helping novice designers to more fully understand the solution and the problem, reflection on the process further builds the designer's knowledge base. Then they can apply the principles learned from their experience to a new problem and context (Lawson & Dorst, 2009). Students and practitioners of design in any context should know how to organize their thoughts, document their process, and communicate both effectively. Why did they decide on this solution? Why did they brainstorm these alternatives? How did they arrive at this problem and context? Who are they communicating with and why? Designers must provide logical rationale for their decisions and evaluate themselves on the performance. In fact, using design journals to document and become conscious of the design process and answer questions about the actions of that process involves a reflective process that reciprocally reinforces learning (Lin, Hmelo, Kinzer, & Secules, 1999). The design journal assignment described and analyzed below was specifically meant to help students practice this important step of documenting design processes in preparation for communicating and justifying those process to others in a variety of contexts.

Integrated Instruction for Design Thinking

Design Thinking in Technology is a required, college-specific course for all majors in the Polytechnic Institute at Purdue University. In this course, students are expected to identify and think critically about a user's problem, choose and clearly define that design problem within the context of a global grand challenge, and research the implications of previous solutions. Students are also expected to synthesize multiple data sources to make informed design judgments. To provide evidence for their design process, students must be able to communicate in both an oral and written format.

Administrators and faculty within the Polytechnic Institute and the College of Liberal Arts developed an Integrated First-year Experience program aimed at connecting the curricula of three introductory courses: Design Thinking in Technology, Introductory Composition, and Fundamentals of Speech Communication. In the integrated versions of Design Thinking, half of the students in the course are concurrently enrolled in a Composition (English) course together, and half are enrolled in a Speech Communications course (Chesley, Mentzer, Jackson, Laux, & Renner, 2016). In this integrated version of the Design Thinking course, curricular connections to Composition and Communication courses were meant to support and foster holistic improvement in students' composition, writing, oral presentation, and critical design thinking skills. A student enrolled in this Integrated First-Year Experience during the Fall 2016 semester would share instructors from two of the three disciplines—either in Design Thinking and Composition or Design Thinking and Speech Communication. In addition, about one-half of the students in each section of Design Thinking were in the Composition course while the other half were in the Speech Communication course. Each Design Thinking course thus acts as a central point in a "trio" of integrated courses.

The partnerships among all three courses emphasize productive and symbiotic intersections between the humanities and STEM disciplines. Instructors and administrators from each subject, Technology, Communications, and Composition, collaborated to weave their curricula together and provide students with a variety of direct and indirect opportunities for making connections between Design Thinking and their humanities course. These opportunities, depending on individual instructors' implementation, included in-class activities focused on applying concepts of effective communication, assignments in one course drawing on content or topics covered in another, and shared teaching events where instructors joined each other's classrooms to discuss connections across their curricula. Table 1 outlines the substantive differences between a non-integrated and integrated Design Thinking course.

Table 1
Comparison of Non-integrated and Integrated Design Thinking Course Sections

Non-integrated ("regular") Design Thinking	Integrated Design Thinking
Students majoring in any Polytechnic major, typically first year.	Students majoring in any Polytechnic major, typically first year.
Students may or may not be enrolled in an Introductory Composition or Communication course. If enrolled, they will not be in the same section as their Design Thinking course peers.	Students also enrolled in an Introductory Composition or Communication course as a cohort.
Design Thinking, Introductory Composition, and Communication instructors are not communicating or collaborating.	Instructors collaborating with Introductory Composition and Communication instructors.
There are no structural connections between projects in Design Thinking, Introductory Composition, or Communication. No learning outcomes from Introductory Composition or Communication are emphasized in projects.	Final project coordinated with Introductory Composition and Communication to include a longer formal presentation and specific written and/or multimodal composition elements.

A primary difference for all integrated sections of Design Thinking involved a modification of the final design project to directly include and draw on skills and concepts from all three disciplines—Composition, Communication, and Design. Various pieces of the final project were ultimately presented as a culmination of students' cross-disciplinary teamwork in all three courses. Many students composed detailed research papers, posters, websites, or videos in their Composition course on the same problems and solutions they worked with in Design Thinking. All teams in the Design Thinking course also prepared an oral presentation about their innovative design projects. To accompany their more formal design work, student teams also compiled a design journal documenting their process over the final half of the semester. The pieces of this final project offer several obvious points of assessment as to the impact of the integration. For this particular study, we focus on the design journals students completed concurrently with the design work of their final projects. Additional details about the assignment and its context are included in the next section.

Our hypothesis is that instructors' pedagogical efforts to integrate Design Thinking, Composition, and Communication would lead students to create stronger, more robust, more organized design journals, with clearer, more logical answers to questions about why, how, and how well they made the choices they did during the second half of the semester. Because students in the integrated sections of this course were simultaneously learning, either in a Communication course or a Composition course, about the most effective ways to arrange and present information to an audience, we expected evidence of this learning to make a difference in the quality of the design journal assignments students submitted.

Design Thinking and Design Journals

The final design journals utilized in this study were assigned as the culmination of the students' final project in Design Thinking. This final project asked each team to select a grand global challenge, identify a localized manifestation of the problem related to the challenge, and develop a solution via research, prototyping, and testing. Articulating the logical path of one's design decisions is an important step in successfully thinking and working like a designer. The final design journal assignment required a full documentation of the final project described above. Near the beginning of the final project's eight-week duration, students were introduced to the design journal assignment and instructed to track and save all their individual and group work (most of which is also turned in at intervals throughout the project). Throughout the project, students were asked to document and communicate their process and results, using a shared storage space or shared document that would eventually become a portfolio of their collaborative design process.

In the Team Design Journal assignment prompt students received prior to the beginning of the final project, students were asked to "keep a single team journal to which all members have access (i.e., it should be kept in a collaborative workspace). This journal will be used to document all work by all members of the team, which includes work performed both collaboratively and individually." In class as well as in assignment prompts, teams were encouraged to take advantage of Google Drive, Microsoft OneDrive, or Blackboard as shared workspaces where materials can be collected from and shared with all team members. In addition to the basic assignment prompt, students were also given a copyable Google Doc template with some further instruction and placeholders for all required elements of the design journal, from the beginning (Problem Definitions & Fieldwork Planning) to the end (Final Presentation Preparation materials). Prefacing these placeholders, a brief set of instructions tells students that "All your work should be entered in the design journal here," and "The name or description of the assignment should be first on the new page and be a heading of an appropriate level (notice a few have been built as examples to modify and follow)." The template also advises students to "Begin with the format suggested here, but be creative in telling your story. The purpose is to document your journey this semester with this journal." The journal was an ongoing collaborative assignment throughout the seven or eight weeks of each team's final project, ultimately submitted during the final weeks of the course.

The design journal portion of the final project was meant to be an overarching portfolio describing the design process of each team, submitted at the end of the semester to accompany their final project and presentation (Groves, Abts & Goldberg, 2014). Students' documentation of their final project design processes forms the basis of our artifact analysis. Each student team's collaborative journey from problem to solution is what their design journal deliverable should cover. This study looks at the design journal as a unit of analysis because it is the culmination of the students' thinking and design decisions over the eight weeks of this final design project.

Research Goals & Methods

Integrating the curriculum of our Design Thinking course with that of the Communications and Composition courses is specifically meant to help develop a stronger design thinking mindset in all first-year technology majors. Making explicit connections, thinking critically about problems and solutions, and communicating effectively are common objectives among all three disciplines. In assessing the impact of this integration on student's design abilities, we ask: did students in the integrated version of Design Thinking learn to more effectively document and communicate their design process as they completed their final project?

To explore whether this integration is improving student learning of design thinking, we collected and compared final design journals from students in both integrated sections and non-integrated sections of the course. The design journals were used as the best assessment method because they are "worthwhile activities that relate to [our] instructional outcomes and allow [our] students to demonstrate what they know and can do" (Perlman, 2003, p.3). Analyzing the design journals from students' work on their final projects should provide an indication of the students' design thinking mindset after the course instruction.

The Engineering Design Process Portfolio Scoring Rubric

The Engineering Design Process Portfolio Scoring Rubric (EDPPSR) is meant to "allow student performance in the underlying knowledge and skill areas to be reliably and repeatably [*sic*] rated" (Groves, Abts, & Goldberg, 2014, p. 24). The EDPPSR was originally developed as a tool for evaluating capstone engineering design project journals in K-12 settings, and the rubric is continually being tested and validated for reliability (Groves, Abts, & Goldberg, 2014). Although the rubric is still being refined, we selected the rubric for this study because the elements aligned with the project outcomes of the assignment artifacts we collected (Coots et al., 2017). This rubric will help us quantify evidence of students' design thinking mindsets as collected in the final design journals.

The EDPPSR covers 14 elements of the engineering design process, all identified by a collaborative research team throughout a decade-long development process through their collective engineering design experience and expertise in performance-based assessment (Groves, Abts, & Goldberg, 2014). Each element within the EDPPSR is evaluated at one of six scoring levels: 0 (no evidence), 1 (novice), 2 (developing), 3 (proficient), 4 (advanced), and 5 (exemplary). For example, for Element A, "Presentation and justification of the problem," a design journal received evaluation of 5 if "The problem is clearly and objectively identified and defined with considerable depth, and it is well elaborated with specific detail; the justification of the problem highlights the concerns of many primary stakeholders and is based on comprehensive, timely, and consistently credible sources; it offers consistently objective detail from which multiple measurable design requirements can be determined."

Not all rubric elements were ultimately relevant for our application of the EDPPSR. After an initial review of the design journals, two elements in the rubric were deemed irrelevant for this particular artifact. Element E, the application of STEM principles and practices, was omitted from the evaluation because students had not been asked to evaluate their designs utilizing these principles. There was limited evidence in the final design journals that this element was a part of the course curriculum, and it was thus removed from the rubric. Element M, presentation of the project portfolio, was likewise omitted. While there was an in-class final presentation for the project, researchers were not evaluating the oral presentations but rather the written documentation. All other elements of the rubric were evaluated on a 0–5 scale as prescribed in the original rubric.

Each design journal was evaluated, and each element scored according to the EDPPSR. The EDPPSR was also used for grading and assessment in the Design Thinking course. However, researchers applied this rubric not to assess student effort for a grade, but to independently come to better understand the students' abilities to communicate their design process.

Analysis

Our research team received all Fall 2016 design journals from the individual instructors of each section of the Design Thinking course after the semester concluded. Of these, 92 design journals came with students' permission for evaluation. The full sample of 92 design journals included 44 journals from the integrated sections and 48 from non-integrated sections. We made note of the Design Thinking students' demographics at this stage to ensure a baseline similarity between both integrated and non-integrated groups: the population of students in integrated sections included 93 freshmen, 4 sophomores, and 1 junior; non-integrated sections comprised 45 freshmen, 12 sophomores, and 1 senior.

All collected artifacts were evaluated with the Engineering Design Process Portfolio Scoring Rubric, or EDPPSR (2011). To minimize researcher bias, all design journals were de-identified prior to evaluation, and researchers were blind as to which journals came from which sections. Grades for each assignment were not attached, which ensured there would be no grade-related biases in researchers' evaluations. All data identifying individuals and instructors were also removed.

Before scoring the full sample, two researchers independently evaluated approximately 22% of the journals using the EDPPSR and then analyzed their level of agreement on each element (Coots et al., 2017). Both raters had formerly taught multiple sections of the Design Thinking course, and were graduate students with interests in teaching design. This experience gave them the background needed to build appropriate expectations leading into the rating process. The inter-rater reliability of their independent scoring on this smaller sample, as determined via Cronbach's alpha values, was at least .75 for each rubric category and was .97 for the total score—an acceptable reliability coefficient (Nunnaly, 1978). After establishing an acceptable reliability coefficient, the raters split the remaining journals and each evaluated approximately one-half of them.

Once the full sample of 92 design journals had been scored, analysis was conducted on all rubric elements as well as on the overall summed scores. Based on descriptive statistics (Table 2) and visual inspection of the distributions, we considered the distribution of scores on each rubric element and the total score approximately normal. While this judgment satisfies the statistical assumptions for parametric statistics, the limited outcomes on each rubric element led us to apply non-parametric statistical tests which are more appropriate for nominal data (Aron, Aron, & Coups, 2009; MacFarland & Yates, 2016). Differences between the integrated and non-integrated course on each rubric element were tested using the Mann-Whitney U test. The total score was calculated as a sum of each element and had greater variation, while still being approximately normal. Therefore, we conducted an independent means t-test to consider a difference between the two-course types on overall design journal score. Ultimately, there was not a significant difference between integrated sections and non-integrated sections on any of the EDPPRS elements, or overall (Table 2).

Table 2
Average design journal scores for non-integrated and integrated sections, per rubric element.

EDPPRS Rubric Element	Integrated Section M (SD)	Non-Integrated Section M (SD)	*p* value
Element A: Presentation and justification of the problem	3.16 (0.64)	3.33 (0.66)	.38
Element B: Documentation and analysis of prior solution attempts	3.61 (0.58)	3.60 (0.74)	.79
Element C: Presentation and justification of solution design requirements	2.25 (1.10)	2.56 (1.09)	.13
Element D: Design concept generation, analysis, and selection	2.91 (1.27)	3.15 (1.15)	.33
Element F: Consideration of design viability	2.59 (1.04)	2.62 (1.06)	.76
Element G: Construction of testable prototype	3.07 (1.07)	3.25 (1.19)	.25
Element H: Prototype testing and data collection plan	2.55 (1.02)	2.75 (1.06)	.24
Element I: Testing, data collection and analysis	1.68 (1.16)	1.67 (1.04)	.91
Element J: Documentation of external evaluation	1.91 (1.48)	2.50 (1.09)	.05
Element K: Reflection on the design project	1.11 (1.30)	1.60 (1.41)	.07
Element L: Presentation of designer's recommendations	1.73 (1.26)	2.10 (1.29)	.14
Element N: Writing like an Engineer	2.86 (0.55)	3.00 (0.58)	.26
Total Score	29.43 (6.94)	32.15 (7.49)	.07

Discussion

From this research, it appears students enrolled in Design Thinking in Technology in the fall of 2016, overall, have a similar understanding of the design process regardless of their section's use of integration. The area where students' design journals performed most highly across both groups was in the documentation and analysis of prior solutions (Element B). This section of the design journal assignment required students to include work from previous assignments meant to scaffold their final project design work. The high scores on this element may be due to that particular assignment's highly structured nature. Instructors provided students with a template to structure their investigation of previous solutions, along with significant time in class to discuss strategies for searching existing literature and evaluating sources. Further, we engaged students in comparing previous solutions and ranking them.

In general, students' design journals scored the lowest on Element K (Reflection on the design project), with students in integrated sections scoring slightly lower than those in non-integrated sections. It could be that the persistent engagement with the project hindered students' abilities to slow down and reflect on their purpose and process. It is also possible that students in the integrated sections were implicitly expected to record reflections in other places, perhaps in their Composition or Communications course.

The artifact of analysis, the final design journals, was intended as an assessment of students' overall understanding of the design process. As such, students' writing and communication skills were not necessarily emphasized in connection with this assignment, which could explain the non-significant results between integrated and non-integrated sections. During our study, researchers noticed that many design journals were incomplete, disorganized, and to some degree incoherent documents. It was somewhat surprising that these college students, at the end of a full semester of instruction focused on design, generally scored so low on a design rubric initially intended for use in high school contexts. The highest average score on each element of the rubric was 3.61, and the lowest was 1.11 on a scale of 0 to 5 points total (the average total score was equivalent to only 30.85 out of 60, 51.41%). Recognizing these low scores as a potential sign of a more complex problem, researchers were prompted to review the sample of design journals again, this time to ask specifically what percentage of journals were as complete as expected.

A third researcher, also a previous Design Thinking instructor, analyzed a random sample of 10 design journals (five from integrated sections and five from non-integrated sections, approximately 10% of the total sample), marking against a list of the required elements whether each was at least present (regardless of quality, completeness, or placement of the entry itself). Disaggregation of the EDPPSR shows 25 separate entries expected. For each journal reviewed, a count was made indicating if each item was there or not, and the completion percentage calculated (the number of entries divided by the number expected). This follow-up research revealed that student design journals were consistently incomplete. Average completeness for this sample was only 59%. This average held true for both non-integrated and integrated sections.

From this follow-up investigation, we also learned that many teams arranged their design journals out of the expected chronological order. Rather than following the indicated template and building their design journals as a group as they worked through the project over eight full weeks, it appeared as though students assembled their team journals after the fact, filling in the blanks they could without concern for following chronological order. Rather than collaborating and sharing their individual projects during the term, students seem to have more often copied and contributed their portions of the design work individually at the end of the term. None of the design journals analyzed for completeness contained every assigned element.

Students may not have prioritized this design journal assignment for many reasons. The assignment itself may have been difficult for some to understand fully, or the assignment may have seemed minor in comparison with the larger final design project and presentation. It is also possible that aspects of the EDPPSR are not congruent with the assessment from the course. However, we did not use elements imperceptible in the design journals, and we believe the rubric elements do demonstrate good practices for documentation regardless of external assessment. Whatever the case may have been for students in these sections of Design Thinking, the assignments collected for this study do not reflect well-documented or satisfactorily complete design journals.

Conclusions and Directions for Future Research

Our initial research question involved asking whether or not students in the integrated version of a Design Thinking course learned to more effectively document and communicate their design process. Answering this question would determine whether or not the integrated course helped teach design thinking more effectively. The study described above shows that the integration appears to have made little difference to students' abilities to document their design process.

However, our project has also brought up serious concerns about the validity of using this set of largely incomplete design journals to measure students' abilities to document their design skills and demonstrate clear organized design thinking. That there were no differences for students in the integrated sections, and that the proportion of incomplete design journals was even across both section types do suggest that there is important work to be done in developing design documentation pedagogy. Incomplete entries in student design journals are missing data in much the same way that omitted survey questions might be problematic. As Tabachnick and Fidell (2007) noted with regard to missing data, "its seriousness depends on the pattern of missing data, how much is missing, and why it is missing" (p. 62). Therefore, our follow-up as researchers and teachers of Design Thinking in Technology should be to more fully understand what student and/or teacher characteristics might predict these shortcomings in design documentation. In so doing we may identify aspects of the course or instruction that need to be improved broadly. On the other hand, we may identify exemplary strategies for design reflection, documentation, and communication.

As part of our continued efforts to develop the Integrated First-Year Experience, we are considering potentially worthwhile changes in how the design journal assignment is implemented and taught. We may also expand our study to include Design Thinking instructors' experience with and perspectives on the design journal assignment. Instructors with experience teaching and grading this assignment may have suggestions for better ways of encouraging students to complete the design journals thoroughly. It may help some students if the Design Thinking course fully standardized all requirements of the design journals, in order to make the end product easier to envision. While such a fixed structure may take away from the "design" or creative element that students are asked to engage with, offering footholds and scaffolding for these first-year students will hopefully guide students as they develop a stronger design thinking mindset.

We plan to replicate this study in coming semesters, drawing on a larger sample of potentially more complete artifacts. An analysis using artifacts collected from integrated and non-integrated Fall 2017 sections of Design Thinking is currently underway. This research and the teaching practices of Purdue's Polytechnic Institute, as well as those of other programs teaching principles of design in user-centered, project-based technology courses, would benefit greatly from further discussion on this important topic.

References

Aron, A., Aron, E., & Coups, E.J. (2009). *Statistics for psychology* (5th ed.). Upper Saddle River, NJ: Pearson Prentice Hall.

Bannerot, R., Kastor, R., & Ruchhoeft, P. (2010). Multidisciplinary capstone design at the University of Houston. *Advances in Engineering Education* 2(1), 1–33.

Brown, Tim. (2009). *Change by design: How design thinking transforms organizations and inspires innovation*. New York: Harper Collins

Casner-Lotto, J. & Barrington, L. (2006). *Are they really ready to work? Employers' perspectives on the basic knowledge and applied skills of new entrants to the 21st Century U.S. workforce*. Workforce Readiness Consortium. Retrieved from www.p21.org/storage/documents/FINAL_REPORT_PDF09-29-06.pdf

Chesley, A., Mentzer, N., Jackson, A., Laux, D., & Renner, M. (2016, June). Integrating technology, English, and communication courses for first-year technology students. 2016 ASEE Annual Conference & Exposition, New Orleans, LA. Retrieved from https://peer.asee.org/25414

Coots, M. Knapp, S., Chesley, A., Mentzer, N., & Laux, D. (2017). An evaluation of STEM integration effectiveness by artifact analysis. 2017 ASEE Annual Conference & Exposition, Columbus, OH.

Cronbach, J.L. (1995). Coefficient alpha and the internal structure of tests. *Psychometrika* 16, 297–334.

Cross, N. (1982). Designerly ways of knowing. *Design Studies, 3*(4), 221-227. doi: 10.1016/0142-694X(82)90040-0

De La Paz, K. (2013). Technology and engineering bring STEM to life. *Technology and Engineering Teacher*, 8-9.

Engineering Design Process Portfolio Scoring Rubric (2011, August). Retrieved from: http://teams.mspnet.org/media/data/EDPPSR.pdf?media_000000008449.pdf

Groves, J. F., Abts, L. R., & Goldberg, G. L. (2014). Using an engineering design process portfolio scoring tubric to structure online high school engineering education. 2014 ASEE Annual Conference & Exposition, Indianapolis: IN. American Society of Engineering Education. Retrieved from https://peer.asee.org/23254

Grubbs, M., and Strimel, G. (2016). Engineering design: The great integrator. *Journal of STEM Teacher Education*, *50*(1), 77-90. Retrieved from http://ir.library.illinoisstate.edu/jste/vol50/iss1/8

Guthrie, J. B., & Estes, A. C., & Nelson, J., & Nuttall, B. (2012, June), Interdisciplinary capstone design: Architects, structural engineers, and construction managers. Paper presented at 2012 ASEE Annual Conference & Exposition, San Antonio, Texas. Retrieved from https://peer.asee.org/20764

Hill, R. (1998). What sample size is “enough” in Internet survey research? *Interpersonal Computing and Technology: An Electronic Journal for the 21st Century*, 6, 3–4.

Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, D.C.: The National Academies Press.

Isaac, S., & Michael, W. B. (1995). *Handbook in research and evaluation*. San Diego, CA: Educational and Industrial Testing Services.

Kellam, N., Walther, J., Costantino, T., Dodd L., & Cramond, B. (2013). Integrating the engineering curriculum through the synthesis and design studio. *Advances in Engineering Education* Winter 2013, 1–33.

Kelley, T & Kelley, D. (2013). *Creative confidence: Unleashing the creative potential within us all*. New York: Crown Business.

Lawson, B., and Dorst, K. (2009). *Design expertise*. Abingdon, Oxon: Architectural Press.

Lin, X., Hmelo, C., Kinzer, C.K., & Secules, T.J. (1999). Designing technology to support reflection. *Educational Technology Research and Development*, *47*(3), 43-62. doi: 10.1007/BF02299633

MacFarland, T. W., & Yates, J. M. (2016). Introduction to nonparametric statistics for the biological sciences using R. Springer. doi: 10.1007/978-3-319-30634-6

Nunnaly, J. (1978) *Psychometric theory*. New York: McGraw-Hill.

Reeve, E. M. (2014). STEM thinking! (Cover story). *Technology & Engineering Teacher*, *74*(4), 8–16.

Rhee, J., Oyamot, C., Parent, D., Speer, L., Basu, A., & Gerston, L. (2014). A case study of a co-instructed multidisciplinary senior capstone project in sustainability. *Advances in Engineering Education* Summer 2014, 1–29.

Perlman, C. C. (2003). Performance assessment: Designing appropriate performance tasks and scoring rubrics. In Janet E. Wall & Garry R. Walz (Eds.), *Measuring up: Assessment issues for teachers, counselors, and administrators*. Greensboro, NC: ERIC Counseling and Student Services Clearinghouse.

Rittel, H. W. J & Webber, M. M. (1984). Planning problems are wicked problems. In Nigel Cross (Ed), *Developments in design methodology*. Wiley. 135–144.

Schön, D. (1995). Knowing-in-action: The new scholarship requires a new epistemology. *Change: The Magazine of Higher Learning*, *27(*6), 27–34.

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

Wang, H., Moore, T., Roehrig, G. H., & Park, Mi Sun. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research*, *1*(2). Retrieved from http://dx.doi.org/10.5703/1288284314636

About the Authors

Amelia Chesley (chesleya@nsula.edu) is an assistant professor of English and Technical Writing at Northwestern State University of Louisiana.

Michael W. Coots (coots@purdue.edu) is a graduate student in Engineering/Technology Teacher Education at Purdue University.

Andrew Jackson (andrew.m.jackson@yale.edu) is a postdoctoral research associate in Mechanical Engineering at Yale University.

Sarah Knapp (knapps@purdue.edu) is a PhD Candidate in the Polytechnic Institute at Purdue University.

Nathan Mentzer (nmentzer@purdue.edu) is an associate professor of Engineering and Technology Education at Purdue University.

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

Book Review

STEM Leadership: How do I Create a STEM Culture in my School

Buckner, T., & Boyd, B. (2015). *STEM leadership: How do I create a STEM culture in my school?* Alexandria, VA: ASCD. ISBN: 978-1-4166-2092-1 $12.99. 46 pages.

As our world becomes a global society, educators must ensure students have the skills to succeed. Many of the skills students need to succeed focus on the science, technology, engineering, and mathematics (STEM) fields. Every school year brings new changes from staff to curriculum, and it can be hard as an administrator to decide what to prioritize or and specifically focus on for the school year. Buckner and Boyd's expertise in STEM education, along with their drive to provide educators a way of learning best practices in STEM, led to their creation of the book *STEM Leadership: How do I Create a STEM Culture in my School?* Buckner and Boyd do an outstanding job at describing how middle and high school administrators or school leaders can create a STEM culture in their building, and why it is important to do so.

A Brief Synopsis

Buckner and Boyd begin by focusing on what STEM education looks like, including how it entails meaningful learning experiences, real-world connections, and is available to all students. The authors emphasize throughout the book that STEM skills need to be taught to students beginning in kindergarten and continue through twelfth grade to ensure students have the opportunity to become STEM-literate. One of the key aspects of STEM education is that lessons should be rich and rigorous experiences for students. However, even if educators know the importance of STEM education, they often have reservations about implementing STEM-created lessons because of the extended amount of time it takes to plan and teach them.

Buckner and Boyd move on to discuss how further professional development is needed for in-service teachers to develop 21st Century learning skills and to build the STEM culture within their school. Educators will need to work together to establish and maintain a STEM culture; it cannot be accomplished or sustained by a sole individual. The authors recommend administrators or school leaders set aside time to meet and collaborate with each educator on staff per semester to begin creating a culture of collaboration, open dialogue, and trust. Buckner and Boyd also recommend creating a team of individuals who are on board with the implementation of STEM education to set the stage for STEM culture and what it will mean for school as a whole. It is important for administrators and school leaders to remember that not only is educator buy-in crucial, but so is educator respect. By educators working together to create a STEM culture at the school, they can begin to create curriculum, bring in outside connections, and ultimately enhance student learning with high-quality STEM instruction.

Critical Analysis

Overall, Buckner and Boyd do a terrific job at presenting ideas logically for easy implementation; they also provide a self-check rubric to help leaders evaluate how well they are creating a STEM culture through rich and rigorous learning experiences. Another helpful addition in the book is "10 Key Questions to Assess Your Learners' 21st Century Skills"; these questions allow administrators and staff to analyze the implementation of professional development techniques and critique what is working and what is not.

There were two areas of the text, in my opinion, that could have been expanded. First, the authors could have expanded on—especially with mentioning the need for STEM education throughout all grades—how to create a STEM culture at the elementary level. The ideas throughout the book are specifically written for middle and high schools, and thus exclude almost half of a student's education. If there is such a push for STEM education to be included in all grades, why would the authors exclude how to implement a STEM culture at the elementary level? Another area in which the authors could have expanded on is how educators individually can create a STEM culture within their classroom. The book is geared toward administrators or school leaders and how they can establish a STEM culture, but it does not detail how educators can begin the process themselves. There are situations when an administrator may not be on board with implementing STEM or even the possibility of working in a small school where such an undertaking is not feasible.

Conclusion

This fifty-two-page book is a quick, easy to read, and provides needed information for middle and high school administrators or school leaders who want to focus on creating a STEM culture in their school. A STEM culture consists of having a safe an open dialogue between all parties involved to share ideas, expand learning, and to create new opportunities for students. It is also necessary that all individuals involved, whether it is staff members, outside professionals, or students, understand the goals and expectations of the STEM culture being created. The creation of a STEM culture will not happen overnight, nor will it be an easy task. Administrators and school leaders are going to have to work alongside educators guiding and supporting them in what will be a challenging and time-consuming process.

Carlotta Vaughn (carlottavaughn@u.boisestate.edu) is an Elementary Teacher at Stephensen Elementary School in the Mountain Home School District #193 in Mountain Home, Idaho, and a Doctoral Student at Boise State University in the Educational Technology Department.

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.

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.