Contents

The Demise of Traditional Technology and Engineering Education Teacher Preparation Programs and a New Direction for the Profession

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Abstract

For nearly 40 years, there has been a serious decline in the number of new technology and engineering education teachers and teacher preparation programs in the United States (Akmal, Oaks, & Barker, 2002; Daugherty & Boser, 1993; Edmunds, 1980; Greene, 2016; Moye, 2009; Volk, 1993). Currently, only 15% of the technology and engineering education degree-granting university programs remain since 1970, with nearly half of those remaining barely surviving with three or fewer students graduating annually (Rogers, 2017; Wall, 1970). Perhaps most telling about the health of technology and engineering education is the following question: With nearly half the states no longer having a technology and engineering education teacher preparation program, how can it continue to be considered a "legitimate" subject to be taught in schools?

Declines in the number of technology and engineering education teachers and teacher preparation programs since the 1970s show no signs of abating. There are several reasons for this continued decline. First, the transformation of technology and engineering education programs to industrial technology and engineering eliminated the need to accommodate the preparation of teachers or continue their past mission. Second, those few technology and engineering education programs that still exist may not reflect the reality of many school programs, creating a mismatch between content and expectations when recruiting new student teachers. Finally, with justifications for technology and engineering education and its inclusion in the broader science, technology, engineering, and mathematics (STEM) umbrella being based on economic justifications and national standards, there has been an increase in corporate-driven and foundation-sanctioned technology and engineering education programs. Of particular focus is Project Lead the Way (PLTW), who's training for their program (product) reduces the need for traditional technology and engineering education teacher preparation programs.

This article first examines recent trends in technology and engineering education teacher preparation programs in the United States, including the number of graduates and university programs available. Following a discussion of the aforementioned impacts on technology and engineering education teacher programs, a summation is provided, contending that the few traditional teacher preparation programs that remain are in jeopardy and that new teachers in technology and engineering education will likely come through alternative means such as PLTW.

Keywords: Alternative certification; teacher preparation; technology and engineering education; university programs.

Trends in Traditional Technology and Engineering Education Teacher Preparation Programs

To examine trends in preparing technology and engineering education teachers, data from past studies (Volk, 1993, 1997, 2003) were updated with program information contained in the *Technology and Engineering Teacher Education Directory* (Rogers, 2010, 2015, 2017; Schmidt & Custer, 2005). From 1970, Directories were used at 5-year intervals to report the number of technology and engineering bachelor's degrees awarded for each university listed, with the 2017 Directory included to provide the most recent data. Although there have been reservations as to the comprehensiveness and therefore accuracy of the data contained in the Directories (Litowitz, 2014), they continue to be a common resource for studies that rely on university teacher preparation program data (Harris, 2008; Litowitz, 2014; Moye, 2017; Oaks & Leopp, 1989).

To address Litowitz's concerns and to help validate numbers recorded in the most recent Directory (Rogers, 2017), email letters were sent to 21 faculty members listed in the 2017 Directory. Faculty were identified to be contacted if their programs were missing from the most recent Directory but listed in the 2005 or 2010 Directories. Universities that reported combined degrees such as technology education and agriculture and universities that had wide variations between current seniors and graduate numbers were also contacted to obtain more accurate data. Of particular interest were the large population states of Florida, Texas, and California that had either no program or one program reported.

From the Directory numbers and confirmations through correspondence, it was determined that in 2017, 158 students graduated with undergraduate degrees to teach technology and engineering education. California does not produce teachers with undergraduate degrees, so the number of teachers certified through a university program was obtained through their Educator Preparation Committee (2017) that reports newly certified teachers. The Committee reported six student teachers from all universities in the state. Using Directory numbers and the aforementioned verifying sources, the best estimate for new technology and engineering education teachers being produced through traditional university teacher preparation programs in 2017 was 164.

Concerns raised by Dugger (2007) and Moye (2017) in their research to determine the status, supply, and demand of technology and engineering education teachers indicated that university contacts were not easily identifiable or that feedback was not universally obtained. However, in this study, the majority of faculty members contacted were quick to reply, their responses were detailed, and, in many ways, they were very personal in describing the situation at their respective universities.

As shown in Figure 1, the downward trend that has been occurring since the mid-1970s is continuing. In fact, the current number of technology and engineering education teachers graduating from universities can best be described as paltry. Using Ernst and William's (2015) robust estimation of 46,730 technology and engineering education teachers nationwide and the National Center for Education Statistics' (2018) data suggesting that approximately 7% of the total teachers leave each year (with 2.2% of the total retiring), over 3,000 new technology and engineering education teachers would be required to meet this demand. Even using Dugger's (2007) more conservative estimate of 25,000 to 35,000 technology and engineering education teachers, over 1,700 teachers would be needed to replace those leaving each year. Clearly, 164 new teachers are not enough to replace the number of teachers retiring or just leaving teaching. Alternative certification routes that use other subject-matter teachers or those having a relevant bachelor-level degree to teach technology and engineering education in schools are certainly options that might help meet new teacher demand. Alternative certification will be discussed later.

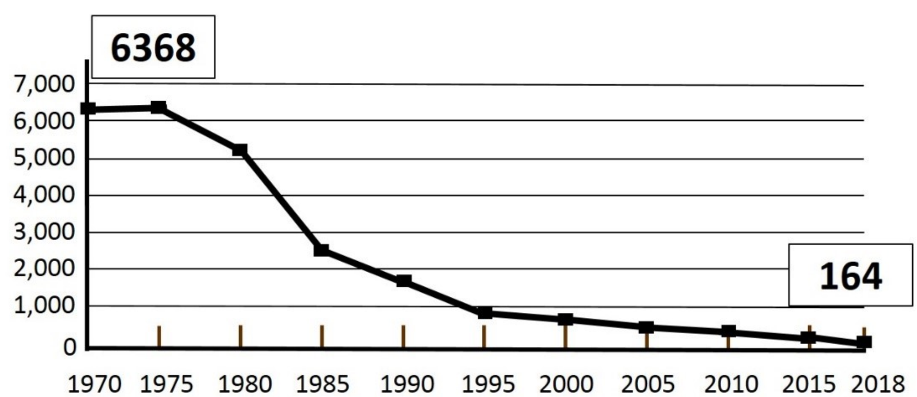

Figure 1. The number of bachelor's degree graduates in technology and engineering education.

The number of universities with programs in technology and engineering teacher education (or similar) was also examined. As shown in Figure 2, the number of programs remaining is very small, with many states having no program at all. This is particularity concerning in large population states like Florida for those seeking a technology and engineering education teaching degree. Florida A&M was the last university left in the state that prepared technology and engineering education teachers and was not able to use this fact as justification to keep the program open (D. White, personal communication, November 23, 2017). Of the 32 universities found to still have programs, nearly half (14) reported three or fewer graduates, hardly a sign of strength or permanence. Correspondence received from colleagues at universities with programs now closed suggested that alternate certifications were not satisfying schools' needs or may not be producing the quality of teachers expected. Several colleagues also lamented "the good old days" and suggested that program changes that moved the focus onto engineering and away from teaching were not appealing to or attracting new technology and engineering education students.

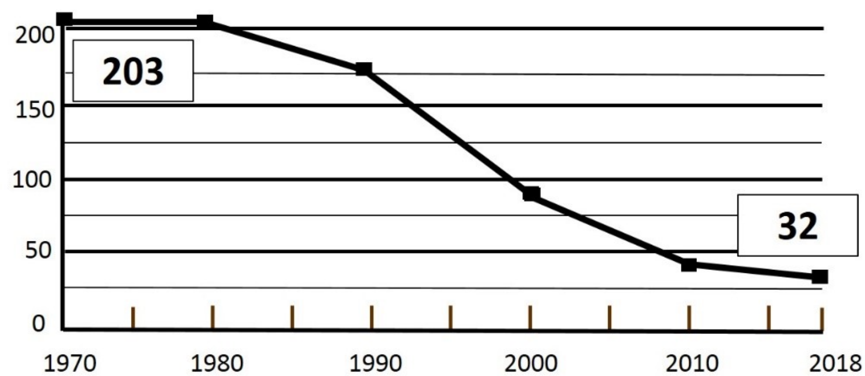

Figure 2. The number of universities preparing technology and engineering education teachers (BA/BS).

Once programs are gone, they do not come back. An admirable attempt was made in 2004 at St. Petersburg College in Florida to start a new program; however, it soon closed in 2012 due to low enrollment (St. Petersburg, 2018). Although not completely dead, with less than 200 new teachers graduating annually from university technology and engineering education programs, combined with the small number of viable university programs remaining, technology and engineering education teacher preparation programs could be considered on life support.

Focus on Engineering, Not Teacher Preparation

The vast majority of the over 200 teacher preparation programs identified in the 1970 Directory are now exclusively engineering or industrial technology programs. From the 32 remaining universities identified with technology and engineering education programs, their programs are housed in a college of professional studies (41%) or in a college of engineering/technology (59%). Only a few of the technology and engineering education programs offered through a college of professional studies, such as the State University of New York College at Oswego, provide both professional studies and technical courses. Now, most programs only provide the professional studies component.

Having the technical courses provided by a college or department outside the actual professional studies program's home may impact program emphases, faculty allegiances, and faculty's professional contributions. In Brown's (2017) study of the number of general education and technical courses students in technology and engineering education teacher preparation programs take, he found no significant differences between programs housed in education departments and programs in noneducation departments. He attributed this to state licensing standards and controls setting the number of general education courses required. However, one caveat of Brown's findings was the possibility of challenges or impacts on other aspects of the program or faculty housed in noneducation departments, such as resource allocation, faculty expertise, and morale.

For teacher preparation programs that are now a minor component in a college or department of engineering, these challenges have been acknowledged. Batey's (2018) description of Texas State University's Department of Engineering Technology transformation from an industrial arts program illustrates this predicament. Originally an Industrial Arts Department located in a teachers' college that prepared industrial arts teachers and provided some pre-engineering courses, in 1985, the department was renamed the Department of Technology and moved from the School of Education to the School of Applied Arts and Technology. With this move and change in name, the new focus was on preparing professional managers for industry rather than focusing on teacher education. More simply put, courses like woods, metals, drafting, and electronics don't fit well with the university's Research I model (A. Batey, personal communication December 6, 2018).

The increased focus on engineering and not teacher education in universities also impacted professional dialog. For example, in 1973, the National Association of Industrial Technology Teacher Education (NAITTE) had over 700 members, but by 2004, it had declined to 182 (Gagel, 2006). With declining membership, NAITTE broadened its scope in 2010 and changed its name to the Association of STEM Teacher Education (ASTE). Their journal, first published in 1963, also changed from the *Journal of Industrial Teacher Education (JITE)* to the *Journal of STEM Teacher Education*. Unfortunately, the effort to maintain contributions only lasted 2 years, and their budget balance was transferred to the Association for Career and Technical Education's eTED division for scholarships (G. Rogers, personal communication, July 15, 2018). Their sponsorship of the *Industrial Teacher Education Directory* also ended, leaving that responsibility to rest solely upon the International Technology and Engineering Educators Association's (ITEEA) affiliate Council on Technology Teacher Education (CTTE).

The *Journal of Industrial Teacher Education* was not alone in changing its scope because the audience had changed since its original mission. Since 1974, the *Journal of Epsilon Pi Tau* bore the name of the parent honorary organization but changed its name to *The Journal of Technology Studies* in 1993. Although the Board debated this change for 10 years (Streichler, 1993), they finally agreed that it was needed to reflect an audience wider than the field of education and that the new title "would not put off potential contributors" (p. 2). Today, the majority of the articles in *The Journal of Technology Studies* still focus on education, but some are now strictly technical.

Teacher Preparation Programs Not Matching the Reality of Schools

With most technology and engineering education teaching programs now transitioned to engineering and traditional school technology and engineering education courses such as woodworking and metalworking not seen as relevant, appropriate, or reflecting modern technology (International Technology Education Association [ITEA], 2007), there may be a mismatch between the type of technology and engineering education teacher being produced and what's actually still being taught in schools. It is also possible that prospective student teachers are not attracted to the new technology and engineering education teacher preparation programs. Simply put, students who went through more traditional school programs that are still very prevalent (Kelley & Wicklein, 2009; Rigler, 2017; Sanders, 2001) may be more attuned to be industrial arts teachers. For many years, it has been recognized that teachers, enjoying the course, and hobbies are the strongest influences for students to enroll in a technology and engineering education teacher preparation program (Beauter, 1984; Donnell, 1975; Freeland, 2013; Harris, 2008; Weber, 2011; Wright & Custer, 1998). There is anecdotal and empirical evidence that this is true today.

Welty (2016) described the mismatch in what prospective technology and engineering education teachers studied in his university's program and what he observed during their student-teacher supervision. Despite preparing technology and engineering education teachers with specific subject-matter skills and philosophy, he noted, "I spent last Tuesday observing metalworking classes. Tomorrow I will be observing woodworking and metalworking. This Tuesday, I will spend the morning in a welding lab." In this way, Welty suggested this was a good way to figure out "who we [really] are today." What was observed in

Wisconsin is not an isolated case. School fairs in California, Iowa, Kansas, Minnesota, Montana, Texas, and other states still proudly showcase students' projects in metalwork and woodworking.

In presenting best practices to recruit technology and engineering education teachers, Love, Love, and Love (2016) profiled Pennridge High School in Pennsylvania and Allen Androkites' success in having 28 of his former students become teachers during his 35 years of teaching. Androkites' program was recognized as an ITEEA Program of Excellence in 2018; however, when his program is examined, it would be considered traditional industrial arts and not technology and engineering education. The Pennridge High School program has four levels of woodworking, two classes in metals, five in drafting, one in robotics, and a noted class in guitar building (Pennridge, 2017). Although many students must have enjoyed their courses and teachers in the Pennridge High School program, like in countless other schools throughout the United States influencing them to become a teacher, some would probably be surprised and disappointed to not find the industrial arts courses that they are familiar with in any university's technology and engineering education teacher preparation or engineering program. A mismatch between what is actually occurring in schools (Rigler, 2016, 2017) and what professional associations such as ITEEA and universities profess should be occurring may be discouraging to those entering the teaching profession.

Alternative Certification Meeting Shortages?

Alternative certification paths for new technology and engineering education teachers have been recognized as a way to alleviate teacher shortages, with teachers licensed through means other than through a traditional university-based teacher preparation program (Hoepfl, 2001). In a nationwide comprehensive review of teachers using the *Schools and Staffing Survey* (SASS) administered by the U.S. Department of Education, Ernst and Williams (2015) found that technology and engineering education teachers are more likely to receive certification through an alternative certification program than other teachers (21.6% vs. 14.5%).

Every state now views alternative certification as a valuable and necessary means to address teacher shortages (National Education Association, 2016). For example, Texas has seen the number of alternatively certified career and technical education teachers double since 2008 to over 1,200 in 2017 (Texas Education Reports, 2018). Prospective technology and engineering education teachers in Texas can choose from 45 Education Preparation Providers to obtain their teaching credentials (Texas Education Agency, 2019). Providers include local school districts, universities, and organizations such as A+Texas, iteachTEXAS, Teacher Builder, and Teachers for the 21st Century. It must be noted that the universities listed by the Texas Education Agency now have defunct technology and engineering education teacher preparation programs and thus use their School of Education courses.

Although some alternative certification programs may dovetail into existing university teacher preparation programs, as is the case in Texas, providers such as community colleges, for-profit corporations, or even local school districts can supply the required professional content without any university connection. Simply put, alternative certification programs will do little to preserve traditional technology and engineering education teacher preparation programs.

Several studies pointed to differences between the preparation of the two groups of teachers. For example, traditionally certified teachers were perceived by principals to be better prepared and effective (Bartholomew, Bullock, & Nadelson, 2018). A concern raised by Strimel and Grubbs (2016) was that technology and engineering education teachers coming through nontraditional certification programs did not fully understand technology and engineering education. This could have implications as to alternatively certified teachers' understanding of the history, philosophy, rationale, challenges, and situational contexts of technology and engineering education. Finally, although alternative programs may be addressing teacher shortages, those prepared through such routes leave the profession at higher rates than those completing a traditional program (Harris, Camp, & Adkison, 2003). This may be leaving schools facing the recurring problem of frequently having to recruit teachers, and if recruitment is low, their technology and engineering education programs may just close.

Teachers Certified for Corporate Curriculum

Corporate involvement in technology and engineering education curriculum and teacher preparation is not new. As early as the mid-1960s, the Industrial Arts Curriculum Project enlisted the help of industry to develop a structure and accompanying teaching activities, guides, and manuals (Andrews, 1984). A few years later, the *World of Construction* (Industrial Arts Curriculum Project [IACP], 1970) and the *World of Manufacturing* (IACP, 1971) instructional materials were produced through this project. In-service workshops for teachers wanting to transition their traditional junior high school program were also made available but were not required to teach the program.

Gaining popularity in the 1980s was the so-called "modular approach" that utilized vendor-produced equipment for students to then rotate through prescribed activities. As noted by Petrina (1993), such programs represent "a divestiture of control and authority from a domain of technology teacher education, and a conceding of that authority to product companies and their operational context of corporate economics and politics" (p. 75). Companies providing modular equipment like Graves-Humphreys, Synergistic, Marcraft, and Hearlihy would supply teachers with amenities that included instructor's notes, daily activities, tests, and even information on how to acquire funding to purchase their equipment. Although training on how to use the modules would have been offered to teachers at gatherings such as the International Technology Education Association's (ITEA) annual conference, it was not required by vendors as a prerequisite to use their product.

Herschbach's (2009) contention that the philosophical shift from industrial arts to technology in the 1980s was largely based on political agendas and economic competition facing the United States is even more prevalent today with the justification and call for technology and engineering education in STEM education. ITEEA's renamed *Technology and Engineering Teacher* (TET) journal regularly features articles that justify technology and engineering education on economic competitiveness grounds (Bybee, 2010; Christman, 2012; Flanigan, Becker, & Stewardson, 2012; Hughes, 2010; Roberts, 2013; Strimel, Grubbs, & Wells, 2017).

ITEEA's *Engineering byDesign*™ curriculum is based on national standards but also acknowledges its contribution to U.S. economic competitiveness, with the program helping students to "understand why technology and its use is such an important force in our economy" (ITEA, 2006, p. 3). Although each school grade is structured on thematic units, teachers are not required to use a standard activity, instructional approach, tools, or materials. Professional training and certification are not specifically required to teach *Engineering byDesign*™, but ITEEA's STEM Center for Teaching and Learning offers teachers opportunities for sharing strategies with collaborative online communities and fee-paying summer institutes. These institutes may be using faculty from technology and engineering education teacher training institutes, but more often, they are just experienced teachers.

A more serious threat to the continued existence of the small number of technology and engineering education teacher training institutes remaining is Project Lead the Way (PLTW). Started in 1997 by a few schoolteachers in upstate New York, PLTW has grown into a large nonprofit organization that provides curriculum and instructional materials to over 11,000 schools to teach technology and engineering education within the larger realm of STEM. "As a 501(c)(3) charitable organization, PLTW exists to prepare students for the global economy" (Bertram, 2013, p. 1). Positioned as a way to teach engineering in schools, PLTW promotes and advertises commissioned research to validate claims of success (Tai, 2012), utilizes public relations firms costing over one million dollars a year to promote (sell) their product (GuideStar, 2016, Part VII, Section B), and partners with Fortune 500 corporations, local businesses, and foundations such as the Kern Family Foundation (Project Lead the Way [PLTW], 2019a). With the CEO's total compensation of nearly $750,000 a year and salaries of over $200,000 a year for all eight officers (GuideStar, 2016, Part VII, Section A), PLTW has quickly grown to an educational behemoth that is usurping the need for traditional technology and engineering education teacher training institutes. Professional organizations that represent technology and engineering education, such as ITEEA, are at a disadvantage and certainly do not have the same size, clout, or compensation package.

With the growth and reach of PLTW, it is becoming difficult for traditional programs to compete or even remain relevant. For example, in order to be certified to teach PLTW, teachers are required to attend a prescribed PLTW training program. Most of the sites used are not associated with technology and engineering education teacher training institutes but rather engineering schools with engineering faculty contracted by PLTW to conduct workshops. With costs ranging from $500 for a 1-day workshop to $2,400 for 2 weeks, PLTW has a captive audience of teachers certified in any subject area being able to teach their program. To date, over 55,000 teachers have gone through one of their programs specifically designed for each of their specialized programs (PLTW, 2019b). Similar to companies such as McDonald's, Walmart, or Starbucks whose customers recognize and expect a standard product no matter the location, PLTW's customers expect their product to be the same; however, their customers are teachers, administrators, students, and the public.

Encouraging schools to adopt the program, PLTW generously provides grants for teacher training or for the purchasing of equipment needed to teach the program. Many corporations such as Intel, Lockheed Martin, and Chevron have also provided resources to establish PLTW in schools. In 2016, PLTW provided over $8,000,000 in grants to "domestic organizations and domestic governments" (GuideStar, 2016, Part I, Line 13), but for their business model, received over $43,000,000 in revenue (GuideStar, 2016, Part I, Line 12), through equipment purchases, training, and annual participation fees that schools must pay. If a PLTW-trained teacher leaves the school district, they will provide a grant to the school in order to train another teacher, thus keeping the program and annual fees going. With PLTW using a seamless approach of providing the instructional material, teacher training, and complete equipment packages for schools to purchase, traditionally prepared technology and engineering education teachers (and their programs) have become less significant and perhaps even less marketable. Online employment search sites such as Indeed.com and Monster.com regularly advertise for PLTW-trained teachers not technology and engineering educators.

Despite creating an educational product that requires training for any certified subject-matter teacher to use their product, PLTW's CEO publically questioned the value and necessity of traditional teacher preparation programs (Bertram, 2015). Bertram states that schools have made great strides providing quality STEM education, but "outdated teacher qualification standards in many states make it difficult to find teachers who are trained and experienced in these subjects" (para. 1). He goes on to say that state leaders and legislators should address restrictive policy barriers:

> One of these barriers exists in the form of state teacher certification requirements that often prohibit experienced STEM professionals from teaching high school or middle school courses in their areas of expertise without having to take additional, often unrelated, coursework. (para. 8)

As "a national nonprofit organization dedicated to STEM curriculum and teacher training" (para. 10), having a wider pool of potential customers for their product would be welcome. By advocating an easier route to teach PLTW, the company would not need to rely on certified teachers to then be PLTW trained and approved, thus eliminating technology and engineering education programs as well as any traditional or alternative certifications programs from the equation.

Conclusion

The school subject of technology and engineering education has gone through many changes over the years, not only in name, rationale, and content but in how teachers are prepared. Besides a traditional teacher preparation program, today, alternative certification is another option to prepare teachers. Outside forces such as standards, economic imperatives, and perceptions of teaching as a career have impacted the recruitment of all subject-matter teachers, but technology and engineering education has been particularly hard hit. Traditional technology and engineering education teacher preparation programs have been changed to focus on engineering, and these changes are affecting the continuation and viability of those few programs remaining.

Instructional trends like the "modular approach" required a shift in the type of technology and engineering education teacher because their role was more of a facilitator using vendor-supplied notes, activity guides, and tests. Although this approach was different than what was traditionally practiced, it did not specifically impose new teacher training in order to use the vendor's product. This has significantly changed with Project Lead the Way.

Although many members of a community would embrace the arrival of a McDonald's, Walmart, or Starbucks as a sign of respectability, status, and economic modernity, others would view such an "achievement" as a threat to local control, the local economy, and local traditions. In many ways, PLTW is similar, ending years of tradition to welcome a brand name that's touted by corporations, politicians, and educators as a way to develop engineers in order for the United States to compete economically. It may not be too difficult convincing a public about the value of PLTW—a public who is already skeptical about the quality of their schools and teachers. The growth of PLTW has certainly been impressive and will no doubt last a lot longer than the modular approach. Also, with the teacher training and equipment investments made and annual fees required for schools to maintain their stamp of approval for an assumed quality (student) output, it will be difficult for any school administration to later justify the decision to terminate the program.

Although PLTW now uses certified teachers in any subject to be trained to use their product, PLTW will more likely need to train uncertified teachers to meet increased program demand, as previously suggested by their CEO (Bertram, 2015). In a way, once PLTW makes its way into a community's school, a professionally certified teaching professional will not be required, just a person trained to order stock, greet people at the door, and fill a cup according to a canned activity's instructions and company specifications.

With Perkins funds being made available for equipment and leadership development, which will certainly be used to implement and support the continuation of PLTW in schools, there is even more certainty about PLTW's permanence and increased influence. Perhaps this new direction is inevitable. Most technology and engineering education teacher preparation programs are now closed, the few remaining programs are under great pressure because of low student numbers, and no new programs have been started. Traditional technology and engineering teacher education is following the path of subjects such as Latin and Philosophy—subjects that once needed universities to produce specialized, trained, and highly qualified teachers. Sadly, these programs are no longer relevant and, for the most part, long gone. *Requiescat in Pace*.

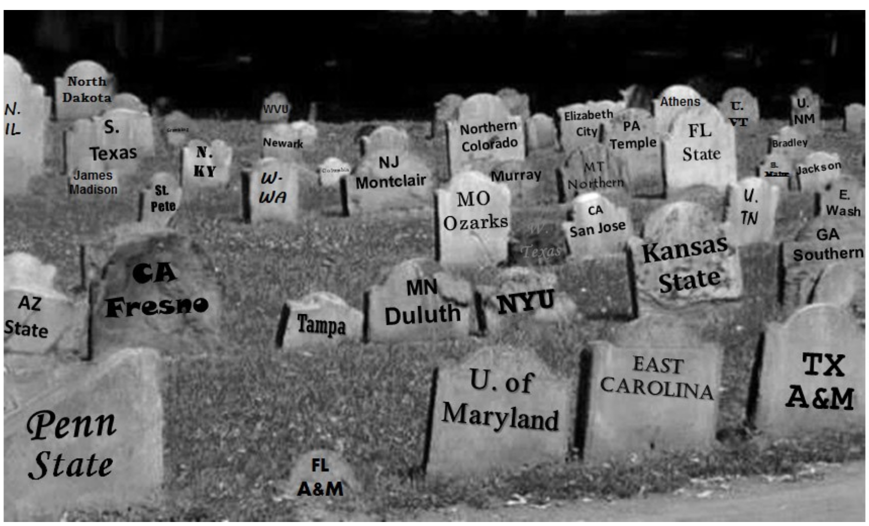

Figure 3. RIP: University programs long gone.

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Evidencing STEM Content Knowledge Transfer: Abstraction in Technological/Engineering Design Challenges

Fred J. Figliano & John G. Wells

Abstract

This study outlines the development of the Design Log Instrument (DLI), which is intended for use in identifying moments of abstraction as evidence of STEM content knowledge transfer. The DLI prompts participants to be reflective during technological/engineering design challenges. During the development of this instrument, a three-phase, multiple-case, embedded design was used. Three distinct phases accommodated the collection and analysis of data necessary for this investigation: (1) pilot case study, (2) establishing content validity, and (3) establishing construct validity. During Phase 3, data from the DLI were collected at each of seven work sessions from two undergraduate design teams working through different engineering problems. At the end of Phase 3, a comparison of abstractions found in DLI responses and observation data (audio/video transcripts) indicated the extent to which the DLI independently reflected the abstractions revealed in observations (audio/video transcripts). The results of this comparison showed that the DLI has the potential to be 68% reliable in revealing abstracted knowledge.

Keywords: Abstraction; knowledge transfer; STEM; technological/engineering design; design log

Few would argue that in the past decade, science, technology, engineering, and mathematics (STEM) literacy has become a significant driving force in 21st-century education (Honey, Pearson, & Schweingruber, 2014; National Research Council, 2011; Partnership for 21st Century Skills, 2011). A STEM-literate population provides the basis for America's global competitiveness, and its central tenet is the preparation of individuals who recognize and understand the connections between STEM content and practices. Such preparation calls for divergence from the traditional silo method of education whereby STEM disciplines are taught independent of one another. A more authentic pathway for achieving STEM literacy follows the integrative STEM education (I-STEM ED) approach in which disciplinary content and practice are concurrently and intentionally taught within design-based learning environments (Change the Equation, 2016; International Technology and Engineering Educators Association, 2015; Katehi, Pearson, & Feder, 2009; Kelley, 2008; Wells, 2008, 2016a, 2016b, 2017).

In Technology and engineering education (TEE), I-STEM ED is often defined as

> 'the application of technological/engineering design based pedagogical approaches to *intentionally* teach content and practices of science and mathematics education through the content and practices of technology/engineering education. Integrative STEM Education is equally applicable at the natural intersections of learning within the continuum of content areas, educational environments, and academic levels' (Wells & Ernst, 2012/2015). (Virginia Polytechnic Institute and State University, 2019, para. 4)

TEE utilizes the I-STEM ED approach to intentionally teach science, technology, engineering, and mathematics content and practice within the design of real-world technological and engineering solutions. As such, technological/engineering (T/E) design challenges have great potential as a valid instructional strategy for developing the higher order cognitive skills needed in the 21st century (Partnership for 21st Century Skills, 2011; Wells, 2010, 2016a, 2016b, 2017). Instructionally, throughout any T/E design challenge, there are multiple opportunities for students to intentionally use the knowledge acquired in one discipline together with that from another to solve a design problem. For example, if a student is attempting to design the trusses for a bridge, the student will need to have some understanding of the connections to the forces (load, sheer, etc.), material properties, and measurements within this context. Most of this knowledge is gained in the study of the physical sciences. The student would also need to understand how to decide what mathematical calculations are best in helping to solve this design problem. This process of activating disciplinary knowledge gained in one context and used in another is characterized as knowledge transfer, which is traditionally defined as "the ability to apply knowledge or use knowledge from one problem, situation or context to another" (Anderson, 2005; as cited in Pitts Bannister & Mariano, 2015, p. 139). To support the design used in the research being presented, the following operationalized version of Anderson's (2005) definition provided the basis for assessing student demonstration of knowledge transfer: *the abstraction of any knowledge, information, or experiences by participants and used when trying to understand higher order concepts.* The use of T/E design challenges within such instructional environments is uniquely suited to fostering knowledge transfer because of the cognitive demand for STEM content and practice knowledge that is inherently imposed on the learner within any given T/E design challenge (Wells, 2016b, 2017). The intent of the research presented was to provide evidence of the potential for T/E design challenges to foster the transfer of STEM content knowledge.

Research Design

Evidencing the potential of T/E design challenges to foster knowledge transfer required a mechanism for documenting that transfer. While working through a design problem, many decisions are made based on different information. It can be challenging to capture those decisions and the logic behind them. For that reason, the researchers felt that a formative instrument was needed rather than a summative instrument such as a standardized posttest. The purpose of this study was to develop an instrument with undergraduate engineering students that could provide data demonstrating student transfer of STEM content knowledge. Utilizing a case-study approach, this study sought to answer the following research questions:

- In what ways does the use of a design log provide evidence of the transfer of STEM content knowledge while students are engaged in a technological/engineering design-based learning challenge?
  - RQ-S1: What phrasing of design log reflective prompts effectively reveal STEM content connections?
  - RQ-S2: To what extent can a design log instrument allow a researcher to make judgments regarding the transfer of STEM content knowledge?

The research design for this study employed a multiple-case, embedded design. Multiple T/E design teams comprised the cases in this study, and individual students within each team comprised the embedded units of analysis (see Yin, 2009, p. 29). In the context of this study, data from each participant within a team were independently collected and analyzed as a distinct embedded unit of analysis. As such, the multiple-case, embedded design approach was appropriate for accommodating the process of instrument development by allowing for instrument modification over three phases of administration with multiple T/E design teams (see Yin, 2009). Triangulation of data collected from T/E design teams and interview data from both teams and individual participants (units of analysis) was conducted to identify points of convergence regarding the transfer of STEM content knowledge across all data sources.

Previous studies addressing knowledge transfer served as references for considering what data sources would be adequate for answering each research question across all three phases of data collection and analysis (Barlex & Trebell, 2008; Hill, 1997; Kelly, 2008; Kolodner, 2002; Kolodner et al., 2003; Puntambekar & Kolodner, 1998, 2005). Data necessary for investigating the research questions were generated, collected, and analyzed across the following three distinct phases: (1) pilot case study, (2) establishing content validity, and (3) establishing construct validity. Data sources included interviews, field notes, design logs, and audio/video recordings of participant work sessions. During all periods of student engagement in the T/E design challenges, data were collected concurrently in order to provide the necessary mechanism for data convergence through triangulation.

Participants

This study describes the initial development of the Design Log Instrument. For that reason, the researchers felt that undergraduate engineering students were well suited to participate. By using these students, it was possible to refine the instrument at a higher level. The researchers did not intend for this instrument to be used in a K–12 classroom in its current state, though that may be possible in the future.

The nature of this instrument development required the participation of individuals involved in T/E design challenges. Such individuals were drawn from the college of engineering at a major university in which design is a central focus of the curriculum. Undergraduate engineering students, specifically those in engineering science (ES), were targeted for this study. The ES department is uniquely suited to accommodate research investigating the transfer of STEM content knowledge in T/E design challenges because of their focus on intentionally necessitating the transfer of STEM content knowledge to solve T/E design problems. ES programs "focus on imparting and using fundamental interdisciplinary skills that address engineering problems" (Puri, 2008). Particularly immersed in T/E design are senior undergraduate engineering students in ES during their required fourth-year, capstone, design course, which is designed to foster their use of knowledge learned in previous college courses. During this capstone course, seniors work in teams to solve a T/E design challenge. Senior capstone design teams were selected to participate in Phase 1 (the pilot case study). At this particular southeastern university, sophomore ES students are also engaged in T/E design challenges in teams as a way to expose them to design at an early stage in their collegiate engineering preparation. Sophomore teams were selected to participate in Phase 3, during which construct validity of the Design Log Instrument was to be established.

Phase 1: Pilot Case Study

Phase 1 was conducted to develop the initial Design Log Instrument (DLI). Assessment of the initial DLI occurred over a period of 5 weeks with senior capstone teams engaged in a T/E design challenge. Two design teams met once a week for the duration of the 5 weeks. Concurrent collection of audio/video recordings and field-note data occurred during each work session. At the end of each work session, data were collected from both team interviews, and the DLI administered to each team member. Triangulation of these data points provided the basis for iterative DLI revisions across the 5 weeks. The primary data source for DLI revisions was the interviews conducted at the end of each work session, which provided participant feedback for evaluating the clarity of the reflective prompts. The coding of these data provided information about participant perceptions of the DLI and its ease of use. Based on the collective responses of all participants, the DLI was modified to improve the use of the prompts and increase their ability to report instances of transfer.

Triangulation of data points was used to judge the degree to which participant responses to the DLI corresponded with the field notes and audio/video recording transcripts as a means for establishing the validity and reliability of the DLI as an independent measure of transfer. The triangulation process described above was instrumental in making iterative revisions to the DLI following each weekly session with both design teams. A comparison of the initial and final iteration of the DLI reflective prompts is presented in Table 1.

Table 1
Comparison of Initial and Final DLI Prompt Iterations

Prompt #	Initial reflective prompt	Final iteration of reflective prompt
1	Of all the tasks you have worked through during this work session, which have you started to work on but have not completed?	Look at your notes on the previous page and identify the main topics that were discussed during this work session.
2	What information did you need to search for that you did not already know and what knowledge did you already have that you used during this work session?	Considering the phase(s) you indicated on the previous page and the main topics you listed in question one, what Science, Technology, Engineering, and Mathematics (STEM) content did you know and what STEM content did you not know about each topic?
3	How did you solve any problems that arose during this work session?	List any design constraints, design trade-offs, or design failures that you were confronted with during this work session. Then explain how what you were confronted with allowed you to improve your proposal (design solution).
4	Based on the expectations for your final solution that were framed in phase 2, how does the work you completed during this work session align with those expectations?	Looking at the design constraints, design trade-offs, or design failures you listed in question three, how do those modifications affect your original proposal (design)

		scenario criteria?
5	How would you predict your final solution to work based on the decisions which you have made during this work session?	From the effects stated in question four, how do you predict they will influence your final proposal (design solution)? Explain your answer.

As illustrated in Table 1, iterative revisions to the DLI were derived from and are reflective of the data analysis and participant responses to the interview questions. The results from Week 1 of data collection in Phase 1 indicated that approximately 89% (8 of 9) of all participants reported confusion and misunderstanding regarding use of the DLI. However, based on data analysis from interviews across the 5 weeks of team engagement, final analysis of Phase 1 results indicated that 100% (9 of 9) of all participants reported that the DLI had improved over time and was now clear and easy to use. This final version of the DLI was used in Phase 2 for establishing content validity of the instrument.

Phase 2: Establishing Content Validity

Following a well-documented content validity process (Yaghmaie, 2003), a group of STEM content experts reviewed the DLI reflective prompts to determine their adequacy for eliciting participant demonstration of STEM content knowledge transfer. This process utilized four experts who were chosen for their expertise in a STEM field or in educational psychology. Each expert had published extensively in their field and was knowledgeable in the area of transfer. Experts rated each DLI reflective prompt based on its relevance, clarity, simplicity, and ambiguity using a 4-point Likert scale: (1) *strongly disagree*, (2) *disagree*, (3) *agree*, and (4) *strongly agree* (Yaghmaie, 2003). Of the four variables, ambiguity was rated using a reverse scale.

Analysis of expert ratings utilized the Content Validity Index (CVI) developed by Waltz and Bausell (1983), which is the "proportion of items [criteria] given a rating of 3 or 4 by the raters involved" (p. 71) if using a 4-point Likert scale. As suggested by Yaghmaie (2003), only those criteria receiving a CVI score of 0.75 or higher were considered suitable for the study as written. As part of the protocol followed during each consensus meeting, experts met to present their ratings and discuss the DLI reflective prompts. Discussions regarding ratings and possible ways to improve each reflective prompt continued until consensus among all experts was reached for necessary DLI revisions. Table 2 shows consensus results of the CVI ratings for each of the DLI reflective prompts.

Table 2
Content Validity Consensus Results

Prompt #	DLI reflective prompt	CVI score
0	Which phase(s) of the design process are you currently in? Please circle the phase(s).	1
1	Look at your notes on the previous page and identify the main topics that were discussed during this work session.	.917
2	Considering the phase(s) you indicated on the previous page and the main topics you listed in question one, what Science, Technology, Engineering, and Mathematics (STEM) content did you know and what STEM content did you not know about each topic?	.75
3	List any design constraints, design trade-offs, or design failures that you were confronted with during this work session. Then explain how what you were confronted with allowed you to improve your proposal (design solution).	.75
4	Looking at the design constraints, design trade-offs, or design failures you listed in question three, how do those modifications affect your original proposal (design) scenario criteria?	.50
5	From the effects stated in question four, how do you predict they will influence your final proposal (design solution)? Explain your answer.	.75

Note. CVI = Content Validity Index.

Of the six reflective prompts analyzed, Reflective Prompt 4 received a CVI score of less than 0.75 and therefore required further discussion among experts in order to improve the item and reach consensus on content validity. Experts agreed that the content and sequence of the original Reflective Prompts 3 and 4 were confusing and that participants might not understand the difference between their final proposal and their original proposal. In resolving this issue, experts reached consensus that participants should simply list the design constraints, design trade-offs, and design failures in Reflective Prompt 3. In so doing, it clarified that the required responses to Reflective Prompt 4 were now asking specifically for an explanation of how each variable led the designers toward making changes in their original proposal. All of these modifications resulted in a sixth iteration of the DLI for use in Phase 3 of this study. In addition to establishing content validity for the reflective prompts, experts were also tasked with reaching consensus on suggested modifications (Table 3) for improving the readability and clarity of each item. Collectively, final conclusions from the expert analyses resulted in DLI reflective prompts that were more cohesive and specific in their ability to guide participants in generating responses with the potential for evidencing knowledge transfer.

Table 3
Phase 2 Revisions of DLI Reflective Prompts

Prompt #	Initial reflective prompt	Revised reflective prompt
1	Look at your notes on the previous page and identify the main topics that were discussed during this work session.	Look at your notes on the previous page, then ***identify and list*** the main topics that were discussed during this work session.
2	Considering the phase(s) you indicated on the previous page and the main topics you listed in question one, what Science, Technology, Engineering, and Mathematics (STEM) content did you know and what STEM content did you not know about each topic?	Considering the main topics ***you listed in question one***, describe what Science, Technology, Engineering, and Mathematics (STEM) content you **knew** and what STEM content you did **not know** about each topic?
3	List any design constraints, design trade-offs, or design failures that you were confronted with during this work session. Then explain how what you were confronted with allowed you to improve your proposal (design solution).	***List any design constraints, design trade-offs, or design failures*** that you were confronted with during this work session.
4	Looking at the design constraints, design trade-offs, or design failures you listed in question three, how do those modifications affect your original proposal (design) scenario criteria?	***Explain how these design constraints, design trade-offs, or design failures led you to change your proposal.***
5	From the effects stated in question four, how do you predict they will influence your final proposal (design solution)? Explain your answer.	***Given your response to question three***, what is your prediction of how each design constraint, design trade-off, or design failure will affect your final proposal? Explain your answer.

Phase Three: Establishing Construct Validity

Establishment of construct validity in this study was critical in determining the degree to which the DLI reflective prompts, as validated in Phase 2, would elicit responses that were in alignment with the theoretical construct of knowledge transfer. The test of DLI construct validity took place during Phase 3 with participants from two different design teams using the content validated DLI during a T/E design challenge. While working through two different design problems, participant data from audio/video recordings and field notes were collected during each design session for later analysis and triangulation. After each work session, participants were provided 5 to 10 minutes for entering responses to reflective prompts in their DLI. Individual interviews with each participant were scheduled for mid-phase (Week 3) and end-of-phase (Week 7) points to gather detailed explanations of DLI entries and to clarify how participants were using their knowledge. The same DLI that participants were provided at the beginning of the T/E design challenge was used throughout the project for recording responses.

Interrater Reliability

An initial coding scheme was developed and tested for interrater reliability using five STEM content raters. STEM content raters were chosen based on their experience with both teaching and research in the field of STEM education. Each rater had 10 or more years of teaching experience in the STEM areas and had published research on design-based learning techniques. Data from each participating team of sophomores were analyzed independently using an established method for achieving interrater reliability. Utilizing the initial coding scheme, raters coded approximately 10% of the data from each team, about one transcribed audio/video recording per team (Cox & Cox, 2008; Fink, 1995; Fink & Kosecoff, 1985). Based on the results of coding by raters, a percent agreement was calculated. This measure is the ratio of the number of criteria on which the raters agreed divided by the total number of criteria: (Total number of agreements / Total number of observations) X 100. An overall percent agreement equal to or higher than 80% was used as the cutoff point for acceptance (Cox & Cox, 2008; Fink, 1995; Fink & Kosecoff, 1985).

Team 1 Data Analysis

The design challenge for Team 1 dealt with wind energy, asking participants to examine the feasibility of a wind farm based on several specific parameters. The specifics of their design challenge were as follows.

> **Wind Power in** [redacted]: Governor [redacted] has expressed strong interest in establishing wind farms in the state as an important new industry. One of the key areas currently under consideration for a wind farm is off the Eastern Shore of [redacted], in the Atlantic and on [redacted]. The

> governor has asked your engineering consulting group to examine the feasibility of these projects and prepare a brief presentation for members of the state congress who will be asked to support the project. Wind energy is subject to a number of different controversies, including technical (Can it really generate enough power to be worthwhile?), environmental (Will it harm native wildlife?), and social (Will it be an eyesore and destroy tourism?).

Due to the nature of this design challenge, participants would engage in a design-without-make (Barlex & Trebell, 2008; Hennesey & McCormick, 1994) and arrive at a plausible solution by working through all but the prototyping phases of T/E design. Table 4 shows a consolidation of results from data analysis for Team 1 spanning 6 weeks.

Table 4
Team 1 Consolidated Results of Data Analysis

Week	Design phase (observed)	DLI entry	Audio/video observation data
1	3	Weather	Weather, Environmental, Install issues
		Efficiency figures	Highly efficient, Size vs. efficiency
		Location	Amount of area, Finite, Maximum theoretical energy, Traffic (boats)
		Cost	Cost, money, life cycle cost, cost to build, cost to stick it in, payback
		Environmental Effects	Environmental, Effects on animals, Eye sore, Tourism
		Design	Efficiency, Energy, Design, Advantages, Disadvantages
		Feasibility	Tie into the power grid, atmospheric thermal warming, convenience
2	3	Weather	Weather Patterns, Potential Wind, Average Wind Speed, Effect on TV Antennas
		Cost	Life cycle costs, Material, Recyclability, Maintenance, Break-even point
		Environmental Impacts	Environmental Impacts, Noise, Eye Sore, CO2 Production, Greenhouse Gasses, Nitrogen
			Feasibility
			Designs
			Efficiency
		Location	Available Land, Spacing, Land Analysis
3	3		***Efficiency***
		Environmental Impacts	Environmental Impacts, Killing birds, Construction, Erosion, Cleaner than coal, Endangered birds
		Location	Locations, Wind maps, Scale, Acers, Weather, Reactive Power, Transmission lines, Homes, International waters, Navy
		Design	Designs, Alternate designs, Versatility, Efficiency, Weather, Scalability
		Cost	Cost, Competitive, Becoming cheaper, Technology, Budgetary constraints, Available money
		Weather	Weather, Wind speed, Potential wind energy
4	3	Design	Designs, New Model, Metric, Maintenance, Wind VAR, Stabilization of power grid,
		Cost	Cost, Government support, Overhead cost, Comparison, Instillation over time
			Location
5	6		***Environmental Impacts***
			Cost
			Design
6	6	Cost	Cost, Cost vs. output, Cost vs. distance, Total output, Amount of turbines, Capacity
		Feasibility	Feasibility, Advantages, Stabilizing the power grid, Producing reactive power with no wind
			Efficiency
			Environmental Impacts

Note. Words in bold italics indicate abstractions that were observed but not reported by participants.

Findings from analysis of Team 1 data indicated that the DLI was 67% reliable with Team 1 over 6 weeks. Of importance to note in Table 4 are the data represented in bold italics that reflect observed abstractions not reported by participants. The DLI reliability per week is shown in Table 5.

Table 5
Team 1 Reliability Ratio

Work sessions	Observed abstractions	Reported abstractions (DLI)	Reliability ratio (reported / observed)	Average reliability (∑ reported / ∑ observed)
1	7	7	100%	
2	7	4	57%	
3	6	5	83%	
4	3	2	67%	
5	3	0	0%	
6	-	-	-	
7	4	2	50%	
Total	30	20		67%

Note. The team did not meet for Work Session 6.

Team 2 Data Analysis

The design challenge for Team 2 dealt with creating an exercise regimen. The specifics of their design challenge were as follows.

> **Exercise for Bone Health**: A recent report in the [redacted] raised questions about the types of exercise individuals should engage in to maintain healthy bones. Confused by the conflicting findings reported in the magazine, a group of family physicians has asked your biomechanics research group to come give a talk at their next monthly meeting. They'd like your group to give them guidelines that they can use for recommending exercise programs for their older patients in particular. Note that these doctors are general practitioners, not orthopedists or gerontologists or related specialists. They are concerned both about what kinds of exercise will help their patients and about what exercises they can reasonably expect their patients to engage in.

As previously explained, participants in Team 2 similarly engaged in a design-without-make (Barlex & Trebell, 2008; Hennesey & McCormick, 1994) engineering challenge, and were to arrive at a plausible solution by working through all but the prototyping phases of T/E design. The results of data analysis for Team 2 appear in Table 6.

Table 6
Team 2 Consolidated Data Analysis

Week	Design phase (observed)	DLI entry	Audio/video observation data
1	3		***Design Process***
		Exercise Rigor	Running, joints, knees, hips, energy, brisk walking, swimming, resistance, water aerobics
2	3	Supplements	Supplements, Calcium, Exercising, Genetic
		Exercise Rigor	Exercise Rigor, High Impact, Low Impacts, Older People, Power Walking, Dancing, Tennis
		Design Process	Problem statement, Steps 1/2/3, Frame the problem, Presentation, Marketing, technical, friendly version
		Exercise Constraints	Exercise Constraints, Length of time, Frequency of exercises, Physical Limitations, How strenuous, Amount of Impact
3	3	Design Process	Framed out, Criteria, Solution, Negotiation, Sources, Recommendations
		Exercise Constraints	Exercise Constraints, Access to local gyms, Implementation, aerobics classes, Swimming Pool
4	3, 4, 5	Design Process	Poster slide, Final solution, Presentation, Journals, References, Audience, Terminology, Background knowledge, Solution, Organization, Consensus
		Exercise Rigor	Exercise Rigor, Length of exercise, Frequency, Rigor, Impact level, Jumping, Pre-existing conditions, Impact, Balance
		Exercise Constraints	Exercise Constraints, Accessibility, Do at home, Running, Jumping, Frequency, Aerobic muscle strength
		Exercise Plans	Exercise Plans, Work out plan, Customizable, Categories, Jumping, Climbing stairs, Walking, Jogging, Gardening
			Age Range For Elderly Adults
5	5, 6	Design Process	Poster, Introduction, Abstract, Conclusions, Frame the problem, Objective, Method, Tables and graphs, Limitations, Requirements
			Exercise Plans
			Logistics
			Exercise Rigor

Note. Words in bold italics indicate abstractions that were observed but not reported by participants.

Findings from analyses of Team 2 data indicated that the DLI was 70% reliable over 5 weeks (see Table 7).

Table 7
Team 2 Reliability Ratio

Work sessions	Observed abstractions	Reported abstractions (DLI)	Reliability ratio (reported / observed)	Average reliability (∑ reported / ∑ observed)
1	2	1	50%	
2	4	4	100%	
3	-	-	-	
4	-	-	-	
5	2	2	100%	
6	5	4	80%	
7	4	1	25%	
Total	17	12		70%

Note. The team did not meet for Work Sessions 3 and 4.

Teams 1 and 2: Combined Data Analysis

Using results from independent analysis of data from Teams 1 and 2, an average reliability of the DLI over the entirety of Phase 3 could be calculated. Analysis of the combined data from Teams 1 and 2 (DLI responses, audio/video transcripts, field notes, interviews per work session) found there to be a 68% average level of reliability (see Table 8) across all seven work sessions.

Table 8
Combined Teams Reliability Ratio

Work sessions	Observed abstractions	Reported abstractions (DLI)	Reliability ratio (reported / observed)	Average reliability (∑ reported / ∑ observed)
1	9	8	88%	
2	11	8	72%	
3	6	5	83%	
4	3	2	67%	
5	5	2	40%	
6	5	4	80%	
7	8	3	37.5%	
Total	47	32		68%

Prompt 2. Further analyses of data gathered across all seven work sessions per individual DLI reflective prompt was also conducted in order to reveal the relative strength of each criterion for eliciting STEM content knowledge transfer. The percent abstractions found per DLI reflective prompt appear in Table 9. The analysis indicated that the majority of the abstractions (36%) were revealed through participant responses to DLI Reflective Prompt 2 in which they were asked to describe what STEM content knowledge they knew and did not know regarding the topic of the design challenge.

Table 9
Percentage of Abstractions Found Per DLI Reflective Prompt

Prompt #	DLI reflective prompt	% abstractions
1	Look at your notes on the previous page, then identify and list the main topics that were discussed during this work session.	20%
2	Considering the main topics you listed in question one, describe what Science, Technology, Engineering, and Mathematics (STEM) content you **knew** and what STEM content you did **not know** about each topic?	36%
3	List any design constraints, design trade-offs, or design failures that you were confronted with during this work session.	22%
4	Explain how these design constraints, design trade-offs, or design failures led you to change your proposal.	9%
5	Given your response to question three, what is your prediction of how each design constraint, design trade-off, or design failure will affect your final proposal? Explain your answer.	13%

The DLI reflective prompts were purposefully developed to align with the phases of the T/E design process, and data collected across all seven work sessions were again analyzed per phase of the T/E design process. In this study, participants were presented with a prescribed context and challenge (identified problem, including parameters and criteria), which resulted in initiating their T/E Design primarily working within Phase 3 of the design process. Analysis of this data indicated that the majority of abstractions occurred during Design Phase 3, which corresponds with Reflective Prompt 2 of the DLI. This analysis suggests that when participants are investigating a problem, they begin with an evaluation of what is known and unknown, which predisposes them to transfer of STEM content knowledge. Similarly, when participants are tasked with choosing a solution and developing that solution, they are confronted with design constraints, design trade-offs, and design failures. To resolve issues that arise from these design parameters, participants must draw on their resident knowledge of STEM content (knowledge domain) in order to envision plausible solutions (concept domain), making strategic decisions based on disciplinary connections (Wells, 2016b, 2017). The percent of abstractions associated with each T/E design phase are presented in Table 10.

Table 10
Percentage of Abstractions Found Per T/E Design Phase

Design phase #	T/E design process phase description	% abstractions
1	Identify a problem either by observation or a human need	0%
2	Frame criteria for the final solution	0%
3	Investigate what is known about the problem	71%
4	Develop alternate solutions to the problem	5%
5	Choose an appropriate solution from the alternate solutions	10%
6	Develop detailed plans for constructing your chosen solution	14%
7	Simulate or prototype your chosen solution	0%
8	Check to see if your chosen solution meets the criteria that were identified earlier	0%
9	If the chosen solution does not meet the criteria make any improvements necessary and present your findings	0%

Prompt 4. Results from the data analysis also revealed that participants were not responding well to Reflective Prompt 4, which accounted for only 9% of total abstractions identified during Phase 3 (see Table 9). When prompted during mid-phase interviews (Week 3) to discuss why, participants reported that they did not feel as though they had a proposal to change until later in the T/E design process. However, when prompted further during interviews to verbalize how their thinking changed, 100% (9 of 9) of participants were able to respond to this prompt. Based on these findings, at the end of Phase 3, Reflective Prompt 4 was modified to ask participants how design constraints, design trade-offs, or design failures led them to change their thinking on the project. This modification of Reflective Prompt 4 was incorporated into the final iteration of the DLI (see Table 11).

Table 11
Final DLI Reflective Prompt Revisions

Prompt #	Initial reflective prompt	Final reflective prompt
1	Look at your notes on the previous page, then identify and list the main topics that were discussed during this work session.	Look at your notes on the previous page, then identify and list the main topics that were discussed during this work session.
2	Considering the main topics you listed in question one, describe what Science, Technology, Engineering, and Mathematics (STEM) content you **knew** and what STEM content you did **not know** about each topic?	Considering the main topics you listed in question one, describe what Science, Technology, Engineering, and Mathematics (STEM) content you knew and what STEM content you did not know about each topic?
3	List any design constraints, design trade-offs, or design failures that you were confronted with during this work session.	List any design constraints, design trade-offs, or design failures that you were confronted with during this work session.
4	Explain how these design constraints, design trade-offs, or design failures led you to change your proposal.	Explain how these design constraints, design trade-offs, or design failures led you to change ***your thinking of the project***.
5	Given your response to question three, what is your prediction of how each design constraint, design trade-off, or design failure will affect your final proposal? Explain your answer.	Given your response to question three, what is your prediction of how each design constraint, design trade-off, or design failure will affect your final proposal? Explain your answer.

Conclusions

The first research sub-question (RQ-S1) dealt with development of the phrasing for the DLI reflective prompts: What phrasing of design log reflective prompts effectively reveal STEM content connections? To answer this question, the DLI was tested, evaluated, and refined throughout all three phases of this research. At the conclusion of Phase 2, the DLI contained reflective prompts that were content valid and poised for testing of their ability to provide evidence of STEM content knowledge transfer. Testing of the DLI took place in Phase 3 in which data were collected from two teams working independently through different engineering design challenges. Analysis of these data resulted in a final iteration of the five reflective prompts, as illustrated in Table 11.

Throughout this study, each revision of the reflective prompts became more specific, encouraging participants to respond in a precise way. Analysis of data derived from both DLI responses and interview responses allowed better recognition and understanding of points at which disconnects were occurring. This process proved ideal for using specific participant feedback to construct reflective prompts that more closely represented language and content that participants were familiar with while preserving the types of data that were necessary for this study.

The second research sub-question (RQ-S2) asked the following question: To what extent can a DLI allow a researcher to make judgments regarding the transfer of STEM content knowledge? Data collected in this study consisted of audio/video recordings, field notes, interviews, and DLI responses. Through iterative revisions of the DLI, the goal was to develop a set of reflective prompts that would aid in the independent collection of data reflecting knowledge transfer without the additional need for audio/video recordings, field notes, and interviews.

Findings in Phase 3 of this research indicate that the DLI shows the potential for being 68% reliable (see Table 8) as an independent measure of knowledge transfer. Meaning that 68% of the time, the DLI would consistently provide data similar to that derived through triangulation of the audio/video recordings, field notes, and interviews (Cox & Cox, 2008, p. 40; Fink, 1995; Fink & Kosecoff, 1985) and could serve as an independent method of data collection. Although the reliability of the DLI is relatively high, reflective prompts must be further developed to foster greater discussion of topics. The triangulation data provides a deep level of insight into how knowledge is used to solve problems that the DLI alone, in its current form, does not. In order for the DLI to truly be used as an independent measure of STEM content knowledge transfer, this insight must be present in DLI responses. Further refinement and development may improve the reliability of the DLI and the ability of the reflective prompts to elicit responses that not only provide evidence of STEM content knowledge transfer but also explain those instances.

The overarching question of this study was: In what ways does the use of a design log provide evidence of the transfer of STEM content knowledge while students are engaged in a T/E design-based learning activity? Data analyzed to answer each sub-question provided direction in answering this overarching question. As this study progressed, the DLI required fewer substantial changes, indicating that as time went on, the DLI was more accurately providing evidence of knowledge transfer. At the end of Phase 3, the DLI showed the potential to be 68% reliable as an independent measure of STEM content knowledge transfer. Though this shows a degree of success with the instrument, it is still not reliable enough for use as an independent source of data. Participants were providing evidence of STEM content knowledge transfer in their DLI responses, but they were not providing as many instances as were identified in the observation data (audio/video recordings and field notes).

Participants also gave rather simple explanations of topics discussed during their team work sessions that did not corroborate the more robust descriptions provided by the observation data. There are several plausible reasons for the gap between the observed and reported abstractions. Knowledge abstraction is more likely to occur in some T/E design phases than in others. It is plausible that participants did not recognize that they were abstracting knowledge but rather thought they were applying knowledge from a previous design phase. For example, 71% of the total abstractions occurred during T/E Design Phase 3, which dealt with investigating the problem. Participants used the abstracted knowledge gained during this phase and applied it to develop alternate solutions during T/E Design Phase 4. Although participants did not report abstractions during this design phase, observation data shows that participants were abstracting knowledge, causing the gap between observed and reported abstractions. It is also possible that motivation may have affected a participant's willingness to respond to DLI reflective prompts. The DLI required participants to do additional work after each work session; thus, fatigue may have caused them to respond without the effort necessary to provide meaningful data. For these reasons, assigning STEM content codes to abstractions found in the DLI responses was difficult without the accompanying observation data.

Participants in both Phase 1 (the pilot study) and Phase 3 (implementation) reported that the DLI provided a valuable record of design decisions throughout the T/E design process. During both mid-phase (Week 3) and end-of-phase (Week 7) interviews, 100% of the participants reported that required journaling in the DLI allowed them to keep track of past decisions and reflect on them while making new decisions. This level of reflection improved the ability of participants to make informed decisions and to consider the positives and negatives of each. Specifically, in Phase 3, as an unintended outcome, the DLI allowed participants to monitor their own learning and acted as a guide through the T/E design process. In this way, there is potential to use the DLI as an instructional tool as well as a method for collecting data.

Although the DLI is not yet ready to be used as an independent measure of STEM content knowledge transfer at this time, it does show promise for providing such data independently. With future iterations, the reliability of the DLI can increase as an independent instrument. The intended target audience for this instrument was students in undergraduate programs that engaged them in T/E design challenges. The reliability of this instrument is also bound to the studied context and therefore needs further development in other contexts to verify the reliability.

Implications

This study provides the first step in developing an instrument that can be used by TEE to evidence transfer through abstraction. Although the instrument cannot be used in its current form with all TEE students, the groundwork has been laid, and future studies may bring us to that point. This research provides additional support for T/E design-based learning as a valuable pedagogical approach to teaching and learning that fosters a deep understanding of STEM content and practice. For TEE to contribute to the body of research generated by other core STEM disciplines, similar cognitive investigations will need to become a larger part of the TEE research agenda.

This study represents an initial instrument development examining the first half of the T/E design process. The researchers believed that the first half of the design process is where students conceptualize a possible solution and utilize an integrated approach that is discipline agnostic. It was at this stage that we felt we were most likely to identify instances of knowledge transfer. Due to the nature of the challenges used, the participants, and using the first half of the design process, the findings of this study are not generalizable. However, the initial findings have given the researchers a good foundation for further refinement. In a future study, we will use a larger population and utilize a T/E design challenge that encompasses the entire design process, thus allowing for an improved instrument that can be used with a broader population.

Note: This article was based on the first author's dissertation study (see Figliano, 2011). This study was also previously discussed in a conference paper (Figliano & Wells, 2012).

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STEM Leader Excellence: A Modified Delphi Study of Critical Skills, Competencies, and Qualities

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Abstract

With the push by government and business leaders for greater emphasis on STEM education at all grade levels, STEM leaders (i.e., educational leadership and teacher leaders) are challenged to pioneer integrative praxes that prepare students for success in a scientifically and technologically driven society. Additionally, these STEM leaders must transverse the barriers of developing transformative educational experiences that involve diverse stakeholders. This study utilized a modified Delphi technique to investigate what STEM leader skills, competencies, and qualities are identified as critical by STEM professionals within integrative STEM education. Findings are presented for the following seven themes: mission and culture, equity and social responsibility, infrastructure and programming, curriculum and instruction, professional growth, evaluation and assessment, and extended learning. These findings may inform the development of courses and programs that prepare or provide professional development for STEM leaders.

Keywords: Educational leadership; integrative STEM education; modified Delphi study; STEM leaders; teacher leaders

Integrative science, technology, engineering, and mathematics (I-STEM) education provides direction for teaching, leading, and learning practices related to students' abilities to identify, think critically about, and propose solutions to real-world problems. However, many educators are unfamiliar with the conceptualization and praxis of I-STEM curricula (Havice, Havice, Waugaman, & Walker, 2018; Herro & Quigley, 2017). School program leaders cultivating an I-STEM culture also encounter difficult challenges such as reorganizing STEM subjects for greater integration and fostering teacher's knowledge, confidence, and pedagogical practice (Shernoff, Sinha, Bressler, & Ginsburg, 2017; Nadelson & Seifert, 2017). Several states have developed STEM-certification systems that both recognize exemplars of I-STEM instruction and curriculum and promote the development of an I-STEM culture within schools. In particular, the Indiana Department of Education, Office of Workforce and STEM Alliances (2018) emphasizes the deployment of problem-, project-, and inquiry-based approaches to learning "while developing critical thinking skills and creating pathways to postsecondary readiness" (p. 6).

Although effective models of I-STEM education are still emerging (LaForce, Noble, King, Holt, & Century, 2014), positive outcomes in administrator and teacher praxis are evident. Professional development (PD) programs have been shown to significantly increase teacher and administrator self-efficacy in problem- and project-based learning (Havice et al., 2018), teacher collaborative efforts and educational technology use (Herro & Quigley, 2017), mathematics achievement (Burghardt, Hecht, Russo, Lauckhardt, & Hacker, 2010), and teacher involvement in community engagement (Havice, 2015). However, it is important to note that the catalysts for transformative paradigms and praxis are school administrators and teacher leaders. According to Myers and Berkowicz (2015), "no school district, or school for that matter, can prepare for a systemic change without a profound and abiding understanding among that system's leaders" (p. 58–59).

School leaders must be progressive and knowledgeable about I-STEM approaches to ensure that students are receiving quality curriculum and instruction that would prepare them to be well-informed, globally aware, and employable in a scientifically and technologically driven society (Daggett, 2010). Innovative leaders who aspire to make changes in the educational culture of the school must support and coach the faculty they lead (Day, Fleenor, Atwater, Sturm, & McKee, 2014).

Purpose

I-STEM education will require a significant shift in the philosophical framework and culture of schools (Myers & Berkowicz, 2015). Therefore, the skills, competencies, and qualities of leaders that underpin transformative I-STEM experiences should be identified to inform leader preparation and PD programs. The purpose of this study is to identify the critical facets and praxis needed for STEM leaders, both school and teacher leaders, that would more likely lead to program transformation with an I-STEM lens.

Methodology

Our effort to identify qualities of a STEM leader striving for excellence involved site visits to schools, semi-structured interviews with STEM leaders, and a three-round modified Delphi study. The Delphi technique enables a distributed panel of respondents—typically a purposeful sample of experts—to offer opinions and judgments anonymously and then compare their judgments against the aggregated results of all panelists during subsequent rounds. During the final round, the panel validates the study results. The Delphi technique has been used to identify retention barriers among female STEM professionals (Mlinar, 2015) and challenges encountered with teaching a STEM curriculum (Branscum, 2018).

Participants

A list of potential participants was compiled from school leaders (principals, directors, and STEM coordinators), state STEM leaders, and STEM experts (university faculty, professional development providers, and researchers). Twenty-four of the individuals invited to participate (around 70) granted informed consent and joined the panel. The majority of participants (62.5%) were principals or directors of schools, and 58.3% of participants were from Indiana (see Table 1).

Table 1
STEM Leaders Participating in the Delphi Study

	Elementary	Middle	High	Postsecondary	Indiana	Total
Principal or Director	4	3	3		9	10
Teacher Leader	2		1		2	3
State Administrator					2	2
	Science	**T&E**	**Math**	**Other**	**Indiana**	**Total**
STEM Professionals	1	2		2	1	5
University	1	2	1		0	4
Total					14	24

Round 1: Instrument and Results

School visitations and interviews were conducted with principals, directors, and evaluators of Indiana’s STEM Certified Schools (Indiana Department of Education, Office of Workforce & STEM Alliances, 2018) to inform the development of the initial instrument. Analysis of field notes, interview transcripts, and the literature resulted in an extensive list of desirable qualities of a STEM leader. A systematic review of all qualities resulted in the emergence of seven distinct themes. Table 2 offers descriptions of the themes and the number of items within each theme.

Table 2

Structure for Three Delphi Questionnaires and the Number of Pre-established Items for Each Theme

Theme: The knowledge, skills, dispositions, or initiatives that enable a STEM leader to…	Round 1	Round 2	Round 3
Mission and Culture …develop a common vision of STEM education and garner commitment from faculty, students, and the community.	12	8	8
Equity and Social Responsibility … promote equity, fairness, and social responsibility as it relates to I-STEM.	8	10	5
Infrastructure and Programming …develop a school infrastructure (physical environment, scheduling, educational technology, and counseling) that supports I-STEM education.	20	6	9
Curriculum and Instruction …effectively facilitate the development of implementation of coherent systems of curriculum and instruction that promotes the I-STEM mission and goals of the school.	28	9	10
Extended Learning …effectively encourage and facilitate STEM teaching and learning beyond the regular school day.	10	1	2
Professional Growth … effectively facilitate professional growth as it relates to I-STEM.	26	10	9
Evaluation and Assessment … effectively facilitate student assessment and evaluation of curricular programs as it relates to I-STEM.	13	11	8
Total	117	55	51

In the Round 1 questionnaire, panelists considered each of the seven themes separately. After reviewing the description of the theme, panelists listed up to three critical qualities and then rated the pre-established items on a 5-point scale from *not at all important* (1) to *critically important* (5).

To analyze the open-ended responses from panelists (n = 432), two researchers independently analyzed each set of responses by first classifying each response as relevant or irrelevant to the current theme. For relevant items, the item was classified as either a unique quality, a variation of a preexisting rated item, or a generic quality of a school leader (e.g., persistent, passionate, and respectful). Interrater agreement ranged from 80% for Mission and Culture to 95% agreement for Professional Growth. A third researcher determined disagreements. After consolidating redundant items, the researchers identified 55 responses that added new qualities to the original list (see Table 3).

Of the 117 rated items, panelists rated 85% of items at 4.0 or higher, meaning that most qualities were deemed *important* (62 items) or *critically important* (37 items). Comparing participants by Indianans vs. non-Indianans and K–12 administrators vs. non-K–12 administrators using a Mann–Whitney U test yielded no statistically significant differences for items combined within the same theme.

Relative to themes, all of the Evaluation and Assessment items were deemed *important* or *critically important*; however, none of the items for Extended Learning were deemed *critically important*. This finding supports previous research on school leadership agreeing that "after-school programs are sound educationally but struggle to operate and sustain such programs" (Miller, 2005, p. 20). The challenges of implementing afterschool and summer-school programs include "recruitment, staffing, transportation, maintaining high quality programming, developing and maintaining robust community partnerships, and planning for their own long-term sustainability" (Mette, Biddle, & Fairman, 2016, p. a).

Table 3
Number and Examples of Panelists Responses to Open-Ended Items in Round 1

	Responses		
Theme	Total	Unique	Examples of unique responses
Mission & Culture	72	8	• understand change theory and implement strategies to foster an integrative STEM culture. • advocate for STEM educational opportunities at all grade levels.
Equity & Social Responsibility	69	10	• model cultural competence.

			• implement a transparent enrollment process that promotes equitable access for all.
Infrastructure & Programming	69	6	• foster the development of plans for educational technology support in STEM-based instruction. • effectively provide opportunities for support personnel (e.g., educational technologists, counselors, nurses….) to be a part of planning and implementing STEM initiatives.
Curriculum & Instruction	59	9	• include STEM and curriculum specialists in the development of curriculum and instruction. • create opportunities for students to develop 21st Century skills and subsequently increase their employability potential.
Extended Learning	55	1	• offer afterschool STEM activities and programs for families and community members.
Professional Growth	53	10	• enable STEM teams and teachers to visit STEM-certified schools. • initiate team-based professional learning, such as the Lesson Study approach and book study.
Evaluation & Assessment	55	11	• model how to assess students' STEM achievement integratively. • design and implement assessments that are differentiated based upon student needs.
Total	432	55	

Round 2: Analysis and Results

In the Round 2 questionnaire, panelists were asked to rate only the 55 unique items proposed by the panelists in Round 1. Results indicated that 12 of the items were rated *critically important* (mean of 4.5 or higher).

Round 3: Analysis and Results

During Round 3, 14 panelists completed the questionnaire by (a) validating the breadth of the *critically important* qualities of a STEM leader (mean of 4.5 to 5.0 on a 5-point scale) and (b) rerating those items from Round 1 and 2 that received a borderline score of 4.25 to 4.49 (51 items).

Panelists indicated 86% to 100% agreement for the breadth of the critically important qualities (mean of 4.5 or higher) of a STEM leader. Two categories—Evaluation and Assessment and Equity and Social Responsibility—received 86% agreement with two panelists noting eight minor exceptions (e.g., a rationale to elevate "safe learning/laboratory spaces"). None of the means for borderline items rose to the critical threshold of 4.5 of 5. As indicated in Tables 4–9, panelists achieved consensus as to the critical qualities of I-STEM leaders.

Findings, Discussion, and Implications

A modified Delphi technique was used to identify the critical qualities of a STEM leader striving for excellence. As stated previously, the panel consisted of 24 STEM educational leaders in total. Although participation waned during the three rounds of surveys, a consensus arose among the panel. In this section, findings are organized by theme.

Mission and Culture

Results indicated that an I-STEM leader embraces innovation, problem-solving, and evidence-based decision-making by employing collaborative leadership strategies (see Table 4) that engender value for an I-STEM curriculum and a mission that is focused upon the well-being and academic success of students. The collaborative leader embraces shared decision-making through team-based structures, in particular, a STEM leadership team comprised of a cross section of educational stakeholders. Collaborative leadership is based upon building relationships among people who recognize their interdependence, share a common goal, and share responsibilities. Facilitating a collaborative vision and learning culture is prominent among professional standards for school leaders (e.g., National Policy Board for Educational Administration, 2015). Collaborative leadership behaviors have been associated with higher trust levels among teachers, including shared visioning and collaborative decision-making (Owen, 2018).

Table 4
Critical Characteristics Related to Mission and Culture

	Mission and Culture	Mean	*SD*	Round	*n*
1	promotes a culture of innovation, inquiry, problem-solving, and evidence-based decision-making.	4.83	0.38	2	18
2	impanels a STEM leadership team comprised of diverse stakeholders, e.g., faculty, students, parents, business and community leaders.	4.75	0.44	1	24
3	empowers a STEM leadership team to guide the development, implementation, and evaluation of I-STEM goals, expectations, programs, and initiatives.	4.67	0.56	1	24
4	articulates the value of I-STEM education to promote the well-being and academic success of students.	4.58	0.78	1	24
5	collaboratively develops an educational mission that promotes I-STEM curriculum and instruction.	4.54	0.59	1	24

Reducing the isolationism and independent decision-making that is pervasive within conventional schools is a challenge to creating a collaborative culture (Elbousty & Bratt, 2009). Overcoming these barriers is essential to the complex task of cultivating I-STEM curriculum because expertise is distributed among professionals. The facilitation practices of a collaborative leader often reflect the underlying tenets and processes of inquiry, cooperative learning, and design thinking. Thus, question posing, examining the relevance of evidence, considering possibilities, and experimentation with new ideas for I-STEM learning are commonly embedded facilitation practices.

Equity and Social Responsibility

Several qualities related to equity and social responsibility were rated as critical characteristics (see Table 5). Responses indicated that I-STEM curriculum and instruction should be provided for all populations of students, including students with disabilities, females, minorities, low socioeconomic students, and veterans. These paradigms were supported in school observations and interviews with successful I-STEM leaders who indicated that they were aware of inequities for marginalized groups and purposefully integrated multiple opportunities for students to engage in formal and informal STEM learning experiences.

Table 5
Critical Characteristics Related to Equity and Social Responsibility

Equity and Social Responsibility	Mean	*SD*	Round	*n*
1 ensures that all students have equitable access to I-STEM curriculum and instruction.	4.88	0.34	1	24
2 promotes equal access to STEM educational programming, e.g., participation in STEM academies, projects, competitive teams, and community-based learning experiences.	4.67	0.49	2	18
3 creates nonintimidating learning environments that are accessible to all students, including those with disabilities.	4.63	0.49	1	24
4 addresses female students, minority students, low socioeconomic students, and veterans.	4.58	0.50	1	24
5 Focuses on increasing participation of underrepresented students in STEM education.	4.50	0.59	1	24

Inclusivity in STEM education is complex because student needs are diverse, and barriers are often structural, cultural, and unconscious. Studies have shown that praxis of inclusivity leads to greater advocacy by teachers for student engagement in STEM opportunities (Frank & Hjalmarson, 2016) and increases the presence of marginalized groups in STEM positions (Huston, Cranfield, Forbes, & Leigh, 2019). The I-STEM leader striving for inclusive excellence has the acumen for identifying gaps in programming equity and social responsiveness and is compelled to implement solutions. Tanenbaum (2016) recommended increasing staff knowledge of equity issues, developing accessible measures of learning, engaging in the community, incorporating interdisciplinary approaches and STEM-themed play, and reducing historical biases through exposure to societal and cultural systems as key strategies for shaping inclusive school programs.

Curriculum and Instruction

The interconnected principles of science, technology, engineering, and mathematics and the "habits of mind" used by STEM professionals offer compelling content and authentic learning processes by which to plan curriculum and instruction within K–12 education. Although a variety of school models for STEM education are evident in the United States (LaForce et al., 2014), few large-scale research efforts compare different approaches to STEM integration (Honey, Pearson, & Schweingruber, 2014). Thus, the facilitation skills of STEM leaders are especially important in structuring a curriculum development team, mapping the curriculum, and assuring the adoption and skillful implementation of preferred I-STEM pedagogies and practices.

An effective I-STEM leader often initiates STEM program development by assembling a multidisciplinary curriculum planning team comprised of individuals who are committed to the ideal of improving STEM learning outcomes. Delphi panelists emphasized that the STEM curriculum team should be populated with teachers from science, mathematics, technology, engineering, and career and technical education, teachers across grade levels, curriculum integration specialists, and teachers of students with special needs and high abilities. Engaging student, parent, community, and business representatives was deemed less critical, but still important, by the panelists. However, broader representation on the team offers other advantages, such as fostering future community partnerships.

The Delphi panel emphasized that mapping the existing curriculum to identify common points for integration among the STEM content areas was the most critical step to achieving integrative curriculum. I-STEM leaders should be well versed in the processes and tools that support collaborative curriculum mapping, as well as the value of these processes to evaluate the coherence of the curriculum and promote shared understandings among teachers.

Consistent with K–12 standards from the *Standards for Technological Literacy* (International Technology Education Association, 2007) and the *Next Generation Science Standards* (NGSS Lead States, 2013) as well as engineering education in K–12 (e.g., Purzer, Strobel, & Cardella, 2014), the Delphi panel emphasized that learning experiences should engage students in the design and engineering of solutions to real-world problems (see Table 6). Related to problem-based learning (PBL) and project-based learning, design and engineering pedagogies (e.g., Donna, 2012) are learner-centered approaches that require students to grapple with problems by exercising their reasoning, creativity, and critical-thinking skills when proposing or testing a potential solution. Teachers facilitate this design process as students inquire into the nature of the problem, identify design goals and constraints, envision potential solutions, analyze computational and physical models, and predict potential trade-offs.

Delphi panelists emphasized that students should be given the opportunity to examine problems that exist within the local community, thereby enabling students to “explore uncertainties and build knowledge through experience.” It was reasoned that locally situated problems help students understand how STEM content and practices are connected to each other and relate to their daily lives as well as commit to learning as a valuable lifelong process. However, planning locally situated, design-based learning experiences takes cognitive focus as well as more time and coordination of resources and will likely generate stress among teachers related to managing an open-ended learning experience (Shernoff et al., 2017). To address these challenges, I-STEM leaders should help teachers build their confidence and ability to implement PBL effectively, become knowledgeable about design and engineering pedagogical practices and principles (e.g., Crotty et al., 2017; Cunningham & Lachapelle, 2014), and dedicate time for collaborative curriculum and instructional development.

Table 6
Critical Characteristics Related to Achieving I-STEM Learning Outcomes

	Please rate how critical these are to achieving integrative STEM learning outcomes.	Mean	*SD*	Round	*n*
1	Ensure students engage in designing, engineering, making, testing, reflecting, and documenting.	4. 82	0.50	1	22
2	Continuously improve strategies that develop students' reasoning, problem-solving, creativity, and critical-thinking skills.	4.68	0.65	1	22
3	Focus learning upon real-world problems and projects.	4.64	0.58	1	22
4	Focus learning upon open-ended assignments that require students to reason using an integrated approach.	4.64	0.49	1	22
5	Encourages commitment to learning as a lifelong process.	4.61	0.50	2	18
6	Encourage creative thinking assignments which also engages in complex and difficult content.	4.59	0.59	1	22
7	Promote the use of technology and engineering processes for modeling and testing solutions.	4.59	0.59	1	22
8	Focuses on student-centric pedagogical approaches	4.56	0.62	2	18
9	Assure that part of the learning process comes from exploring uncertainties and constructing knowledge from experience.	4.55	0.60	1	22
10	Provide opportunities for students to pursue solutions to problems or needs within the local community.	4.50	0.80	1	22

Professional Development

"Effective educational leaders [have an obligation to] develop the professional capacity and practice of school personnel to promote each students' academic success and well-being" (National Policy Board for Educational

Administration, 2015, p. 14). To do so requires an assessment of staff learning needs, awareness of effective strategies that stimulate STEM learning, the selection or development of a professional learning program matched to that need, and resources to implement the impact of the initiative.

This study indicates that a critical characteristic of an I-STEM leader is to engage and sustain school staff in professional learning that enhances their STEM teaching practice by providing effective models of preferred I-STEM pedagogies, including inquiry, experimentation, design, and engineering (see Table 7). Panelists emphasized that time and resources were essential to exploring their own ideas for I-STEM approaches, but also valued mentoring and peer-to-peer coaching as part of their professional learning process.

Table 7
Critical Characteristics Related to Professional Development

	A STEM leader striving for excellence …	Mean	*SD*	Round	*n*
1	provides time and STEM-related professional development for educators to enhance their teaching practices.	4.71	0.46	1	21
2	encourages, supports, and challenges teachers to revise and explore their ideas for new I-STEM approaches.	4.67	0.58	1	21
3	provides mentoring or peer-to-peer coaching among staff members on I-STEM.	4.57	0.51	1	21
4	provides effective models in the instructional use of inquiry, experimentation, design, and engineering pedagogies.	4.57	0.75	1	21

School leaders have partnered with a plethora of PD providers, both nonprofit and for-profit, to enhance STEM teacher pedagogies and understanding of STEM content. Often, workshops and institutes mirror the learning process that their students would experience when encountering similar design challenges in school. Evidence regarding the impact of these PD programs on teacher practice is inconsistent. However, PD programs that were longer in scope and provided on-site or online support tended to show more positive impacts, especially regarding increasing one's teaching efficacy (e.g., Havice et al., 2018).

Job-embedded or site-embedded strategies should also be considered because they offer more continuous, personalized opportunities for professional learning within the teaching environment. Common strategies include peer observation, peer coaching (Staley, 2018), and integrated PD and curriculum design initiatives where STEM teachers learn together while collaboratively developing curricular units (McFadden & Roehrig, 2017). For job-embedded strategies, the STEM leader must bring to bear expertise as a collaborative facilitator, coach, and mentor as well as more extensive knowledge of STEM content and pedagogies. This expertise is invaluable in helping staff face their biases, overcome fears associated with using open-ended inquiry and design pedagogies, and build teaching efficacy.

Infrastructure and Programming

Developing spaces and facilitating time for meaningful I-STEM education planning and implementation involves “a reinvestment in usable instructional tools, including modern technology, to support transformative learning” (Basham, Israel, & Maynard, 2010, p. 18).

In this study, critical characteristics included creating school infrastructure and programming that provide accessible STEM learning and laboratory spaces that enabled inquiry, experimentation, and engineering to all students (see Table 8). Panelists indicated the need for current and relevant materials, resources, and technology in the learning spaces and time in the schedule that allows for authentic and collaborative learning to take place. Additionally, panelists emphasized the importance of shared teaching and planning times for educators as a part of an integrative, transdisciplinary approach to teaching STEM.

Table 8
Critical Characteristics Related to Infrastructure and Programming

	An effective STEM leader creates the school infrastructure and programming that...	Mean	*SD*	R	*n*
1	has STEM learning spaces accessible to all students.	4.79	0.41	1	24
2	has laboratory spaces equipped with technologies that enable inquiry, experimentation, and engineering.	4.63	0.49	1	24
3	provides appropriate and up-to-date materials, resources, and technology that facilitate integrative approaches to learning.	4.63	0.58	1	24
4	implements a schedule which allows time for authentic learning.	4.56	0.62	2	18
5	promotes transdisciplinary learning—wholistic understandings—through coplanning and coteaching.	4.56	0.70	2	18
6	has learning spaces that enable collaboration and project work among students.	4.54	0.59	1	24

The environment of I-STEM schools, classrooms, and programs should encourage collaboration, shared leadership, and knowledge sharing opportunities among teachers, students, and school leaders (Spillane, Lynch, & Ford, 2016). In a qualitative case study of an I-STEM model in one school district, Gardner and Tillotson (2019) found that school administrator support and encouragement regarding access to the Internet and technological devices for all students, schedules for teacher collaboration, and intentional pairing of teachers for coteaching promoted innovative experiences for students to learn, discover, and achieve in school.

The I-STEM leader must consider infrastructural school features that provide all students with access to educational spaces and current technologies for students to collaboratively explore engineering techniques and experimentation. To facilitate growth in I-STEM, makerspaces are becoming more popular and are utilized more in educational settings (Fasso & Knight, 2019). Within the school building, the development and use of makerspaces may be considered to facilitate exploration, experimentation, and teamwork to solve ill-defined problems.

Evaluation and Assessment

"A major aspect of expanding STEM education programs is providing compelling evidence of their effect" (Malyn-Smith, Na'im, Cedrone, & Supel, 2013, p. i); therefore, STEM leaders should be able to document evidence of I-STEM merit, deliver informed judgment, and communicate actionable feedback that would lead to measurable program outcomes. Delphi participants rated skills of conducting systematic evaluation and assessment as critical for an I-STEM leader while emphasizing that "providing actionable feedback to teachers" was the most critical (see Table 9).

STEM leaders should employ evidence from multiple sources to guide classroom- and school-level programming decisions. For example, performance-based assessments can convey to what extent the student is a good thinker and designer (Shively, Stith, & Rubenstein. 2018). Performance-based assessments were also identified by Delphi participants as a critical characteristic to promote inquiry, design-based, project-based, and problem-based learning. In their investigation of higher order proficiency through school-wide, performance-based assessment models, Ernst, Glennie, and Li (2017) found that "students demonstrated proficiency specific to brainstorming through drawing maps, exploration through collecting and tabulating data, and research and investigation" (p. 24). However, the researchers noted that proficiency separations amongst school sites were potentially impacted by school climate, individual teacher willingness and attitude to pursue performance-based assessments, and classroom practices.

Participants also rated the educational leadership's capabilities to align evaluation and assessment as critical for striving for excellence. In the state of

Indiana, the Indiana Department of Education (2019) has embedded alignment of academic standards within the STEM-certified school evaluation instrument. The expertise to assess the merit of I-STEM classroom and programming strategies are important qualities of a STEM leader because these outcomes are not traditionally measured in schools. Research has shown that STEM programs with purposeful STEM assessments positively increased STEM perceptions and career interest among diverse student populations (Lam, Doverspike, Zhao, Zhe, & Menzemer, 2008) and encouraged collaboration with stakeholders (Huffman, Lawrenz, Thomas, & Clarkson, 2006).

Table 9
Critical Characteristics Related to Evaluation and Assessment

	A STEM leader striving for excellence…	Mean	*SD*	Round	*n*
1	provides actionable feedback to teachers that enhances STEM instruction.	4.71	0.56	1	21
2	encourages the development and use of authentic performance assessment for design-based, project-based, and problem-based learning activities.	4.67	0.49	2	18
3	uses a variety of methods to measure students' understanding of and ability to implement an engineering design process.	4.67	0.49	2	18
4	Uses observation protocols to support high-quality STEM instruction.	4.64	0.58	1	21
5	gathers data from multiple sources to inform the evaluation of STEM programs.	4.62	0.50	1	21
6	develops a systematic process for evaluating STEM programs.	4.52	0.68	1	21
7	effectively evaluates the vertical alignment of I-STEM curriculum.	4.52	0.60	1	21
8	models how to provide actionable feedback to students that enhances their STEM learning outcomes.	4.52	0.68	1	21
9	assures that STEM evaluation and assessments are aligned with grade-level state standards.	4.50	0.62	2	18

Extended Learning

No characteristics in the Extended Learning category were rated as critical characteristics in this study. There are, however, compelling reasons for STEM leaders to form partnerships with community organizers and extend STEM learning opportunities beyond the school day. Heintz (2014) indicated that

STEM programs that take place outside of the school day promote partnerships with school and district staff, families, and community stakeholders, thus supporting the creation of internships, mentorships, and collaborative projects.

Researchers reported that STEM-focused extended learning opportunities increased students' interest and motivation in STEM, enhanced their perceptions of STEM subjects, and enhanced their understanding and practice in STEM fields (Chittum, Jones, Akalin, & Schram, 2017; Moreno, Tharp, Vogt, Newell, & Burnett, 2016). According to the Afterschool Alliance (2018), afterschool programs make "STEM more accessible, more interesting, and helps to build fluency" by engaging "students in hands-on, real-world projects," encouraging them to be entrepreneurial and innovative (p. 1). Afterschool robotics clubs and competitions have demonstrated several positive outcomes, such as increasing confidence in problem-solving and computer programming among students of underrepresented populations (Karp & Maloney, 2013).

In addition to afterschool programs, leaders should enable STEM-related learning experiences outside of the classroom, such as museum visits, science fairs, and field trips, and sponsor STEM-related student organizations or competitive teams, such as the Technology Student Association or Odyssey of the Mind. Alternatively, I-STEM leaders may encourage the use of simulations, media tools, and virtual environments that engage learners beyond the regular school day. STEM leaders should seek and foster partnerships with universities, 4-H, museums, and community centers for the development and delivery of services to underrepresented populations in STEM fields.

Limitations, Conclusions, and Recommendations

The reader should be alert to biases of the panel and researchers who reside at the same institution. The Delphi panel was purposefully populated with STEM education experts and school leaders whose schools had successfully achieved Indiana STEM certification. Thus, the results are likely biased toward the Indiana STEM certification criteria.

I-STEM education initiatives strive to prepare students as STEM-capable citizens in a scientifically and technologically driven world. Six themes were identified as critical for I-STEM leaders who strive for excellence, including mission and culture, curriculum and instruction, equity and social responsibility, infrastructure and programming, professional growth, and evaluation and assessment. The results are intended to inform the development and evaluation of programs that prepare school leaders who seek to advance I-STEM.

Recommendations

We recommend that institutions of higher education embed I-STEM leadership content in current courses or design and implement new leadership courses or programs to meet the needs of school and teacher leaders. Preservice and in-service building- and district-level administrators need to deepen their understanding of STEM education in order to promote innovation in I-STEM education, especially as it relates to supporting teachers' use of student-centered pedagogies, building their collaborative facilitation and STEM coaching skills, and fostering community partnerships.

Policymakers should fund and offer incentives to I-STEM leaders who implement evidence-based STEM practices, especially job-embedded PD programs, that empower teachers to develop, implement, and assess locally relevant I-STEM curriculum. To further diffuse I-STEM education, policymakers should support a centralized network by which I-STEM leaders could access STEM research, programming strategies, willing community partners, and PD opportunities.

Researchers should pursue the following questions: What are the conditions that best build I-STEM leaders' facilitation and coaching skills? What quality indicators are appropriate for evaluating I-STEM graduate and PD programs? Furthermore, the emergence of STEM certification programs indicates opportunities to examine and compare the impact of these programs upon certified and noncertified schools.

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Book Review

Fleming, K. (2016). *The leader's guide to emotional agility: How to use soft skills to get hard results*. New York, NY: Pearson. ISBN: 9781292083070 (Paperback), $16.23, 208 pages.

Technology education is often discussed as a dying profession. According to Volk in his 1997 article reviewing technology education teacher preparation programs, "the demise of the technology teacher preparation programs will occur around the year 2005" (p. 69). The number of technology education teacher preparation programs across the United States, programs that train educators to teach critical thinking about technology tools, are disappearing at an astonishing rate. Without teachers for the programs, tool-based instruction will cease, and our society will not be educated to look at tools in a critical manner. The number of technology education teacher graduates has decreased by 68.35% between the years of 1995 and 2008 (Moye, Jones, & Dugger, 2015). Currently, only 24 undergraduate technology and engineering teacher preparation programs with an enrollment of 20 students or more exist in the United States (Litowitz, 2014). The steady decline of programs that prepare technology and engineering education teachers has been a consistent issue for over 40 years (Moye et al., 2015). In the Commonwealth of Virginia, there is currently only one program that trains students in undergraduate technology education, which is housed in the STEM Education and Professional Studies Department (STEMPS) at Old Dominion University (ODU). Virginia was instrumental in the creation of the *Standards for Technological Literacy* and has been a leader in technology education since the name change from industrial arts in 1978. However, the undergraduate technology education programs at Virginia Tech, James Madison University, Norfolk State, and Virginia State University have all become inactive, making the technology education program at ODU the last remaining program in the Commonwealth.

In order to change this trend, our leaders must begin to re-envision the curriculum and implementation of design. According to research, our field has had a steady decline for over 20 years. Instead of arguing about the reasons, we, the leaders in our field, need to develop new ideas and pathways to implement this valuable curriculum. We need to have discussions that go beyond dismay at our demise and suggest changes that will allow our teacher preparation programs to grow.

My recent read of Kerry Fleming's book, *The Leader's Guide to Emotional Agility: How to Use Soft Skills to Get Hard Results*, helped me to frame our field in a new light. The book caught my attention with its development of emotions as part of a leadership plan. The concept of *emotional agility* was introduced by David and Congleton (2013) to describe the ability to recognize and use positive and negative emotions and the inner voice to develop thoughtful and productive actions. Fleming uses the concept of emotional agility to outline how to become an emotionally reactive leader and how to develop applications in which leaders can use their understanding of emotions in order to develop teams, motivate, and promote innovation.

Key Concepts

Fleming outlines seven steps to becoming a more emotionally aware leader in the first section of his book. The steps include becoming authentic, becoming self-aware, becoming aware of others, using and understanding emotions, managing your own emotions, managing the emotions of others, and creating awareness. The book is written with reference to current research in the areas of emotional intelligence and agility. Each chapter provides background and research on the topic discussed, a case study, an exercise, and a summary that reviews key points of the chapter.

The second part of the book explores the application of the concept of accepting and recognizing emotions in the workplace. Part 2 is written in the same manner as Part 1 with research-based psychotherapy activities and background that lead to exercises and case studies. Part 2 also includes performance tips for the application of each chapter's concept. Part 2 concepts include using emotional agility for difficult performance appraisals, motivating a disengaged team, promoting creativity and innovation, making changes in your organization, and becoming a more effective leader.

Application to Our Curriculum and Leadership

Although this book may be an easy read, it includes many new concepts that could enhance our field. In the age of cutting costs and going digital, our leaders have forgotten the most important aspect of our field: the passion of our teachers for their work. That passion has gone unchanged since the writings of Dewey. "Dewey's concept of experience allows a holistic approach to education, in the sense that it is based on the interaction between the human being and the world" (Hohr, 2013, p. 25). Dewey promoted the idea that learning should be experienced. The human experience includes not only knowledge but also emotions and feelings. Design is not only based on acuity but is also based on the abstract concept of aesthetics. What is beautiful to one person is not to another because of their emotional reaction to or feelings about design. Teaching design-based learning requires the curriculum to include less concrete concepts such as aesthetics and human interactions with the product. In a field based in human emotion, leaders in our field need to recognize and speak to these emotions in our meetings, literature, and lobbying efforts. We need to share our passion and create a stronger, more interactive environment for curriculum training. We need to recognize the need for human interactions when developing meeting schedules and care about the people in our field. In new endeavors to save money by creating online meetings, we still need to connect with our members on a personal level. In the face of dwindling teacher training programs, we should change the tactics that have brought us to this point. Focusing on curriculum and content is important; however, the strength in our curriculum lies in the human (and emotional) connection to design. Concentrating on the value of passion in our curriculum may be the key to strengthening our field and bringing technology education to the forefront again.

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Book Review

Organisation for Economic Co-operation Development. (2015). *Skills for social progress: The power of social and emotional skills*. Paris, France: Author. ISBN: 978-92-64-22614-2 (Print); ISBN: 978-92-64-22615-9 (PDF), doi:10.1787/9789264226159-en, 136 pages.

To the uninitiated observer, technology and engineering education classrooms often appear to be places of organized chaos. This oxymoronic term describes a complex environment- that appears on the surface as disorganized and haphazard while actually functioning with clearly defined objectives and operating procedures embraced by the participants ("Organized Chaos," n.d.; National Center for Learning Disabilities, 2014). These classes are marked by a sense of greater mission. Students have the freedom to toggle between independent and collaborative work and use a variety of tools—both traditional and high tech. The end result of this organized chaos might be a physical prototype or a 3D rendering of a solution or the delivery of a presentation; however, the true value in this loose philosophy lies in the soft skills that students develop along the way.

In *Skills for Social Progress: The Power of Social and Emotional Skills*, the Organisation for Economic Co-operation Development (OECD) quantifies the value and role of social and emotional skills, also known as soft skills, in global education. Hurrell, Scholarios, and Thompson (2012) define soft skills as "nontechnical and not reliant on abstract reasoning, involving interpersonal and intrapersonal abilities to facilitate mastered performance in particular contexts" (p. 162). OECD's *Skills for Social Progress* provides an overlapping and more digestible definition for social and emotional skills, describing them as "the kind of skills involved in achieving goals, working with others and managing emotions" (p. 34), exactly the kind of skills gained by students in the organized chaos of technology and engineering education classrooms. The central finding of *Skills for Social Progress* is that social and emotional skills are increasingly necessary to succeed in the labor market and lead to increased civic engagement and overall life satisfaction. Accordingly, if students need social and emotional skills to succeed in life and technology and engineering education develops these soft skills, the data and conclusions presented in *Skills for Social Progress* support the need for technology and engineering education.

Overview

Comprised of 36 member countries, the OECD (2019) works to "build better policies for better lives" by "establishing international norms and finding evidence-based solutions to a range of social, economic and environmental challenges" (paras. 1–2). *Skills for Social Progress* is one of many publications from the OECD that deals with the broad topics of education and the labor market; however, this is the organization's first book to specifically link both cognitive and social and emotional skills to individual well-being and social progress. Nine OECD countries, including the United States, participated in the study that resulted in *Skills for Social Progress*. The chapters are logically organized, beginning with a detailed description of the state of the world: Access to education is up, youth employment is down, obesity is staggeringly high, incidences of bullying continue to skyrocket, and civic engagement is in decline. With this established, the authors then move on to conceptualizing the relationship between learning contexts, skills, and social progress before progressing to a detailed analysis of the correlations between cognitive, social, and emotional skills and children's outcomes. A variety of tables and graphs are utilized throughout the book, making the content easy to understand.

A Missed Opportunity

Multiple chapters in the book are dedicated to examining contexts in which social and emotional skills bloom. Although a variety of factors nurture this skill development, the OECD authors specifically identify families, schools, and communities as being highly influential in creating a "holistic and coherent" environment for children (p. 90). In addressing the role of the school, *Skills for Social Progress* holds that it is not necessary to carve valuable time out of the school day to teach social and emotional skills in isolation; instead, these skills can be effectually developed within existing subjects by "introducing project-based work that involves dynamic and interactive problem solving based on real-life problems" (p. 85). Despite using these words that so aptly describe technology and engineering education, there is no mention by name of the value of this existing part of the general education curriculum. The authors of *Skills for Social Progress* missed an opportunity to present readers with a ready-made, easily-implementable solution to the question: How do we teach social and emotional skills? The answer is to look to our technology and engineering classrooms. This book only represents the beginning of the research necessary to truly understand the development of social and emotional skills and the impact of these skills on the world, the OECD is embarking on a more involved journey to collect longitudinal data from a variety of OECD countries. Hopefully, this future research will yield even more rich data and will acknowledge technology and engineering education as a viable means to increase social and emotional skill development.

Conclusion

James Heckman, American economist and Nobel laureate, and Tim Kautz (2012) asserted that "soft skills predict success in life" (p. 451). The data and conclusions presented in *Skills for Social Progress* undoubtedly support this claim. Social and emotional skills play a key role in the future well-being of children and provide a clear path for continued social progress. Technology and engineering educators are constantly asked to defend their worth and define their place within the larger educational curriculum. *Skills for Social Progress* provides evidence that although cognitive skills will always remain important, the need for the development of solid social and emotional skills is on the rise. Enterprising technology and engineering educators would be well suited to use *Skills for Social Progress* as a means to garner support for their classrooms, dynamic places of organized chaos in which soft skills naturally flourish.

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Book Review

Caldwell, J. (2018). *Creative coding: Lessons and strategies to teach computer science across the 6–8 curriculum*. Portland, OR: International Society for Technology in Education. ISBN: 9781564846761 (Paperback), $ 37.95, 138 pages.

Integrating computer science (CS) instruction into K–12 classrooms is now part of education reform in many school systems throughout the United States (Tate, 2018). Currently, forty-four states have adopted at least one of nine policies for providing students access to CS education (Tate, 2018). Moreover, this trend has also created suggestions and efforts to include CS into technology and engineering (T&E) education curriculum (Buckler, Koperski, & Loveland, 2018; Hacker, 2018; Love & Strimel, 2016). To help educators with making this transition, in this first edition, Caldwell provides the K–8 educational community assistance in developing foundational knowledge of both CS and coding as well as tips for collaboration. As teachers build their knowledge of CS, the book also provides them with lessons, strategies, and technology tools that connect computational thinking, coding, and aspects of CS to English language arts, mathematics, science, social studies, and other content and subject areas.

At first glance, Caldwell appears to write primarily to content-area teachers because of the emphasize of aligning CS to ELA, math, science, and social studies. However, he clarifies his position in the introduction of the book by highlighting a section titled "For the Technology or CS Teacher." In this section addressing technology teachers about the importance of teachers working together to make curricular connections for students, he states:

> For those already teaching computer science or coding in some form, you'll find this book to be a useful foot in the door to build cross-curricular opportunities for your students. While all of these projects could be used directly without modification in your technology class, I would urge you to use the content area contextual supports to work your peers teaching other courses. The arguments for teaching CS in each content area and the standards are there to help you make your case for initiating this collaboration. (p. 4)

Additionally, Caldwell expresses that by collaborating with colleagues in other content areas, technology teachers would demonstrate the value of their course or courses while strengthening the learning of CS and coding for students in their schools. This is very important because T&E education course content helps teach and reinforce key concepts and practices found in the standards of the four core disciplines through reading and writing, ratio conversion, engineering design, and the impacts of technology on society and the environment (just to name a few connections). Therefore, using T&E teachers to aide in the teaching of CS would aide with cross-curricular efforts in schools and in connecting learning for more students.

Throughout the book, collaboration is not just highlighted for educators. As a tool for furthering the learning of CS and coding, the author also provides methods for developing positive group dynamics amongst students. Regarding the practice of students collaborating around computing, he states:

> Any time you're asking students to work collaboratively, whether pair programming or in larger groups, this can be a great practice to help students improve their general collaboration and communication skills. In this practice students should be working towards the following goals:
> 1. Cultivate working relationships with individuals possessing diverse perspectives, skills, and personalities.
> 2. Create team norms, expectations, and equitable workloads to increase efficiency and effectiveness.
> 3. Solicit and incorporate feedback from, and provide constructive feedback to, team members and other stakeholders.
> 4. Evaluate and select technological tools that can be used to collaborate on a project. (p. 101)

These collaboration goals described by the author are critical for students to achieve when completing activities in T&E projects because they will learn how diverse people solve computing problems in tandem with technology.

Relevance to Technology and Engineering Education

The author challenges educators to teach students programming skills in authentic and creative ways. Caldwell writes:

> Programming sometimes gets a bad rap for being boring, uncreative, and isolating. None of that's actually true, but sometimes perception dictates reality. Break that stereotype by showing students authentic uses for Computer Science and giving them ownership over how they get to engage with those authentic applications. (p. 32)

Many T&E teachers already infuse programming into classroom projects through the use of various technology tools such as robotics and microcontrollers. However, suggestions in the book provide activities that use a variety of technology (e.g., tutorials and app design). T&E teachers can use these activities to help their students further enhance their programming and coding skills by applying their knowledge through multiple scenarios and contexts. Moreover, students enrolled in T&E classes already participate in real-world design challenges that are open-ended and academically rigorous. More concentrated efforts to infuse CS, programming, and coding into design challenges may propel some T&E students to pursue critical computing jobs while still achieving competency in technological literacy. According to the K–12 Computer Science Framework Steering Committee (2016), CS is the discipline that enables the use of computers and is the driving force of innovation in all industries and fields of study. Therefore, it is critical that T&E classes promote preparation for computing jobs.

Key Points of Agreement

The author points out that coding is ubiquitous and stresses that all students should learn to code as a foundational skill regardless of what career or studies they plan to pursue. According to Caldwell,

> We teach students about the digestive and circulatory systems not because we expect all students to become doctors, but because we expect engaged citizens to have a fundamental understanding of the world around them. I would argue that how the internet or a smartphone works is at least as essential as the basic biology that we teach all students. How do we expect students to engage thoughtfully in discussions around internet regulation, information privacy, or the role of artificial intelligence without at least a baseline understanding of Computer Science? (p. 9)

These are critical suggestions that can be readily facilitated in T&E classrooms because these are items that pertain to technological literacy. Additionally, the author provides tips and resources in Chapters 4–7 for helping students build the most basic and foundational coding skills through unplugged activities that do not require technology. Unplugged activities are a great scaffold because they allow teachers to introduce CS in ways that assist learners with understanding foundational CS skills. Some of the skills referenced in the book include how to store data, communicate, break down problems into smaller components, and create algorithms for solving problems logically. As the comfort levels and problem-solving skills of students improve, they can move on to more complex and plugged-in scenarios.

Recommendations for Future Editions

In this book, Caldwell made a rigorous effort to provide all teachers interested in integrating CS and coding across sixth- through eighth-grade curriculum with the foundational tools and activities needed for getting started. Although software development is mentioned, many readers would be interested in knowing what software development looks like in the workplace so that they can mimic the process with students. In T&E classrooms, the hierarchy of the software engineering profession can be a useful visual for this purpose (The

Genius Blog, 2017), and an adaptation of it could be incorporated in a future edition. Because both coders and programmers provide the detail work in computer programs and because it pertains to the software development life cycle (SDLC), T&E teachers should inform students that both software developers and software engineers utilize the SDLC for organizing and solving more extensive and complex problems (Hussung, 2016). Also, software engineers act as project managers and do the work of engineers by designing the specs and documentation required by the coders and programmers. Future editions of the book could benefit from such additions.

Conclusion

Caldwell has written an important book filled with tools and resources for T&E and content area teachers looking for ways to integrate CS and coding into their classes. This review has focused on the topics of developing foundational knowledge of CS and coding and increasing collaboration in T&E classrooms. Additionally, the book provides recommendations for content modification, specifically for T&E teachers, with suggestions for the development of an app or apps that can make a myriad of the calculation's students use while designing. Examples of calculations that T&E educators could have students develop an app for include the circumference of a circle and the length of a triangle's sides. Due to these and other logical connections to T&E, it is hoped that readers will begin to infuse CS core concepts and practices into their coursework. The author of *Creative Coding* compels us to make some additions to our curriculum and provides adequate resources for getting started.

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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.

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

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