Contents

Articles

Book Review

Miscellany

Social Adjustment of At-Risk Technology Education Students

Educators at all academic levels strive to provide students with a high-quality education while maintaining an environment that promotes learning as well as the health and well-being of each individual. However, in a 2011 study, Preble and Gordon recognized that there are confounding difficulties challenging K–12 education, such as student feelings of social isolation and collective student emotional needs not being adequately met. Students identified with at-risk indicators (students with disabilities, students from economically disadvantaged families, or students with limited English proficiency) are specifically susceptible to experiencing the difficulties firsthand (Ernst, Bottomley, Parry, & Lavelle, 2011). Despite numerous readdress and transformation initiatives, these challenges persist in many schools (Preble & Gordon, 2011). Many of these educational challenges are brought on by low social competence or poor social adjustment (MacKay, Knott, & Dunlop, 2007). Krips, Lehtsaar, and Kukemelk (2011) pose that social competence is composed of dimensions pertaining to personality, appropriateness, communication, and human relations, thus highlighting a critical structure for sociometrics.

Abraham Maslow (1970) identified that once a person's basic physiological and safety needs are satisfied, "there will [then] emerge the love and affection and belongingness need" (p. 20). The school setting is one of the first places where an individual will find himself or herself wanting to fit in. Iyer, Kochenderfer-Ladd, Eisenberg, and Thompson (2010) indicated that, "one of the primary tasks of childhood is successful adjustment in the school context, including consistent academic progress across the school years" (p. 362). Students are not exclusively learning course content; they are also learning how to deal with others in the social environments of classrooms, school, and life. Maslow also stated, "All people in our society have a need or desire for a stable, firmly based, usually high evaluation of themselves, for self-respect or self-esteem, and for the esteem of others" (1970, p. 21). Specific to social competence, investigation addressing the sub-population of students at-risk engaged in technology education courses has been insufficient.

The technology education classroom has potential as a vehicle for students to improve self-esteem, social skills, and ultimately fit in the school environment. Cardon found that "the majority of students that he surveyed stated, 'if they had not been allowed to enroll in the technology education courses, they would have dropped out of school" (2000, p. 54). Referring to the technology education classroom, Moye (2011) stated that students "get the

Jeremy V. Ernst (jvernst@vt.edu) is an Assistant Professor in Integrative STEM Education at Virginia Polytechnic Institute and State University. Johnny J. Moye (johnnyjmoye@gmail.com) is Supervisor of Career and Technical Education at Chesapeake Public Schools, Chesapeake, Virginia.

opportunity to communicate (socialize) with their peers. This interaction will require students to learn and use social skills in a controlled environment, something that may not be possible in other courses and classrooms." (p. 28). Further supporting the notion that technology education courses help improve students' social adjustment, Ritz and Moye (2011) identified:

> Important parts of this self-efficacy development are the compliments given to strengthen certain performances and to remove negatives by verbally correcting the learner. Again, in an engineering and technology education learning environment, social and verbal persuasion should be natural for teachers. (p. 3)

Technology education offers students a Science, Technology, Engineering, and Mathematics (STEM) based education, while reinforcing the soft skills necessary to be successful in school, in the workplace, and in society (McAlister, 2009; Moye, 2008, 2011). In technology education, information is presented to students in a contextualized manner, facilitating enhanced understanding (Crawford, 2001; CORD, 2010; Moye, 2008; Ritz & Moye, 2011; Threeton, 2007). Based on contemporary views of motivation theory, interest and student understanding of the actual educational basis underpinning content provides for motivated learning (Murray, 2011). As learners find motivation and experience successes through educational progression, they develop heightened confidence (Ritz & Moye, 2011). If successful experiences evade students, there is an increased likelihood of occurrence of the "Mathew Effect" (Stanovitch, 1986) and often students "give up on school entirely and physically drop out or they continue slogging along with no real hope of ever really making it in school" (Pete & Fogarty, 2005, p. 8).

Nash (2002) identified that, "cognitive and self-efficacy theories suggest that a positive sense of school coherence, belief that school is a comprehensible, manageable, and responsive environment, may be an important individual-level factor for success at school" (p. 76). This is considerably aligned with current educational trajectories, requiring a robust educational experience that provides students with more than just academics. These fully structured approaches to education are developed to also produce students who are:

> Culturally literate, intellectually reflective, and committed to lifelong learning. High-quality education should teach young people to interact in socially skilled and respectful ways; to practice positive, safe, and healthy behaviors; to contribute ethically and responsibly to their peer group, family, school, and community; and to possess basic competencies, work habits, and values as a foundation for meaningful employment and engaged citizenship. (Greenburg, et al., 2003, pp. 466–467)

Considering the broader scope and inclusive expectation of contemporary educational outcomes, formulation of an inviting and healthy school climate that is conducive to the wider spectrum of education that spans academics and social aspects is necessary (Caldarella, Shatzer, Gray, Young, & Young, 2011).

Definition of Students At-Risk

There are varying definitions of *students at-risk*. Sagor and Cox (2004) identify students at-risk as "any child who is unlikely to graduate on schedule, with both the skills and self-esteem necessary to exercise meaningful options in the areas of work, leisure, culture, civic affairs, and inter/intra personal relationships" (p. 1). McCann and Austin (1988) described three overarching characteristic categorizations of a student at-risk:

1. Learner in severe danger of not attaining the ends of education exhibited through failure to reach local or state standards for high school graduation and/or failure to gain the understandings, skills, and dispositions to become an industrious participant of society
2. Learner who displays actions that instructors categorize as interfering with the learning and educational processes
3. Learner whose domestic or community upbringing and/or experience may place him or her at-risk

Conventionally, educationalists have examined the economic status of students and used it as an initial indication in efforts to determine if a student is at-risk of not succeeding in school (McCann and Austin, 1988). Given the susceptibility for students at-risk to discontinue education and the previously identified value of social competence and social adjustments promotion of school climate and the development of academically conducive environments, what is the degree of social competence for technology education students identified as at-risk? For the purposes of this study, students classified as economically disadvantaged based on receipt of government aid through food vouchers/free or reduced-price school lunch as a result of their family being identified as "low-income" according to the Department of Health and Human Services Poverty Guidelines are at-risk (Department of Health and Human Services, 2011).

Schooling, Social Climate, and Students At-Risk

The expansion of social competence is a vital objective of education for each learner. Socially vulnerable students are acutely susceptible to social and academic failures (Walker & McConnell, 1995). One significant influencer of socially conducive structure is school climate (Caldarella, et al., 2011). There are many factors that affect school climate. One of the most important factors is "the relationships that students have with their peers and adults in their school" (Preble & Gordon, 2011, p. 15). An adverse school climate results in "inadequate academic performance, unmotivated students, and frustrated teachers" (Preble & Gordon, 2011, p. 11). Improving school climate fosters an enhanced learning environment that promotes student successes and provides the basis for social adjustment. Moye (2011) identified that there are students who solely attend school as a result of social opportunity. This highlights the strong social basis that school provides beyond academics. Ballentine and Spade (2008) stated, "in the period extending from entry into first grade until entry into the labor force or marriage, the school class may be regarded as the focal socializing agency" (p. 81). However, there are social aspects of a school's climate that have lasting negative impacts on students. School climate is one case in which school climate is deteriorated and social adjustment is hindered. However, in an age where schools are struggling to make Annual Yearly Progress (AYP) and trying to improve student standardized test scores, "addressing school climate issues and the social and emotional development of students remain secondary goals of most schools" (Preble & Gordon, 2011, p. 30). Technology education courses provide an opportunity for students to work and learn in a team setting. When students work together, they have the opportunity to communicate (socialize) with one another. In addition to helping improve students' core academic success, schools can use technology education courses to help improve the school climate.

"Success breeds success. As some students progress through school, the number of successes diminishes" (Moye, 2011, p. 26). People must realize success in an activity in order to have a desire to continue that activity (Maslow, 1970). Students must adequately adjust to the school environment (feel safe and be accepted) in order to fully integrate into a group or class (Tomlinson, 2003). Technology education classrooms could be a resource for developing students' social adjustment, including those considered at-risk.

Research Questions

The goal and intent of this exploratory research project was to identify the degree of social competence exhibited by technology education students identified as at-risk. Self-control, peer relations, school adjustment, and empathy categorizations provide a depiction of the level of social competence (Walker & McConnell, 1995). Supplemental to the social competence measure, linkages between peer relation and school adjustment competencies were gauged to determine associations.

The following research questions guided this exploratory project:

1. Are there differences in social competence between technology education students considered at-risk and a normative student sample?
2. Is there competence measure association between social competence subscale elements (self-control, peer relations, school adjustment, and empathy) for technology education students identified as at-risk?

Research Question #1 was evaluated using an investigational hypothesis: There are no differences in means of the Walker-McConnell normative sample and the technology education student at-risk sample regarding overall social competence and school adjustment.

Study Participants

Participants in this exploratory research project were students determined to be at-risk attending an urban high school located in the southeast region of Virginia. Testing previous evidence that technology education improves students' self-esteem and social skills (Cardon, 2000; Moye, 2011; Ritz & Moye, 2011), the researchers provided two technology education teachers with the selection criteria, based on economically disadvantaged conditions, to identify their students at-risk. Of approximately 120 students, the teachers identified 101 as at-risk. Participant demographical information for students who were determined to be at-risk can be found in Table 1.

Table 1
Technology Education Student Participant Demographics

Gender *n* – (%)	Male	87 – (86%)
	Female	14 – (14%)
Age *n* – (%)	14 Years Old	5 – (5%)
	15 Years Old	16 – (16%)
	16 Years Old	26 – (26%)
	17 Years Old	28 – (28%)
	18 Years Old	21 – (20%)
	19 Years Old	3 – (3%)
	Not Specified	2 – (2%)
Grade *n* – (%)	9th Grade	27 – (27%)
	10th Grade	22 – (21%)
	11th Grade	27 – (27%)
	12th Grade	24 – (24%)
	Not Specified	1– (1%)

Instrumentation

The Adolescent Version of the Walker-McConnell Scale of Social Competence and School Adjustment, through Singular Publishing Group/Cengage Learning, was employed for the purposes of this study. The scale consists of 53 observable items that are rated (1–5 ranging from *never* to *frequently*, respectively) based on student classroom behaviors over time. Each item corresponds to a randomized subscale that is compiled after the completion of the scale. There are four subscales for the Adolescent Version of the Walker-McConnell Scale of Social Competence and School Adjustment: (a) Self Control, (b) Peer Relations, (c) School Adjustment, and (d) Empathy. The Self Control subscale consists of 13 items that reflect social maturity and developmentally appropriate behaviors exhibited (Walker & McConnell, 1995). The Peer Relations subscale focuses on humor, peer interaction, and cooperation within its 16 items. The School Adjustment subscale includes 15 items related to work habits, organization, and promptness. The Empathy subscale consists of six items that are associated with sensitivity and sympathy. Each is identified individually, but consists of four very interrelated dimensions. Test–retest reliability, internal consistency, and interrater reliability have been established for the Walker-McConnell Scale of Social Competence and School Adjustment (Demaray, Ruffalo, Busse, Olson, McManus, & Leenthal, 1995). In addition to student performance scale items and interrelated subscales, the instrument has mean and standard deviation reporting of 1,880 adolescent ratings that serve as the normative sample for outcome comparison.

Methodology

Technology education was selected as the specific educational discipline for the purpose of this exploratory study. Specifically, the applied nature of content, transferable relevance to life, and the structure that promotes social skill development through extended and consistent collaboration with peers led to the individual selection of technology education as the discipline for further exploration. Institutional and administrative approval was requested and granted to the research team for the purposes of this social competence study. Six sections of technology education students within a local education agency served as the sample. Two technology education teachers identified 101 of their students as at-risk. The teachers were provided with introductory, purpose, and instrument completion information for the Walker-McConnell Scale of Social Competence and School Adjustment (Adolescent Version). Three test profile-rating forms were completed for instrument procedure and content observation criteria. Teacher process and scale questions were addressed on an individualized basis by the researchers until there was identified comfort in conducting the item rating form and subscale identification. Once familiar with the scale, it requires approximately 10 minutes per student to complete the rating form (Walker & McConnell, 1995). At the onset of the 18th week of an 18-week course, course instructors initiated the social competence rating that factored recent course interactions and categorical behavior occurrences. The alphanumerically coded rating and subscale information was collected and entered by the social competence researchers. The coded social competence data from the two technology education sites was paired for analysis with the Walker-McConnell Scale of Societal Competence and School Adjustment 1,880-student national normative sample collected for the purposes of identifying social skill separation in individual students.

Data Analysis and Findings

A two-sample *z*-test was conducted based on mean, standard deviation, and sample size of the normative sample of the Adolescent Version of the Walker-McConnell Scale and the technology education student at-risk sample. The normative sample used to perform student comparisons and furnish diagnostic information across subscales was provided by the Walker-McConnell Scale User's Manual (Walker & McConnell, 1995). The *z*-test permitted a normalizing statistical evaluation of the normative sample and the technology education student at-risk sample. Research Question #1—Are there differences in social competence between technology education students considered at-risk and a normative student sample?—was evaluated through the calculation of a *z*-score using the following null hypothesis: There are no differences in means of the Walker-McConnell normative sample and the technology education student at-risk sample regarding overall social competence and school adjustment. Based on analysis of the *z*-statistic and the proportional value, the null hypothesis was rejected providing evidence that there was a significant difference between a normative sample and a sample of technology education students at-risk (see Table 2).

Table 2
Normative and At-Risk Walker-McConnell

Difference	*n*1 Norm	*n*2 At-Risk	Sample Mean	Std Err	*z*-Stat	*P*-value
Norm – At-Risk	1880	101	0.56	0.10	5.43	<0.0001

Additionally, the researchers conducted an itemized analysis of the Walker-McConnell Scale of Social Competence and School Adjustment profile items. These supplemental *z*-tests permitted identification of similarities and separations between technology education students at-risk and the normative group students. Although the vast majority of profile items were determined to be significantly higher for the normative group than that of the technology education at-risk group, items 15, 16, 17, 18, 22, and 23 of the 53 items were not. Table 3 (next page) identifies six of the 53 Walker-McConnell Scale items that were identified through the *z*-test as not significantly different from one another when considering students at risk and students from the normative sample.

Table 3
Normative and At-Risk Walker-McConnell Profile Items Not Significantly Different

Item	Profile Item	*n*1 Norm	*n*2 At-risk	Sample Mean	Std Err	*Z*-Stat	*P*-Value
15	Accepts the consequences of his/her actions	1,880	101	0.17	0.11	1.62	0.10
16	Has a sense of humor	1,880	101	0.15	0.10	1.53	0.13
17	Initiates conversation(s) with peers in informal situations	1,880	101	-0.03	0.09	-0.29	0.78
18	Expresses anger appropriately	1,880	101	0.08	0.10	0.83	0.41
22	Appropriately copes with aggression from others	1,880	101	0.19	0.11	1.73	0.08
23	Responds to conventional behavior management techniques	1,880	101	0.19	0.13	1.52	0.13

Based on the normality of the predictor and independent variable paired with the visually identified linear relationships, the researchers constucted a Pearson product-moment correlation matrix in an effort to determine if there are identifiable associations among Walker-McConnell subscales for technology education students at-risk (Sheskin, 2007). This procedure enabled direct investigation of Research Question #2: Is there competence measure association between social competence subscale elements (self-control, peer relations, school adjustment, and empathy) for technology education students identified as at-risk? Based on the correlation coefficients in the matrix (Table 4, next page), there are several large identifiable associations. The largest strength of association is noted between the Self Control subscale and the Empathy subscale (r = 0.92). Other subscale pairings, such as Peer Relations and Empathy (r = 0.73), exhibit a positive moderate association, while Self Control and Peer Relations (r = 0.64) and Peer Relation and School Adjustment (r = 0.64) show medium positive strength of association.

Table 4
Pearson Product-Moment Correlation Matrix for Students At-Risk

	Self Control	Peer Relations	School Adjustment
Peer Relations	0.64	-	-
School Adjustment	0.90	0.64	-
Empathy	0.92	0.73	0.90

Discussion and Conclusions

Individual technology education students' subgroup dynamic informs progressions of research while apprising technology teacher educators and classroom technology education teachers of intricate differences between students. Recognition of these differences help educators realize that classroom structure, instruction, and activities must be conducive to all learners. These research findings are important in identifying technology education social competence characteristics of students at-risk and how they differ from a normative sample of student learners.

The purpose of this study was to identify the degree of social competence for technology education students identified as at-risk. This study revealed several items of interest. First, it supports the statement made by Cardon (2000) that "technology education programs have historically attracted at-risk students" (p. 50) and that "they [technology education programs] have received little attention regarding their influence on at-risk students" (p. 50). In the context of this study, the large proportion of students considered at-risk in the six participating technology education course sections further evidences Cardon's statement. Whereas the specific data identifying the percentage of students at-risk in this particular high school were not available, it is noted that of the 120 possible students, 101 (approximately 84%) were considered at-risk.

The researchers used the Walker-McConnell Scale of Social Competence and School Adjustment (Adolescent Version) to compare 101 at-risk students to a normative sample of 1,880 students in four different scales. Again, the scale categories examined were: Self Control, Peer Relations, School Adjustment, and Empathy. There were 53 scale items that identified characteristics within each of the four scale categories. This study identified that the sample of at-risk technology education students had very identifiable social competence and school adjustment differences. Given the nature of these scale items and analyses of the results, it can be concluded that at-risk technology education students in this adolescent sample had significantly lower social competence and school adjustment application than the normative sample of 1,880 adolescent students provided by the Walker and McConnell instrument.

This research revealed that there were only six of the 53 scale items where the participants did not have a statistically significant lower rating of social competence and school adjustment. All six of those items fell within the self-control and empathy scale categories. This observation is further supported by the strong positive correlation (highest of all factors) of the Pearson Product-Moment Correlation between self-control and empathy. These findings suggest that at-risk technology education students exhibit somewhat consistent behavior when they engage with other students, how they express themselves, how they cope with a given situation, as well as how they demonstrate sensitivity toward others. This identification highlights potential determining factors in at-risk students' election of technology education courses. This research also identifies that there is potential for technology education courses to be an avenue to further extend educational and social opportunities for students considered at-risk. Clear separations of school factors, classroom structures, and learner variables of students at-risk and normative groups enable curricula developers and practitioners to further provide for collaborative configurations that facilitate participatory and active learner approaches. Increased, but flexible, group peer interactions with specific role designations have the potential to address peer relation and empathy discrepancies in ability concerning learners at-risk while modeling peer displays of self control and adjustment.

For an undetermined reason, students identified as at-risk exhibit tendencies to engage in technology education courses. Conducting research to understand why students take these courses may be significant in finding a means to assist students in attaining potential and becoming more socially and academically successful in school and society. To date, research literature indicating factors or reasoning as to why students at-risk choose to take technology education courses is largely absent. Further study highlighting at-risk students' course selection has the potential to lead to enhanced service to this technology education subgroup, positioning the profession to aid students struggling in other areas of education and life.

References

Ballentine, J. H., & Spade, J. Z. (2008). *Schools and society: A sociological approach to education* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Caldarella, P., Shatzer, R. H., Gray, K. M., Young, K., & Young, E. L. (2011). The Effects of School-wide Positive Behavior Support on Middle School Climate and Student Outcomes. *Research In Middle Level Education Online*, *35*(4), 1–14.

Cardon, P. L. (2000). At risk students and technology education: A qualitative study. *Journal of Technology Studies, 26*(1), 49–57.
Center for Occupational Research and Development. (2010). What is contextual learning? Retrieved from http://www.cord.org/ contextual-learning-definition.
Crawford, M. L. (2001). Teaching contextually: *Research, rationale, and techniques for improving student motivation and achievement in mathematics and science*. Waco, TX: CCI Publishing.
Demaray, M., Ruffalo, J., Busse, R., Olson, A., McManus, S., & Leventhal, A. (1995). Social skills assessment: A comparative evaluation of six published scales. *School of Psychology Review,* 24, 618–671.
Department of Health and Human Services. (2011). Annual update on the HHS poverty guidelines. *Federal Register*, *76*(13), 3637–3638.
Ernst, J. V., Bottomley, L. J., Parry, E. A., & Lavelle, J. P. (2011). Elementary engineering implementation and student learning outcomes. Published Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Vancouver, BC, Session M544B.
Greenburg, M. T., Weissberg, R. P., O'Brien, M. U., Zins, J. E., Fredericks, L., Resnik, H., & Elias, M., J. (2003). Enhanced school-based prevention and youth development through coordinated social, emotional, and academic learning. *American Psychologist, 58*(6/7), 466–474.
Iyer, R. V., Kochenderfer-Ladd, B., Eisenberg, N., & Thompson, M. (2010). Peer victimization and effortful control: Relations to school engagement and academic achievement. *Merrill-Palmer Quarterly, 56*(3), 361–387.
Krips, H., Lehtsaar, T., & Kukemelk, H. (2011). About the differences of teachers' self-perceptions to the statements of social competence. *US-China Education Review B*, (1b), 138–148.
Maslow, A. H. (1970). *Motivation and personality* (3rd ed.). New York: Harper & Row.
MacKay, T., Knott, F., & Dunlop, A. W. (2007). Developing social interaction and understanding in individuals with autism spectrum disorder: A groupwork intervention. *Journal of Intellectual & Developmental Disability*, 32, 279–290.
McAlister, B. (2009). Teaching social/cultural impacts in technology education. In Essential Topics for Technology Educators (CTTE Yearbook Planning Committee, Eds.). New York: Glencoe/McGraw-Hill.
McCann, R. A., & Austin, S. (1988). *At-risk youth: Definitions, dimensions and relationships.* Philadelphia, PA: Research for Better Schools Inc. (ERIC Document Reproduction Service No. 307 359).
Moye, J. J. (2008). Starting a new technology course? An opportunity to develop student technological literacy. *The Technology Teacher, 68*(2), 27–31.

Moye, J. J. (2011). The promise of technology and engineering education. In Ritz, J. M. & Bevins, S. P. (Eds.) *The Connection to the 21st Century Workforce: Technology and Engineering Education*, 22–33, Reston: ITEEA.

Murray, A. (2011). Montessori Elementary Philosophy Reflects Currents Motivation Theories. *Montessori Life*, *23*(1), 22–33.

Nash, J. K. (2002). Neighborhood effects on sense of school coherence and educational behavior in students at risk of school failure. *Children in Schools, 24*(2), 73–90.

Pete, B. M., & Fogarty, R. J. (2005). *Close the achievement gap: Simple strategies that work*. Thousand Oaks, CA: Corwin Press.

Preble, B., & Gordon, R. (2011). *Transforming school climate and learning: Beyond bullying and compliance.* Thousand Oaks, CA: Corwin Press.

Ritz, J. M., & Moye, J. J. (2011). Using Contextualized Engineering and Technology Education to Increase Student Motivation in the Core Academics. In Barak, M. & Hacker, M. (Eds.) *Fostering Human Development through Engineering and Technology Education (ETE)*, (pp. 131–151), Rotterdam: Sense Publishers.

Sagor, R., & Cox, J. (2004). *At-risk students: Reaching and teaching them* (2nd Ed.). Larchmont, NY: Eye On Education.

Sheskin, D. (2007). *Handbook of parametric and nonparametric statistical procedures*. Boca Raton: Chapman & Hall/CRC.

Stanovitch, K. E. (1986). Mathew effects in reading: Same consequences of individual differences in acquisition of literacy. *Reading Research Quarterly, 21*(4), 360–406.

Threeton, M. D. (2007). The Carl D. Perkins career and technical education (CTE) act of 2006 and the roles and responsibilities of CTE teachers and faculty members. *Journal of Industrial Teacher Education, 44*(1), 66–82.

Tomlinson, C. A. (2003). *Fulfilling the promise of the differentiated classroom: Strategies and tools for responsive teaching*. Alexandria, VA: Association for Supervision and Curriculum Development.

Walker, H. M. & McConnell, S. R. (1995). *Walker-McConnell Scale of Social Competence and School Adjustment*. San Diego, CA: Singular Publishing Group, Inc.

When Talent is Not Enough: Why Technologically Talented Women are Not Studying Technology

The position of technology education in Finland is quite different from that in most other European countries, even for Finland's Nordic neighbors. Technology education is incorporated within the scopes of other subjects, such as physics, chemistry, biology, home economics, and craft education. Craft education is, in practice, further divided into technical work and textile work. Although the national curriculum stated as early as 1970 that both technical and textile crafts are compulsory for both boys and girls, traditionally, boys select technical crafts and girls choose textile classes. As technological contents are mostly taught in the technical craft lessons, this division has a negative effect when students select subjects such as physics in upper secondary school and when they make considerations to study in technical universities and science departments in universities. Gender-based segregation and falling recruitment for scientific and technological studies are common phenomena in all the Nordic countries (Sjøberg, 2002). However, paradoxically the inequity is particularly noticeable in Finland where gender equality has been a prime educational goal for decades.

This article builds on two earlier studies. The first one defined and assessed technological competence among adolescents (Autio & Hansen, 2002). The second, traced three students who had achieved the best results in a measurement of technological competence given 15 years ago (Autio, 2011). This study showed that, in terms of technological competence, it is possible to predict students' potential for career success in the technical professions. The aim of this study was to examine how the three highest scoring females have progressed. Are they working in technology today, or did they find other professions? In addition, the researcher tried to determine the elements accounting for the participants' motivated behavioral choices in the area of technology. Finally, in the discussion section, the researcher will highlight some differences within these elements between males and females. The main research questions were as follows:

1. Did technologically talented females choose technological careers?
2. What were the main elements in the test participants' motivated behavioral choices in the area of technology?

The research data was analyzed using content analysis. The analysis was carried out by assessing which of the essential elements in the participants' lives contributed to their motivated behavioral choices in the area of technology. These findings were later classified and finally reported in the conclusions. The

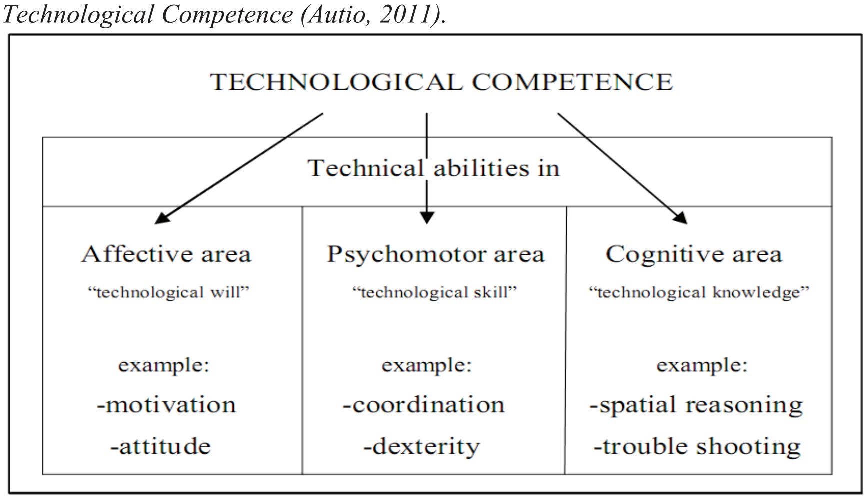
Ossi Autio (ossi.autio@helsinki.fi) is in the Department of Teacher Education at the University of Helsinki.

results from each participant interview are shown in a figure based on Eccles' (2009) Expectancy Value Model of Motivated Behavioral Choice. The model indicates test subjects' motivated behavioral choices in the area of technology during their lives. These figures, which are based on the expectancy value theory, will be explained in more detail later.

Theoretical Background

Despite the fact that skilled behavior underlies nearly every human activity, the profession's understanding of the factors that contribute to the attainment of expertise in technology education is far from complete. However, some attempts to define technological competence have been made. For example, Autio and Hansen (2002) defined technological competence as an interrelationship between technical abilities in psychomotor, cognitive, and affective areas. Based on Dyrenfurth's (1990) and Layton's (1994) work, they identified three components that correspond with what the authors considered the dimensions of technological competence. In the present study, technological competence was defined as an aggregate of the three abovementioned measurements: knowledge, skill, and emotional engagement. A simplified model of technological competence is described in Figure 1.

Figure 1
Technological Competence (Autio, 2011).



During the interviews, typical elements affecting motivated behavioral choices in the area of technology were identified. These were classified according to Eccles' (2009) Expectancy Value Model of Motivated Behavioral Choice. Expectancy value theory has been one of the most important theories on the nature of achievement motivation, beginning with Atkinson's (1957) seminal work and more recently developed by Eccles, Adler, Futterman, Goff, Kaczala, Meece, and Midgley (1983); Wigfield and Eccles (1992) and Eccles (2008). Atkinson's (1957) original expectancy value model defined expectancies as individuals' anticipations that their performance will be followed by either success or failure, and defined value as the relative attractiveness of succeeding or failing in a task. Later the model was expanded to discuss how an individual's expectancies for success, subjective task values, and other achievement beliefs mediate their motivation and achievement in educational settings. The most recent model consists of several factors or themes, including a distal cultural milieu that encompasses the cultural stereotypes and behaviors of key socializers. In addition, an individual's perceptions of emerging self-knowledge generates his or her future goals and shape self-confidence. Furthermore, individual characteristics and experiences are important in the interpretation of previous experiences. These elements later generate the expectation of success and subjective task values. Finally, based on life experiences and complicated decisions between all the elements in the model, individuals make motivated behavioral choices.

It seems that the process of making motivated behavioral choices in the area of technology is more complicated for technologically talented females than for males. This is supported by the statement that women appeared to place high attainment value on several goals and activities; in contrast, the men appeared more likely to focus on one main goal (Eccles, 2009). In addition, women are more likely to desire a job that directly helps other people and involves working collaboratively with other people. This seems to be one reason why mathematically talented women go into the biological and medical sciences instead of physical sciences and engineering (Vida & Eccles, 2003). Moreover, only a few girls are willing to challenge stereotypes about nontraditional careers for women (Silverman & Pritchard, 1996; Mammes, 2004), and even technologically talented females tend to underestimate their own capabilities (Wender, 2004).

Study Method

Case study research excels at bringing people to an understanding of a complex issue or object and can extend their experience or add strength to what is already known through previous research. Case studies emphasize detailed contextual analysis of a limited number of events or conditions and their relationships (Stake, 1995). It is true that a case study is a detailed examination of a single example, but it is not true that a case study cannot provide reliable information about the broader class (Flyvbjerg, 2006).

The research was carried out as a qualitative case study (Merriam, 1988), and the data was collected from individual theme interviews. The analysis was carried out by assessing which of the essential elements in the Expectancy Value Model contributed to motivated behavioral choices in the area of technology during the test subjects' lives. Next, the data was analyzed using content analysis methodology (Anttila, 1996; Baker, 1994). Prior to the interviews, the researcher conducted a short e-mail discussion with each test participant about the concept of technological competence and about the Expectancy Value Model of Motivated Behavioral Choice. Each participant understood that technological competence was defined in the study as an aggregate of three areas: knowledge, skill, and emotional engagement. In addition, they understood that the Expectancy Value Model was just a starting point, and as the interview was based on self-reports, there was no right or wrong answers.

Study Participants

The study group consisted of three women. One of them was born in 1980 and two in 1982, and when they were tested for technological competence 19 years ago as students, they achieved the best results in the girls' test group. In Finnish technology education, boys traditionally select technical crafts and girls choose textile classes. However, the curriculum of technology education in 1994 specified that technical craft and textile craft should be combined into one subject, taught to both boys and girls over their entire comprehensive school lives. This curriculum was tested in 1993, and test participants in this study were given a new curriculum that combined technical and textile craft in grades five to seven. Although there was still much to improve and the curriculum was not optimal for young girls, we can suppose that all the test participants had experiences in the field of technology and were at least aware of the availability of this option. In addition, their schools were clearly aware of gender roles and cultural stereotypes.

Test participants' technological competence (TC) was defined as an aggregate of three measurements: technological will (TW), technological skill (TS) and technological knowledge (TK). The formula of technological competence ($TC = TW \times TS/2 \times TK/5$) was obtained so that each element had equal emphasis, but if any of the elements were close to zero, the technological competence drew close to zero as well. Therefore, the test subjects were selected according to their overall accomplishment in all three areas. In the original test group of 267 participants (161 boys and 106 girls) 19 years ago, a number of girls performed better in certain areas (e.g. technological knowledge) but did not succeed as well in the other areas. Technological will was measured by a questionnaire with fourteen Likert-scale (1–5) statements (final score: average reply to statements). The test of technological skill was called X-boxes and the aim was to construct as many items as possible in five minutes (final score: the amount of constructed items). The test of technological knowledge consisted of 28 questions related to physical laws in simple machines (final score: the amount of right answers). More information on the research group, the test instruments, and other data from the original study is available in Autio (1997) and Autio and Hansen (2002). The results of the test subjects and the average test scores from the previous study held in years 1993–1995 are presented in Table 1.

Table 1
The Results of the Test Subjects and the Average Test Scores

	Technological Will (TW)	Technological Skill (TS)	Technological Knowledge (TK)	Technological Competence (TC)[a]
Subject 1	3.07	10.25	20	62.94
Subject 2	3.70	6.50	22	52.91
Subject 3	2.86	11.25	23	74.00
Average of 3 best female	3.21	9.33	21,67	63,28
Average of 3 best overall	4.19	9.06	26.33	99.95
Average of all females (n = 106)	2.81	6.12	18.20	31.30
Average of all (n = 267)	3.37	6.35	20.34	43.53

[a] Technological competence: TC = TW x TS/2 x TK/5

According to the test results 19 years ago, the selected test subjects were definitely technologically talented but not as talented as the three highest scoring participants overall. The average of their technological competence was 63.28. It was higher than the average of all test participants (43.53); however, it was much lower than the three best scores overall (99.95). The main difference seemed to be in technological will and technological knowledge, whereas the three best females performed better in the measurement of technological skill.

The test participants were difficult to trace, but with the help of their old teachers, old schoolmates, and the Internet, they were found after two months of investigation. Although 267 students were tested 19 years ago, coincidentally, two of the test participants had graduated from the same school in the Helsinki metropolitan area. The third participant was also a resident of Helsinki, but graduated from a smaller upper secondary school. The researcher had no previous knowledge of the test subjects' current employment status. Fortunately, the background of each test subject was somewhat different, and the researcher could find support to previous statements. For example, women value competence in several activities simultaneously (Eccles, 2009), mathematically talented woman go into the biological and medical sciences instead of physical sciences and engineering (Vida & Eccles, 2003), and even technologically talented females tend to underestimate their own capabilities (Wender, 2004).

Two of the participants had studied at a university of technology. The first was quite sure of her decision to choose a career in technology after secondary school, but the second had a lower self-concept related to technology and started her studies in the university of technology a couple of years later. The third test subject was equally talented in technical matters, but mainly due to a lack of self-confidence and encouragement from her main socializers, she began to study economics in vocational high school instead of continuing in a more technological direction. The test participants were named according to their characteristics, as follows:

- Subject 1: From machine technology to an architect
- Subject 2: Academic single mother
- Subject 3: Technological talent without self-confidence

Results

Each test participant's educational path related to technology is presented in the next section. The descriptions of the educational paths were based on the Expectancy Value Model of Motivated Behavioral Choice. The model was first introduced to the test subjects by e-mail and then discussed within the theme interviews in more detail. The elements of the motivated behavioral choices of each test subject are described more precisely in Figures 2–4. As the results were based on self-reports, no absolute value was given to the strength of each element.

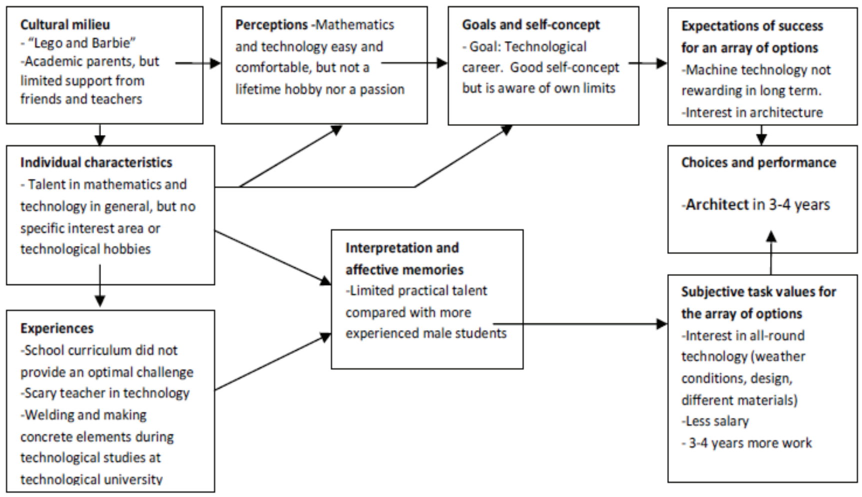
Subject 1: From Machine Technology to an Architect

Subject 1 was born in 1982 and spent her school years in the Helsinki area. She lived with her parents and a little sister. Her father had earned a Master of Science in Technology (machine technology), and her mother was a Master of Science in Economics and Business Administration. Her little sister was currently studying in Italy (bioinformation technology). Subject 1 finished school in 2002 with good grades (the average of all school subjects over 9.0 / 10.00). After finishing upper secondary school, she started to study machine technology at a university of technology. However, after five years she changed her major to architecture. Currently, she is working in an architect office and still has 3–4 years of study before completing her degree.

Subject 1 had become familiar with technology in early childhood using Lego, but she played with Barbie as well. Subject 1 responded positively to technology education: early in comprehensive school she was already interested in how things work in general, but making technology-related products was not especially interesting. The teacher was capable, although the test subject thought that he was somewhat frightening for a small girl. Furthermore, she had no friends with the same interest area to join her in the technology education lessons. Her father was a good role model, but she did not get much support for her technological talent as her father was not at home very often because of his work. In any case, the support from her main socializers was limited, and in upper secondary school she recognized her technological talent mainly because she was good at mathematics, not because of her accomplishments in technology.

Yet she received the best encouragement from being able to understand how things work in everyday life. Her self-confidence in technology was high, and she did not need much support, as she felt comfortable in the technological world. During her later studies in machine technology, she received more experience in a real life technological environment. She became acquainted with welding and making concrete elements. She felt comfortable, but noticed that her skills were limited when compared with other students who had much more experience in the technological world from their hobbies. In any case, she thought that her competence in technology was growing, but she had no passion for any special phenomena in technology. Furthermore, she had no technologically related hobbies to develop her competence further. In the long term, studying machine technology seemed to be meaningless to her future. Because of this, she decided to change her major and started studying to be an architect. As she was a woman of diverse talent, she felt that this area was much more rewarding. She could fulfill her technological interest with topics related to technology: design, different materials, weather conditions, and sociological elements. As she had finally found a technological area that suited her talent, she was willing to accept three to four more years of studies and an even lower salary. The elements accounting for Subject 1's motivated behavioral choices are described in Figure 2 (next page).

Figure 2
The Elements behind Subject 1's Motivated Behavioral Choices



Subject 2: Academic Single Mother

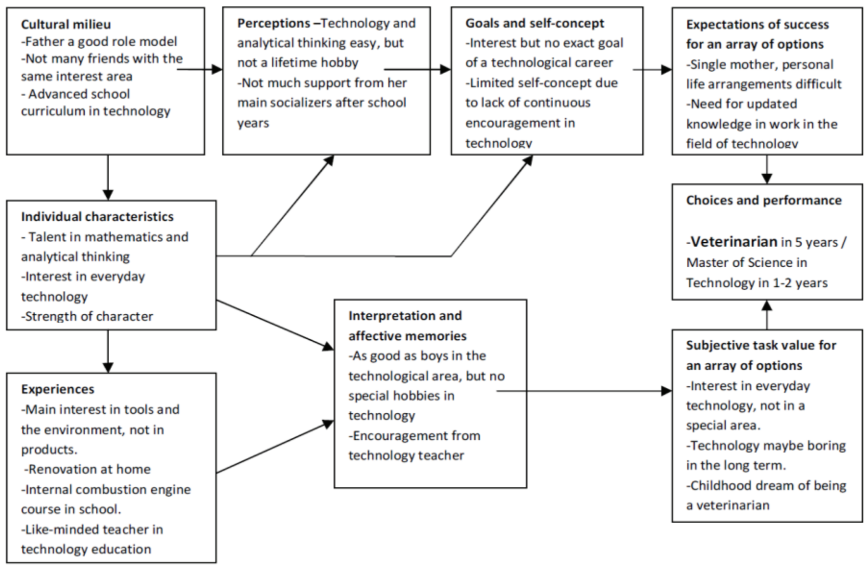
Subject 2 was born in 1982, and she spent all her school years in university training school in the Helsinki area. She lived with her parents and sister. The family was a typical Finnish family with no academic degrees. Her father was a janitor, and her mother was a homemaker, who occasionally worked in a supermarket.

Subject 2 graduated from university training school in 2001. The school was one of the highest ranked upper secondary schools in Finland. She was good at several school subjects and graduated with good grades (the average of all school subjects was about 9.3 / 10.00). After finishing upper secondary school, she started to study computer science in 2002 in vocational high school. However, as the studies were not as practical as she expected, she quickly realized that this was not what she wanted to do for the rest of her working life. In 2003 she transferred to an environmental technology program in a smaller town close to the Helsinki area in another vocational high school. She felt comfortable in her studies and recognized her technological talent, and she felt she had gained enough self-confidence to take part in the qualification exam of the technological university in Helsinki. In 2004, she began to study material technology in the technological university. Currently as a single mother she has had some breaks in her studies, but she thinks she can graduate as a Master of Science in Technology in one or two years. However, she still wonders whether her life as a single mother would be easier if she worked as a veterinarian, which was her childhood dream.

Since her early childhood, Subject 2 has been involved in technology-related activities, as her father was always doing renovations or working with cars. Fortunately, she was her father's favorite girl, and she was able to accompany him in all the work he was doing as a janitor. Subject 2 also had the opportunity to take some extra technology education lessons while studying in upper secondary school; she especially enjoyed the internal combustion engine course. The teacher was encouraging and like-minded, and her self-confidence grew when she could show boys her remarkable skills and knowledge in the technological area. In addition, she always felt comfortable doing the analytical thinking required in the technological area. Nonetheless, she has never had any specific aims or hobbies regarding technology. In order to develop her technological competence further, she thinks that she still needs continuous encouragement, as her self-confidence in real life is still limited.

Currently, she is in the middle of making hard decisions. As a single mother, her life could be much simpler if she worked as a veterinarian. She thinks that she could organize her daily routines much more easily if she had a private practice. On the other hand, she could finish her studies in material technology and graduate as a Master of Science in Technology in 1–2 years. Although she thinks that her ability is well suited to her current study area, she knows that in a technological area a diploma is not enough—updated knowledge is always required. In working as a veterinarian, not as much continuing education is needed. The elements accounting for Subject 2's motivated behavioral choices are described in Figure 3 (next page).

Figure 3
The Elements behind Subject 2's Motivated Behavioral Choices



Subject 3: Technological Talent without Self-Confidence

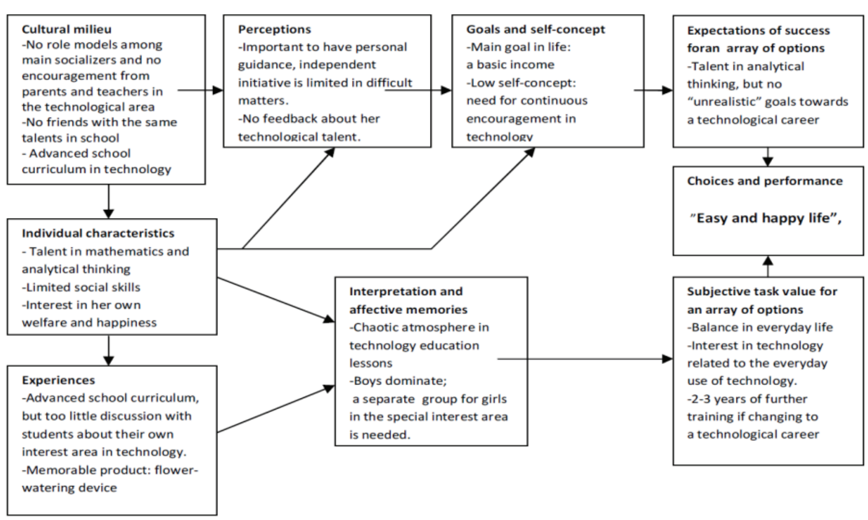
Subject 3 was born in 1980 and spent her school years in the Helsinki area. Her primary education was in a smaller school, but at the secondary level she enrolled in a university training school. In upper secondary school, she studied in a school that specialized in natural sciences. Her father worked for the social services department of the city of Helsinki, and her mother had her own office, which allowed her to freelance as an art director. In addition, her family consisted of an elder sister and a younger brother who was a talented electrician.

Subject 3 finished school in 1999 with good grades. In her opinion, she was good at all subjects, but felt especially comfortable in mathematics. After finishing upper secondary school, she started to study business economy in vocational high school, but she felt that personnel management was not what she wanted for her working life. Soon after she changed her plans, and in 2004, she graduated with a Bachelor of Business Administration degree. Since then, she has worked in several posts as an office assistant and as a contract coordinator. She feels that there is enough challenge in her working life.

Subject 3 had the opportunity to take technology education classes in secondary school, and she thinks that she could have been successful in that area. However, she had no friends with the same interest and no encouragement from teachers, parents, and other main socializers. The main problem for her was that her self-confidence and social skills were limited, and she did not consider technology education studies further, as boys were too domineering in that area. In any case, she finished a few good projects, for example, a flower-watering device, but she wanted more discussion about technological phenomena, not just the product. Sometimes the lessons were chaotic, with loud noise from the machines and from the restlessness of the whole working group. She thinks that special technology education lessons just for girls would not have been as difficult.

Although she had opportunities and enough talent to develop her technological competence further, without any support and with limited self-confidence, she did not even realize that she was talented in the technological area. Thus, considering a technological career was never an option. In mathematics, for example, the feedback that she received was much more positive, and she knew her ability from the results of exams. However, she was not stereotyped as a nerd or as a person who did not matter, but she was not willing to challenge stereotypes about nontraditional careers for women. Nevertheless, her mathematical talent is valuable in her current duties, and she feels comfortable whenever analytical thinking is required. Currently, growing in her work in her current post is her most important priority, and she has no other specific goals in her life. Although she has always thought that her analytical skills would have been valuable in the technological area as well, an easy life with a basic income is enough for her. The elements accounting for Subject 3’s motivated behavioral choices are described in Figure 4.

Figure 4
The Elements behind Subject 3’s Motivated Behavioral Choices



Conclusions

In this study, the three female students who had the best overall results in a test measuring their technical abilities 19 years ago were followed. The researcher had no previous knowledge of how these three test participants were currently employed. This study tried to determine: Did the technologically talented females choose technological careers? The researcher found that two out of three test participants were currently studying at technological university. The third test subject was equally talented in technical matters, but mainly due to lack of self-confidence and encouragement from her main socializers, she did not choose a technological career. The study supports the finding from Autio (2011) that it is possible to predict student potential for career success in technical professions with the instrument used in the measurement. It is not guaranteed, but we can assume that it is not just coincidence that two out of three test participants were currently considering a technological career.

The next study question was: What were the main elements in the test participants' motivated behavioral choices in the area of technology? According to Eccles (2007), the kinds of educational and vocational decisions that might underlie gender differences in participation in physical science and engineering would be most directly influenced by individuals' expectations for success and the importance or value that individuals attach to the various options that they see as available. In this study, many elements had an influence on the motivated behavioral choices in the area of technology long before the test participants considered their expectations for success or gave value to the options that they saw as available. Consistent with the most recent simplified version of the Expectancy Value Model of Motivated Behavioral Choices (Eccles, 2009), cultural milieu, individual characteristics, and previous experiences seemed to be the main elements in the beginning of the process in making motivated behavioral choices. If these elements are not in balance, the individuals do not actively, or consciously, consider the full range of objectively available options in making their selections. Many options are never considered because the individual is unaware of their existence or the individuals think these options are not realistically available to them (Eccles, 2008).

In the measurement of technical abilities 19 years ago, the test participants were found to have technological talent, and it was easy to conclude that the selected test subjects' individual characteristics were suitable for a technological career. According to Byman (2002), students usually prefer and choose subjects and tasks in which they are proficient and can show their competence. In addition, Eccles (2009) predicts that people select those activities for which they feel most efficacious (or for which they have the highest expectations of success). Furthermore, Betz and Hackett (1986) demonstrated a link between the ratings of personal efficacy in various academic subjects and career choice. In addition, all three test participants had an opportunity to take technology education lessons in a school with an advanced technology education curriculum. Although the curriculum was not optimal for introducing technology to young girls, all the test participants had experiences in the field of technology and were at least aware of the availability of this option. What is more, the schools were clearly aware of gender roles and cultural stereotypes. During the interviews, none of the test participants mentioned that these elements were negative features.

Unfortunately, the support from their main socializers in the field of technology was not mentioned as positive during the interviews, and all test participants reported limited support from parents, teachers, and friends. Adolescents are especially concerned with peer relationships and may be in special need of close adult relationships outside of the home (Eccles, 2008). Reeve, Bolt, and Cai (1999) have shown that teachers who support students' autonomy in decision-making create more intrinsic motivation than those who intend to control their students. Support of autonomy is evident when an authority figure respects and takes the subordinate's perspective, promotes choices, and encourages decision-making (Ratelle, Larose, Guay, & Senecal, 2005). Furthermore, parents, teachers, and peers tell people what they are good at or not good at with very little information on which to base such conclusions (Eccles, 2009).

In summary, Subject 1 had talent and enough experience to be aware of the options available in the field of technology. Although the support from her main socializers was limited, her self-confidence in technology was high, and, actually, she did not need much support, as she felt comfortable in the technological world. As she was a woman of diverse talent, she probably can fulfill her technological interest through different topics related to technology: design, different materials, weather conditions, and sociological elements. It seems that she is willing to accept three to four more years of studies to be an architect. Her choice corroborates with the idea that women seem more likely than men to be involved in, and to value, competence in several activities simultaneously (Eccles, 2009; Baruch, Barnett & Rivers, 1983).

Subject 2 was equally talented and had plenty of experiences in the field of technology, but to develop her technological competence further, she thinks that she still needs continuous encouragement, as her self-confidence in real life is still limited. Currently, she is in the middle of making hard decisions. As a single mother, her life could be simpler if she worked as a veterinarian. Her choice is consistent with the statement that mathematically talented woman go into the biological and medical sciences instead of physical sciences and engineering (Vida & Eccles, 2003).

Subject 3 was equally talented in technical matters and had enough experience to be aware of the options available in the field of technology, but mainly due to a lack of self-confidence and encouragement of the main socializers, she did not continue in a more technological direction. Being unaware of her technological talent, she did not even consider a technological career, as she thought that those options were not realistically available to her. This case was also supported by the statement that even talented females tend to underestimate their own capabilities (Wender, 2004).

Discussion

The study had obvious limitations. The research group was small, and the participants could have misremembered details from their pasts, just as the researcher could have misunderstood some of the details during the interviews. In addition, making motivated behavioral choices in practice is a much more complicated process than we can describe with a single figure. In any case, this study corroborates with the Expectancy Value Model of Motivated Behavioral Choices (Eccles, 2009), in which cultural milieu, individual characteristics, and previous experiences seemed to be the main elements in the beginning of the process of making motivated behavioral choices. If any of these basic elements are not present, the individuals' self-concept in technology is limited, and they do not consider the full range of objectively available options in the field of technology. In addition, many options are not even considered because the individuals are unaware of their existence or think that these options are not realistically available to them (Eccles, 2008).

Although we must be cautious about the conclusions, there is some evidence to assume that the process of making motivated behavioral choices in the area of technology is much more complicated for technologically talented females than for males. In previous research (Autio, 2011), male test participants were already working in technological professions, while technologically talented female test participants in this study were still considering other options. It seems that male test participants found their own expertise area much easier and finished their studies quickly with a relatively small amount of other options. This conclusion is supported by Eccles (2009) and Vida & Eccles (2003). In addition, only a few girls are willing to challenge stereotypes about nontraditional careers for women (Silverman & Pritchard, 1996; Mammes, 2004).

According to Autio (2011), the most important elements that affected male participants' technological competence were curiosity, interest, the student's own needs, and intellectual challenge. These elements were not mentioned during the interviews of three highest scoring females, and it was clearly seen that their interest was restricted to everyday technology instead of specialized areas. Technology-related hobbies (e.g. Lego, computers, cars, and electronics) were definitely another element distinguishing between males and females.

Furthermore, in the previous study (Autio, 2011), an emotionally supportive and encouraging teacher-student relationship was mentioned by all the male students as one of the main elements in developing their technological competence. This is consistent with Eccles (2007), who states that males receive more support for developing a strong interest in physical science and engineering from their parents, teachers, and peers than females. In addition, it is reported that males receive more teacher attention than females (AAUW report, 1992; Silverman & Pritchard, 1996), and even parents underestimate their daughters' talent and overestimate their sons' talent in male-typed activity (Eccles, 2009). Moreover, it is absolutely the case that all young people will see more examples of males engaged in these occupations than females (Eccles, 2007). In the long term, this has a strong impact on self-confidence, which is an essential element when individuals consider their expectations for success, give value to the options that they see as available in the field of technology, and finally when they make motivated behavioral choices.

It has been stated in several technology education curriculums that the technical development of society makes it necessary for all citizens to have a new readiness to use technical adaptations and to be able to exert an influence on the direction of technical development. Furthermore, students, regardless of their sex, must have the chance to acquaint themselves with technology and to learn to understand and use it. Nevertheless, technology education has often been blamed for not doing enough to resolve the problem of gender inequality in the field of technology. Based on this research, we have strong evidence for asking what the realistic possibilities are for resolving such a complex problem with just one school subject. The problem of inequality in the field of technology seems to be far more complicated than we previously thought. Action needs to be taken not just by technology education teachers but in cooperation with the whole society.

I would like to acknowledge former *Journal of Technology Education* Editor Dr. James LaPorte for his encouragement with the first related article in 2002, and Dr. Ron Hansen for his continuous support and cooperation.

References

American Association of University Women. (1992). *How schools shortchange girls: A study of major findings on girls and education*. Washington, D.C.

Anttila, P. (1996). *Tutkimisen taito ja tiedon hankinta* [Research skills and the acquisition of knowledge]. Helsinki: Akatiimi.

Atkinson, J. (1957). Motivational determinants of risk taking behavior. *Psychol. Rew. 64,* 359–372.

Autio, O. (1997). *Oppilaiden teknisten valmiuksien kehittyminen peruskoulussa* [Students development in technical abilities in Finnish comprehensive school], Research Reports No. 117. Helsinki: The University of Helsinki, Department of Teacher Education.

Autio, O., & Hansen, R. (2002). Defining and Measuring Technical Thinking: Students Technical Abilities in Finnish Comprehensive Schools. *Journal of Technology Education 14 (1)*, 5–19.

Autio, O. (2011). The Development of Technological Competence from Adolescence to Adulthood. *Journal of Technology Education 22(2),* 71–89.

Baker, T. (1994). *Doing Social Research*. Singapore: McGraw-Hill.

Betz, N. & Hackett, G. (1986). Application of self-efficacy theory to understanding career choice behavior. *Journal of Social and Clinical Psychology 4*, 279–289.

Brauch, G., Barnett, R., & Rivers, C. (1983). *Life prints*. New York: McGraw-Hill.

Byman, R. (2002). Voiko motivaatiota opettaa? [Can we teach motivation?]. In Kansanen, P. & Uusikylä, K. (Eds.) *Luovuutta, motivaatiota, tunteita (pp. 25–41).* Jyväskylä: Gummerus.

Dyrenfruth, M. J. (1990). Technological literacy: Characteristics and competencies, revealed and detailed. In H. Szydlowski, & R. Stryjski (Eds.) *Technology and school: Report of the PATT conference (pp. 26–50)*. Zielona Gora, Poland: Pedagogical University Press.

Eccles, J. (2007). Where are all the women? Gender differences in participation in physical science and engineering. In Ceci, S. & Williams, W. (Eds.) *Why Aren't more Women in Science (pp. 199–210).* American Psychological Association: Washington, DC.

Eccles, J. (2008). Agency and Structure in Human Development. *Research in Human Development 5 (4)*, 231–243.

Eccles, J. (2009). Who Am I and What Am I Going to Do With My Life? Personal and Collective Identities as Motivators of Action. *Educational Psychologist 44(2)*,78–89.

Eccles, J., Adler, T., Futterman, R., Goff, S., Kaczala, C., Meece, J., & Midgley, C. (1983). Expectancies, values and academic behaviors. In Spence, J. (Ed.) *Achievement and Achievement Motives*. San Francisco: W.H. Freeman.

Flyvbjerg; B. (2006). Five Misunderstandings About Case-Study. *Research Qualitative Inquiry* 2006 (12), 219–245

Layton, D. (1994). A school subject in the making? The search for fundamentals. In D. Layton (Ed.) *Innovations in science and technology education* (Vol. 5). Paris: Unesco.

Mammes, I. (2004). Promoting Girls' Interest in Technology through Technology Education: A Research Study. *International Journal of Technology and Design Education 14*, 89–100.

Merriam, S.B. (1988). *Case Study Research in Education:A Qualitative Approach.* San Francisco: Jossey-Bass.

Ratelle, C.F., Larose, S., Guay, F., & Senecal, C. (2005). Perceptions of parental involvement and support predictors of college students' persistence in a science curriculum. *Journal of Family Psychology 19*, 286–293.

Reeve, J., Bolt, E., & Cai, Y. (1999). Autonomy-supportive teachers: How they teach and motivate students. *Journal of Educational Psychology 91*, 537–548.

Silverman, S. & Pritchard, A. (1996). Building Their Future: Girls and Technology Education in Connecticut, *Journal of Technology Education* 7 (2), 41–54.

Sjøberg, S. (2002). Science and Technology Education: Current Challenges and Possible Solutions. In Jenkins, E. (Ed.) *Innovations in Science and Technology Education Vol VIII*, Paris: UNESCO.

Stake, R. (1995). *The Art of Case Study Research*. California: Sage Publications.

Vida, M. & Eccles, J. (2003). Gender differences in college major and occupational choices. In Eccles, J. (2008) Agency and Structure in Human Development. *Research in Human Development 5 (4)*, 231–243.

Wender, I. (2004). Relation of Technology, Science, Self-Concept, Interest and Gender. *The Journal of Technology Studies 30(3*), 43–51.

Wigfield, A. & Eccles, J. (1992). The development of achievement task values: A theoretical analysis. *Devel. Rew. 12*, 265–310.

Impact of Experiential Learning on Cognitive Outcome in Technology and Engineering Teacher Preparation

Historically, practitioners have employed a variety of active techniques to promote the development of professionals in disciplines that necessitate direct skill-associated practice; education at the postsecondary level more habitually relies on conventional teaching methods that often do not permit adequate development of palpable skills (Healy, Taran, & Betts, 2011). The unfortunate result of these traditional abstract practices is the development of professionals with task knowledge but little associated task ability, serving as an indictment of instructional organization and implementation (Anderson, Reder, & Simon, 1996).

The implementation of realistic extension approaches in technology and engineering teacher preparation content courses that simultaneously promote conceptual knowledge and skill-based aptitude is challenging for university curriculum developers. Developing meaningful experiences while maintaining distinguishable curricular alignment requires significant deliberation provided that the intent is to convey authentically reflective and contemporary processes and approaches to future technology and engineering educators. Experiential learning is one method explored in efforts to address the demand for meaningful content experiences. Kemp (2010) characterizes experiential learning as active learning occurrences external to customary academic settings. In the framework of postsecondary education, experiential learning is a viewpoint and approach in which instructors target direct learner experience in efforts to advance individual knowledge and associated authentic skill (Holtzman, 2011).

"Experientially based learning strategies in general have a long history rooted in the early work of John Dewey (1938), and later evolved in work by Piaget (1950), Kurt Hahn (1957), Paulo Freire (1970), Vygotsky (1978), Kolb (1984), Jarvis (1987), and many others" (Marlow & McLain, 2011. p.2). Kolb's theory asserts that learning is a cognitive development linking persistent acclimatization to environmental engagement (Bergsteiner, Avery, & Neumann, 2010). Further, Fry, Ketteridge, and Marshall (2003) identify that concepts of situation-based education incite constructivist practices corresponding to aspects of Kolb's learning cycle. Concrete experience merged with cognitive practice and conceptual application is foundational to the constructivist experiential learning perspective (Jordi, 2011). These experiences span beyond mere environmental conditioning and enter into personal assembly of meaning. This is further supported in the context of technology and engineering education by

---

Jeremy V. Ernst (jvernst@vt.edu) is an Assistant Professor in Integrative STEM Education at Virginia Polytechnic Institute and State University.

Becker (2002), who asserts that a full behaviorism to constructivism shift is necessary in order to effusively prepare students for a technologically advanced global economy and workplace.

Huerta-Wong and Schoech (2010) note that learning is a process that includes more than an amalgamation of inputs and outputs but is largely dependent on the structure and significance of the environment in which learning takes place. Bangs (2011) adds that active student involvement and the application of existing personal knowledge and prior experiences into the new educational environment are significant features of the experiential learning process. Through this structure, students are asked to access current understanding and expand upon it in a direct and genuine fashion. It is well documented that experiential field-based learning has positive K–12 student engagement and retention impacts, but do preservice technology and engineering educators experience similar educational benefits? Additionally, do they perceive experiential learning to be valuable in their personal study, and do they plan to extend this structure of learning into the K–12 technology and engineering education classroom? A formulated investigation has been structured to explore these prospective educational benefits for preservice technology and engineering educators.

Research Questions

This research study was designed to investigate and identify the impacts, if any, that experiential learning activities have on the cognitive achievement of preservice technology educators. Two *research questions were posed to specifically guide this study:*

1. Is there an identifiable cognitive achievement difference in preservice technology educators who engage in experiential learning activities?
2. How do preservice technology educators perceive experiential learning activities?

This research examined experiential learning extension activity implementation through a quasi-experimental design, which consisted of experimental/treatment and control features to measure cognitive outcome but did not use random assignment. The primary intent is to gauge outcome effectiveness and perceptions of students concerning experiential learning in efforts to further inform course iteration.

Study Participants

Participants in this study were enrolled in a technology and engineering education teacher preparation program during the fall semesters of 2010 and 2011. Specifically, the participants were students in an Emerging Issues in Technology course. The Emerging Issues in Technology course explores contemporary agricultural, environmental, and biotechnological topics. Students completed associated learning activities, experimentation/data collection exercises, and modeling projects. However, two sections of the class were provided with experiential activities at a commercial aquaculture facility, an energy technology facility, and a wastewater treatment facility, while two sections of the course engaged in simulated lab-based activities.

Sections of this course were selected as a result of the anticipated academic level of the students enrolled. Students in the Emerging Issues in Technology course are in the secondary level of their major and typically student teach the following semester or spring semester of the following year. Students enrolled in these courses have existing knowledge bases and experiences associated with materials and processes, energy and power infrastructures, electronics, robotics, engineering graphics, architectural graphics, and other engineering design principles and processes. Participants in the selected course of the postsecondary technology teacher education program may have been previously enrolled, although not gauged in information and data collection for this study, in technology and engineering education at the secondary or middle grades level. Table 1 and Table 2 provide general demographical breakdowns of student participants in the Emerging Issues in Technology course.

The majority of the Emerging Issues in Technology student participants were male, from 21–23 years of age, and Technology and Engineering Education majors. The two student groups in this study consisted of 73 participants. Of the 73 participants, 62 were male, 62 were from 21–23 years of age, and 65 were majoring in Technology and Engineering Education. In the teacher preparation program, many students also minor in Graphic Communications. Major classification for the two groups identified in the study is representative of primary major categorization.

Table 1
Non-Experiential Group Demographics

Gender *n* - (%)		**Age Range *n* - (%)**		**Major *n* - (%)**	
Male	30 - (91%)	18–20	3 - (9%)	Tech. & Eng. Education	30 - (91%)
Female	3 - (9%)	21–23	27 - (82%)	Tech./Graphics	3 - (9%)
		24–26	1 - (3 %)		
		27+	2 - (6 %)		

Table 2
Experiential Group Demographics

Gender *n* - (%)		Age Range *n* - (%)		Major *n* - (%)	
Male	32 - (80%)	18– 20	2 - (5%)	Tech. & Eng. Education	35 - (87.5%)
Female	8 - (20%)	21–23	35 - (87.5%)	Tech./Graphics	5 - (12.5%)
		24–26	1 - (2.5 %)		
		27+	2 - (5 %)		

Methodology

Instructor permission was granted for two sections of Emerging Issues in Technology in the 2010 fall academic semester and two sections of Emerging Issues in Technology in the 2011 fall academic semester. Institutional Review Board approval was attained for the use of human subjects in research. The 2010 academic semester consisted of planned course instruction with follow-up experiential learning activities. The course topics of study were Agriculture Technologies, Biotechnologies, Medical Technologies, and Nanotechnologies. The course topics were placed in the context of teaching newly emerging technology topics to K–12 technology and engineering education students.

Experiential follow-up activities consisted of visiting a commercial aquaculture facility, an energy technology facility, and a wastewater treatment facility. The aquaculture facility activity consisted of artificial ecosystem infrastructure development and operative observation. Additionally, students were given interactive tasks associated with commercial applications of tank repositioning, feeding, and water oxidation to promote the development of facility-raised tilapia. The energy technology facility activities consisted of a site orientation followed by interaction with stations that access real-time data feeds from wind, solar, geothermal, and other renewable energy sources. The wastewater treatment facility experience provided a sequenced orientation to sewage and industrial wastewater for reclamation, treatment, and reuse. Students observed suspended solids gravity separation, bacteria waste digestion, filter bed purification, and natural water discharge. During observation, they were periodically invited by the plant supervisor to conduct operations such as systems checks, area shutdown, and process initiation. These three separate experiences served as field-based reinforcement observation and application opportunities for students to authentically situate concepts and processes discussed in a formal classroom setting.

Students attended class meetings and participated in experiential learning exercises for a full academic semester. The course email rosters were acquired from the instructor, and in the 14th week of the semester, an email and survey link was sent to the class requesting their participation in a follow-up survey. No identifying information was requested nor gathered during the survey procedures. Several scales were evaluated for inclusion in this study. Specifically, the Mindfulness Attention Awareness Scale and the Langer Mindfulness Scale were reviewed, but neither prompted the nature of experiential learning targeted within this study, as they both lend themselves primarily to the construct of mindfulness made up of engagement, novelty production, novelty seeking, and attention/awareness factors (Yeganeh, 2006). Therefore, four brief prompts were generated by the investigator, and the instrument was titled the Experiential Learning Perception Survey.

The investigator-generated Experiential Learning Perception Survey had four prompts pertaining to experiential appreciation, perceived experiential value to course, knowledge formation stemming from experiential learning, and anticipated experiential learning in personal teaching practice. Students also completed a 60 item cumulative cognitive assessment composed of 16 true or false items, 32 multiple-choice items, and 12 matching items used each semester in the Emerging Issues in Technology course. At the conclusion of the academic semester, both perception and cognitive data were compiled and entered.

The 2011 academic semester course sections were offered identical course information in a formal classroom setting as the 2010 course sections. However, the 2011 academic semester course sections implemented simulated laboratory-based reinforcement experiences in place of field-based experiential opportunities. A laboratory aquaponics tank was used to explore aquaculture set-up, structure, and function; a series of green technology multimedia aides were used to reinforce discussion of energy technologies; and a groundwater simulation unit and a live bacteria-based water treatment purifier were used to explore wastewater treatment. At the conclusion of the semester, the same 60 item cumulative cognitive assessment was administered. The cognitive data was compiled, entered, and paired with the 2010 course sections for analysis of Research Question #1: Is there an identifiable cognitive achievement difference in preservice technology educators who engage in experiential learning activities?

Data and Analysis of Findings

The first evaluated hypothesis was: There is no difference in cognitive achievement of preservice technology educators who engage in experiential learning activity and preservice technology educators who do not engage in experiential learning activity. This hypothesis was evaluated in Table 3 using the nonparametric Mann-Whitney U test. As indicated by Sheskin (2007), the Mann-Whitney U test was selected for this study based upon its assumptions, sampling, and non-parametric basis (non-Gaussian population). The test statistic for the Mann-Whitney U test was compared to the designated critical value table based on the sample size of each student participant sample. The critical alpha value was set at 0.05 for this investigation. The *p*-value for the test (< 0.0001) was determined to be smaller than 0.05, therefore, the null hypothesis was rejected. The analysis of data suggests that there was a statistically significant cognitive achievement difference between the sample of preservice technology educators who engaged in experiential learning activity and the sample of preservice technology educators who were not engaged in experiential learning activity.

Table 3
Mann-Whitney U Hypothesis Test Results

Difference	*n*1	*n*2	Diff. Est.	Test Stat.	*P*-value
Experiential – Non-experiential	40	33	1.682	1829.5	< 0.0001

As earlier indicated, the experiential group was provided four prompts pertaining to experiential appreciation, perceived experiential value to course, knowledge formation stemming from experiential learning, and anticipated experiential learning in personal teaching practice. Participants were also provided with two open text fields: (a) major advantages of experiential learning format and (b) major disadvantages of experiential learning format. The Experiential Learning Perception Survey was used in this study to investigate Research Question #2: How do preservice technology educators perceive experiential learning activity? Proportional level of agreement for the 30 respondents to the Experiential Learning Perception Survey is identified in Table 4. Ten of the experiential group student participants elected not to complete the survey. Ninety-one percent of respondents identified agreement that they found the experiential activities to be enjoyable, 94 percent identified agreement that experiential activity enhanced course content, 94 percent had a level of agreement that experiential learning heightened their knowledge concerning real-world application of content, and 91 percent either agreed or strongly agreed that they intend to personally implement experiential learning in their teaching.

Table 4
Experiential Learning Perception Survey Results

Statement	Strongly Disagree n – (%)	Disagree n – (%)	Undecided n – (%)	Agree n – (%)	Strongly Agree n – (%)
I found the experiential learning opportunities to be enjoyable.	2 – (6%)	0 – (0%)	1 – (3%)	13 – (44%)	14 – (47%)
The content covered in this course was enhanced by the experiential opportunities	1 – (3%)	0 – (0%)	1 – (3%)	15 – (50%)	13 – (44%)
The experiential learning opportunities have heightened my knowledge concerning real-world application of course content.	1 – (3%)	0 – (0%)	1 – (3%)	13 – (44%)	15 – (50%)
I intend to employ experiential learning in my teaching practice.	1 – (3%)	0 – (0%)	2 – (6%)	14 – (47%)	13 – (44%)

The experiential learning respondents indicated both strengths and weaknesses in the free response portion of the Experiential Learning Perception Survey. Several prevalent trended themes emerged upon review of the major advantages of experiential learning: (a) the hands-on nature of the experiences, (b) the real-world property of the experiences, and (c) the reinforcing of course content through the experiential activities. Similarly, several themes arose upon review of the major disadvantages of the experiential learning free response: (a) the organization of off-campus transportation, (b) concerns with the distance of off-campus experiential locations, and (c) the concern that the transfer and relationship of content to experiential applications was sometimes underlying and not directly apparent. The advantages primarily focused on the attributes of the direct experience, while the disadvantages were largely logistical concerns that without a large amount of prior planning on the instructors' end could present themselves as issues, specifically in a K–12 environment.

Limitations and Contamination Concerns

The nature of this quasi-experiential study design directly targets a specific preservice technology teacher education program. The findings from this study could be informative to other academic institutions with preservice technology teacher education offerings. Attribution of findings to similar but separate groups is problematic where non-Gaussian populations are studied. Additionally, implementation fidelity is an ever-present concern for studies that utilize treatment groups. In this study, one section of the non-experiential group reported participation in tours of course content related non-operational facilities. Although the facilities were identified not to be in operation and did not extend interactive hands-on aspects, this experience deviated from the second section of the non-experiential group. Research Question #1 was re-evaluated excluding the one section of the non-experiential group with reported contamination concerns. Again, Research Hypothesis #1 is: There is no difference in cognitive achievement of preservice technology educators who engage in experiential learning activity and preservice technology educators who do not engage in experiential learning activity. The Mann-Whitney U hypothesis test results can be found in Table 5. The *p*-value for the test (< 0.0001) was determined to be smaller than 0.05, therefore, the null hypothesis was again rejected. The re-analysis of data excluding one of the Non-experiential sections suggests that there was a statistically significant cognitive achievement difference between the sample of preservice technology educators who engaged in experiential learning activity and the single section sample of preservice technology educators who were not engaged in experiential learning activity.

Table 5
Mann-Whitney U Hypothesis Test Results

Difference	*n*1	*n*2	Diff. Est.	Test Stat.	*P*-value
Experiential – Non-experiential	40	15	3.53	1416.5	< 0.0001

Conclusions

In this article, the author has framed an intervention approach based on the personal assembly of meaning in an attempt to reinforce conceptual learning that is designed to culminate in authentically reflective practice while building associated professional skillsets. Through analysis of the study sample outcome data, it was determined that preservice technology and engineering educators who engaged in the organized experiential learning activities benefitted in the form of cognitive outcome from the learning extension approach and structure. However, Gleason et al. (2011) identifies that no independent active or experiential approach is singularly superior, and in fact the approach could be significantly enhanced by instructional styles and learner receptiveness to teacher personality. It is acknowledged that there are influential variables outside of the designed treatment employed in this study. Overall, it is evident that involvement in experiential learner extension opportunities contributes to associated cognitive competency development.

Additionally, experiential learning opportunity was found by the treatment group to be enjoyable, enhance the course offering, have direct real-world extension, and possess course features that will be implemented in the future. It is again acknowledged that experiential learning perception results may have been partially attributable to Gleason's et al. (2011) identification of receptiveness to personality and instructional style. Subsequent variable control and/or variable isolation investigations would enable a clearer determination of impact and influence. However, there is marked receptiveness and identified value by treatment group participants concerning experiential learning activity and application as evidenced by the agreement level pertaining to statements on the Experiential Learning Perception Survey as well as free response items, specifically, major advantages of the experiential learning format.

Jenkins et al. (2007) notes that qualified educational practices through exploratory research have continued to enrich and advance university programs (as cited by Harris & Tweed, 2010). Explorations of instructional interventions not only inform curriculum development, teaching strategies/practices, and course structure but also inform teacher education programs' learner qualities and attributes of their programs' students. A student profile that includes receptiveness, impact, engagement, and the circumstances under which each occurs is informative in developing iterations to courses as well as the expansion of overall programmatic scope.

References

Anderson, J.R., Reder, L.M., & Simon, H.A. (1996). Situated learning and education. *Educational Researcher*, *25*(4), 5–11.

Bangs, J. (2011). Experiential learning in an organizational leadership program. *Journal of College Teaching & Learning*, *8*(10), 29–33.

Becker, K. (2002). Constructivism and the use of technology. *The Technology Teacher*, 61(7), 1–8.

Bergsteiner, H., Avery, G. C., & Neumann, R. (2010). Kolb's experiential learning model: Critique from a modelling perspective. *Studies In Continuing Education*, *32*(1), 29–46.

Fry, H., Ketteridge, S., & Marshall, S. (Eds.), A Handbook for Teaching & Learning in Higher Education. Enhancing Academic Practice (second ed.), Kogan Page, London (2003), pp. 9–26.

Gleason, B. L., Peeters, M. J., Resman-Targoff, B. H., Karr, S., McBane, S., Kelley, K., … Denetclaw, T. H. (2011). An active-learning strategies primer for achieving ability-based educational outcomes. *American Journal of Pharmaceutical Education*, *75*(9), 1–12.

Harris, T., & Tweed, F. (2010). A research-led, inquiry-based learning experiment: classic landforms of deglaciation, Glen Etive, Scottish Highlands. *Journal Of Geography in Higher Education*, *34*(4), 511–528.

Healy, W. J., Taran, Z., & Betts, S. C. (2011). Sales course design using experiential learning principles and Bloom's taxonomy. *Journal of Instructional Pedagogies*, *6*(1), 1–10.

Holtzman, R. (2011). Experiential learning in Washington, D.C.: A study of student motivations and expectations. *Transformative Dialogues: Teaching & Learning Journal*, *5*(1), 1–12.

Huerta-Wong, J., & Schoech, R. (2010). Experiential learning and learning environments: the case of active listening skills. *Journal of Social Work Education*, *46*(1), 85–101.

Kemp, S. (2010). Situated learning: Optimizing experiential learning through God-given learning community. *Christian Education Journal*, *7*(1), 118–143.

Jordi, R. (2011). Reframing the concept of reflection: Consciousness, experiential learning, and reflective learning practices. *Adult Education Quarterly, 61,* 181–197.

Marlow, M. P., & McLain, B. (2011). Assessing the impacts of experiential learning on teacher classroom practice. *Research in Higher Education Journal*, *14,* 1–15.

Sheskin, D. (2007). *Handbook of parametric and nonparametric statistical procedures*. Boca Raton: Chapman & Hall/CRC.

Yeganeh, B. (2006). *Mindful experiential learning*. (Unpublished doctoral dissertation). Case Western Reserve University, Meadville, PA.

Engineering Efforts and Opportunities in the National Science Foundation's Math and Science Partnerships (MSP) Program

The National Science Foundation's Math and Science Partnership (MSP) program (NSF, 2012) supports partnerships between K–12 school districts and institutions of higher education (IHEs) and has been funding projects to improve STEM education in K–12 since 2002. Some projects also include business/industry, informal science organizations, and State Departments of Education as partners (NSF, 2008). As of 2011, a total of 178 MSP projects have received support as part of a STEM education investment of over $900 million. The MSP program has evolved as field-driven strategies and opportunities are created, NSF priorities change, and new national trends appear (e.g., the Common Core State Standards in Science and Mathematics). Indeed, the most recent set of guidelines for proposals (NSF Solicitation 12-518), released in December 2011, is scheduled to be updated again. The MSP program remains a major research and development effort to support innovative partnerships to improve K–12 student achievement in mathematics and science while conducting STEM education research. The current solicitation requests proposals for two levels of partnerships – implementation and prototype – concentrating on one of four focal areas: (a) community enterprise for STEM learning, (b) current issues related to STEM content, (c) identifying and cultivating exceptional talent, and (d) K–12 STEM teacher preparation.

One important movement over the past decade has been increasing interest in incorporating engineering and design content in K–12 teaching and learning, a strategy validated in the National Research Council report, "A Framework for K–12 Science Education: Practices, Crosscutting Concepts and Core Ideas" (NRC, 2011). The goals of K–12 engineering and design content traditionally have been to prepare students to think critically, creatively, and independently by solving problems with real-world applications.

> Engineering is gaining ground as a content area in the K–12 classroom. Numerous programs around the country, some of them quite large (e.g., Project Lead the Way, Infinity Project, Engineering is Elementary, Engineering by Design, Children Designing and Engineering), are developing and delivering curriculum and teacher education in engineering at the pre-college level. (National Academy of Engineering, 2012)

Pamela Brown (PBrown@citytech.cuny.edu) is Associate Provost at New York City College of Technology of the City University of New York. Maura Borrego (mborrego@vt.edu) is Associate Professor of Engineering Education at Virginia Tech. Both served as Program Officers in the National Science Foundation Division of Undergraduate Education between 2011-2012.

Additional benefits more recently identified are the potential for recruitment and better preparation of future engineering students. In an effort to explore how engineering and design are being implemented in MSP projects, we synthesize strategies and findings from the NSF MSP portfolio, including publicly available award information from nsf.gov and MSPnet.org. This descriptive analysis is supplemented by data from annual project surveys conducted by a contractor (Westat) on behalf of NSF. We report on the ways that engineering and design content are being implemented by MSP projects, along with associated challenges and opportunities.

Background and Literature Survey

MSP projects go beyond typical approaches to improving K–12 STEM education through inclusion of educational research as part of project design and intellectual engagement of higher education STEM faculty in K–12 reform. Individual projects differ in their activities and scope. For example, nearly 40% of partnership projects focus on math and nearly 30% on science. Of the remainder, many consider both mathematics and science, four projects focus uniquely on engineering education, and another group attempts to integrate engineering with science and/or mathematics. Of the schools involved in MSP, 45% are primarily elementary, 28% middle, and 27% high school level. Over 90% of projects conduct workshops, institutes, or courses with K–12 teachers that increase content and/or pedagogical knowledge while also developing and utilizing leadership skills. An additional promising mechanism used by far fewer partnerships was providing externship opportunities for teachers. One engineering-focused strategy for improving K–12 education is to introduce engaging engineering design and concepts to teachers in order to provide contemporary real-world examples. These interventions are based on the logic that if teachers are given enhanced professional development through increased content knowledge, model teaching practices, and authentic experiences in one or more of the STEM disciplines, that would impact how they teach, which would then ultimately impact the learning of students. The engineering content has the potential benefit to improve learning in mathematics and science by motivating students and developing their critical thinking and problem solving skills. A shared learning experience focused on relevant, real-world challenges is a proven strategy for fostering student learning of and engagement with mathematics and science (Project Kaleidoscope, 2006).

Another potential benefit to engineering content in the K–12 curriculum, in addition to promotion of engineering awareness and literacy to better prepare engineering majors before starting college, is recruitment of engineering students. Personal interest has been shown to be a key factor in selection of a major. Input from parents, friends, relatives, professor/teachers, and counselors as well as beginning salary, earning potential, and opportunities for advancement are other factors (Beggs, 2008; Kuechler, 2009). However, all of these factors require having knowledge of that major, and the majority of high school students are not currently introduced to engineering professions in K–12. Additionally, in a survey of high school parents, counselors, and science and mathematics high school teachers, their knowledge of STEM occupations was found to be limited, particularly in information technology and engineering (Hall, 2011). Reaching out to high school students to recruit engineering students is critical to increasing the number of engineering graduates. Nationally, 93% of students enrolled in engineering after eight semesters began as freshmen with this same major. In other majors, the same major rate of retention ranged from just 35%–59% (Ohland, 2008). While engineering has a high persistence rate compared to other majors, engineering majors are not attracting undeclared students or those transferring from other majors (Ohland, 2008). An introduction to engaging engineering content prior to the start of college may pique personal interest and hence result in more freshmen selecting engineering majors.

From a pedagogical perspective, engineering is the link that ties together mathematics and science (Katehi, et al., 2009). The integrative, application-focused nature of engineering can improve student learning and increase test scores, which helps schools satisfy standards-driven education requirements (Baker, 2005; Silk, 2009; Custer, 2011). The use of engineering design provides practical classroom benefits for both educators and students. The collaborative, socially beneficial aspects of engineering have also been shown to appeal to students whom the field has traditionally failed to engage, including females and underrepresented minorities (Geddis, Onslow, Beynon, & Oesch, 1993; Wiest, 2004).

Methods

To explore how engineering and design are being implemented in MSP projects, we first searched the abstracts of all active and expired MSP projects (funded through 2011) for the term *engineer*. From this list we excluded any projects that only included engineering as an expansion of the acronym STEM (the sole reference to engineering was that the acronym STEM was written out—Science, Technology, Engineering, and Mathematics). This resulted in 31 projects for further analysis. For each, we examined the original proposal and most recent annual or final report, if available. If the managing program officer was available, we asked this person about engineering aspects of the project. The following are the questions we asked the program officers in an informal interview:

1. Which of these projects do you recall having an engineering component?
2. In what ways are engineering higher education faculty involved in the project(s)?
3. What engineering content is involved, and at what grade levels?

4. In what ways are preservice teachers being trained in engineering? Is teacher training the only way that undergraduates are involved in the project?
5. In what ways are in-service teachers being trained in engineering?
6. What unique challenges and opportunities do you see in incorporating engineering and engineering design into the K–12 curriculum, in order to improve STEM education?

We excluded cases in which engineering was initially included as part of a more general STEM approach but was not mentioned in subsequent work. For example, in one project a focus on energy turned out to be an examination of photosynthesis. This process resulted in the 17 projects listed in Table 1 that we found to include some aspect of engineering. A limitation of this approach is the subjective nature of what is and is not engineering. However, the two authors, both engineers, worked together to develop and apply a consistent definition—projects which included engineering content.

Results and Discussion

A summary of the MSP projects with engineering content, along with the project title, award number, and principal investigator is provided in Table 1 (next three pages). The projects are presented in chronological order with the first two digits of the award number indicating the fiscal year of submission, which is usually also the fiscal year of the award. Note that several early awardees received subsequent awards as well.

Figure 1 (page 47) presents the time frame of the projects. This emphasizes that although NSF's MSP program began in 2002, there is a marked and promising increase in engineering-related projects in recent years. This also means there is limited experience to draw upon to evaluate long-term impact.

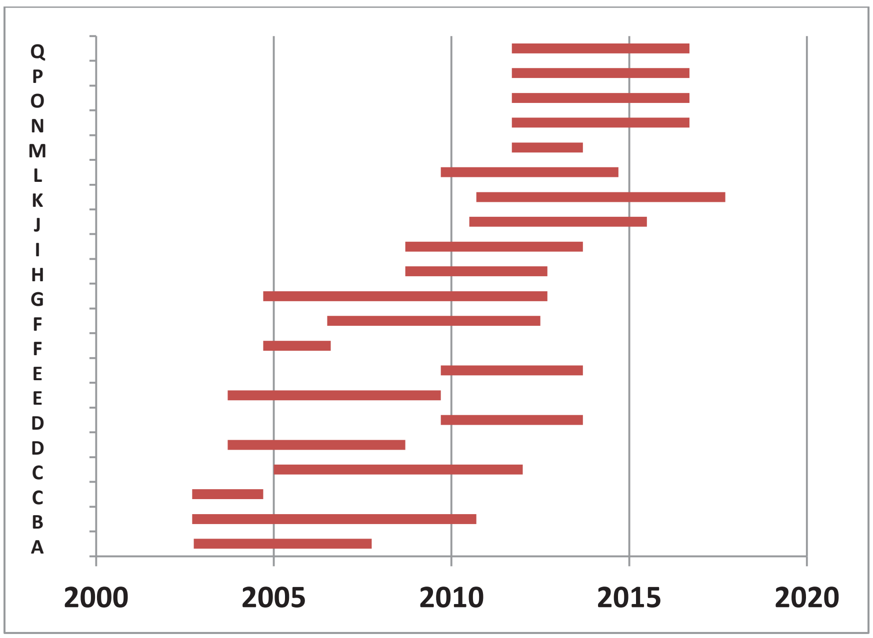
Table 1
Summary of MSP Projects with Engineering and Design Content

Project	Title	Institution of Higher Education	Grant No	Principal investigator (PI)
A	El Paso Math and Science Partnership	University of Texas at El Paso	0227124	Navarro
B	Teachers and Scientists Collaborating	Duke University	0227035	Ybarra
C	SUPER STEM Education	University of Maryland Baltimore County	0227256 & 0514420	Spence
D	Partnership for Student Success in Science (PS3)	San Jose State University	0315041 & 0953069	McMullin
E	Math Infusion into Science Project (MISP)	Hofstra University	0314910 & 0927973	Burghardt
F	A Greater Birmingham Partnership: Building Communities of Learners and Leaders in Middle School Mathematics	University of Alabama Birmingham & Birmingham Southern College	0412373 & 0632522	Mayer
G	Project Pathways: A Math and Science partnership for Arizona Targeted Project Track	Arizona State University in partnership with Intel & Maricopa Community College system	0412537	Carlson

H	Drafting a Blueprint for Educating Tomorrow's Engineers Today	Springfield Technical Community College	0831698	McGinnis-Cavanaugh
I	UTeachEngineering: Training Secondary Teachers to Deliver Design-Based Engineering Instruction/	University of Texas-at Austin	0831811	Allen
J	Partnership to Improve Student Achievement in Physical Sciences: Integrating STEM Approaches (PISA2)	Stevens Institute of Technology	0962772	Sheppard
K	Science Learning through Engineering Design (SLED) Targeted Partnership	Purdue University	0962840	Bowman
L	LEADERS: Leadership for Educators: Academy for Driving Economic Revitalization in Science	University of Toledo	0927996	Czajkowski
M	HR-PAL: Hampton Roads Partnership for Algebra	Hampton University	1050389	Akyurtlu
N	CEEMS: The Cincinnati Engineering Enhanced Mathematics and Science Program	University of Cincinnati	1102990	Kukreti
O	NUTURES: Networking Urban Resources with Teachers and University to Enrich Early Childhood Science	University of Toledo	1102808	Czerniak

P	The NanoBio Science Partnership for Alabama Black Belt Region	Tuskegee University	1102997	Jeelani
Q	The University at Buffalo/Buffalo Public Schools (UB/BPS) Interdisciplinary Science and Engineering Partnership	SUNY at Buffalo	1102998	Gardella

Figure 1
Timeline of MSP Projects with Engineering Content



Engineering faculty involvement is summarized in Table 2 (next page). Engineering faculty provided professional development to K–12 faculty and helped develop engineering activities and curricular materials involving engineering design. Some engineering faculty members were tapped to serve as mentors. Engineering faculty members frequently serve as PIs, Co-PIs, and senior personnel on MSP projects. When their responsibilities are described, they tend to serve as consultants or mentors in developing engineering activities and curricula, as well as helping teachers to implement the activities in their classrooms.

Table 2
Engineering Faculty Involvement in MSP Projects

Projects	Higher Education Engineering Faculty Involvement
C, E, I, J, K, N, O	Help design or develop professional development for in-service teachers
E, H, I, L, N	Help deliver professional development for in-service teachers (typically in summer)
D, H, I, L, P	Principal investigator on MSP grant is engineering faculty member
L, P, Q	Co-PI(s) on MSP grant is engineering faculty member
D, L, Q	Senior personnel on MSP grant includes engineering faculty member(s)
B, N, O	Mentor in-service teachers during professional development
G, K, P	Help develop K–12 curriculum
D	Spend time in K–12 schools working on MSP project
A, K	Receive professional development on how to work with K–12 teachers
A, N	Mentor undergraduate engineering students and STEM majors changing careers, working toward alternative teacher certification

A summary of engineering content and the grade level impacted is given in Table 3 (next two pages). The dynamic of evolving science and math standards ensures that more resources will be directed to these efforts. For example, the recently revised Ohio State Science Standards are centered on real-world applications and connections to engineering. These projects suggest that design approaches and engineering solutions may be an effective way to connect science and math to students' daily lives. We note that the motivation for engineering in K–12 was presented in many proposals as a need for more engineers, a general need for a more scientifically and technically literate public, or both.

Table 3
Grade Level and Engineering Content

Project	Grade Level	Engineering Content
A	High School	Junior or senior level course which is inquiry based, addresses engineering concepts, and meets state mathematics and science standards.
B	K–8	Applications of electrical engineering such as solar power in inquiry-based science curricula. Contributions to "Teach Engineering: K–12 Resources" website: http://www.teachengineering.org/
C	Pre K–12	Engineering emphasized through inquiry and problem/issue-based approaches. Industry engineers help develop & teach STEM modules - automotive, airplane & rocket engines; effects of stress on bridges & skyscrapers; factors involved in constructing roads & bridges; telecommunications. Mentor students, provide internships.
D	K–8	No apparent curricular development.
E	Middle School	26 math infused 8th-grade science units available on the MiSP website - www.hofstra.edu/misp addressing technological literacy standards.
F	Middle School w/ Secondary Focus on High School	Examples include an engineering project on wound healing. http://www.eng.uab.edu/bme/labs/mathgrant/
G	High School	Teams of engineers, mathematicians and scientists partner with master teachers and STEM education faculty to generate portable instruction sequences incorporating engineering design.
H	Middle School	Educational website about engineering for middle-school students (www.talk2mebook.com), primary goal is to motivate interest in engineering.

I	High School	Designed a one-year high school engineering course in anticipation of Texas state standards for a 4th year engineering science course. Created learning outcomes – the narrative of engineering, engineering design skills, engineering habits of mind, design challenge topics. Units are energy generation; design, redesign and reverse engineering; and an extended design challenge.
J	3–8	New curriculum focuses on energy concepts, is interdisciplinary and involves engineering.
K	3–6	Science inquiry guided by an engineering design approach.
L	K–12	Engineering content on renewable energy and its environmental impact through Project-Based Science (PBS).
M	Middle and High School	Engineering applications and practical examples for algebra, particularly in the area of robotics.
N	Middle and High School	Engineering and science content employing design and challenge-based approaches in response to recently revised Ohio State Science Standards.
O	Pre K– 3	Science curriculum employing inquiry-based learning in formal and informal educational settings with input from engineering educators
P	Middle School	Inquiry-based approach focused on NanoBio material science and engineering and 3-D simulations of concepts from their science curricula.
Q	Middle School	Interdisciplinary, inquiry-based science and engineering design, such as tissue engineering and medical physics aligned with state science learning standards.

A summary of undergraduate and preservice teacher involvement and opportunities is provided in Table 4 (next page). Major themes include recruitment of engineering students, creation of educational pathways for engineering majors to enter the teaching profession, and inclusion of engineering content and design in teacher preparation curriculum. One recurring recruitment strategy was for engineering students to work with teachers in order to enrich teacher engineering content knowledge.

Table 4
Summary of Undergraduate and Preservice Teacher Involvement and New Opportunities

Projects	**Undergraduate and Preservice Teacher Involvement**
F, H, K, D, C	New preservice coursework and degrees to better prepare teachers
B, F, C	Internships in schools for preservice teachers
E, P	MSP project assists with recruiting to existing preservice teacher programs
A, L, Q	Undergraduate engineering students mentor or team with in-service teachers
I, J, N, A	Teaching licensure pathways and recruiting for engineering and STEM majors
M,O	(No apparent involvement of engineering undergraduates or preservice teachers)

The role of in-service teachers was also evaluated. All but one project included summer and academic year professional development for in-service teachers focused on development of effective teaching practices and enhanced content knowledge (A–L, N–Q). Special foci included continuing education credits or advanced degrees (B, I, J, L, N), professional development for administrators in order to generate support and better understanding of issues (C, E, F, L), integration of technology into the classroom (E), creation of bilingual materials (G), and effective use of informal learning environments such as zoos, museums, etc. (O, Q).

Opportunities

NSF MSP funding has supported the creation of new initiatives to advance engineering education and models for collaboration. Examples include a new interdisciplinary Center for Engineering Education (I) and The Center for Technological Literacy (E). Professional development including teachers and engineering faculty has enhanced engineering faculty pedagogical skills (e.g., F). Industry engineers mentor high school students in a Future Teachers Club (C). One project was recognized by Microsoft Research University Program as a national K–12 outreach model (B).

Challenges

Early projects included in their reports to program officers some of the challenges to bringing engineering to K–12. Faculty time and responsibilities (teachers and professors) limited engagement with many aspects of the projects. Sometimes different engineering team members disagreed on how to adapt engineering to K–12. If the focus is interdisciplinary STEM or sustainability, science (or math) education focus can begin to dominate over time. Similarly, high stakes testing creates a drill situation, where engineering values of design and creativity are not included in measures of a school's success. To many, opportunities for creative thought are a benefit of engineering in K–12, but testing pressures may create practical implications for sustaining engineering efforts. As in many MSP projects, teacher content background and experience level vary widely. Selection of leadership team members must be done carefully and thoughtfully. The principal's support and leadership is crucial to sustaining teacher participation.

Conclusion and Future Work

This analysis gives an overview of efforts to implement engineering in K–12 through NSF's MSP program. These projects are employing many of the best practices in teacher preparation, professional development, curriculum development, and partnerships that characterize NSF's MSP program in general. Many programs had a focus on alignment of instruction and assessment of mathematics and science to meet state and national standards. Some programs had a focus on teacher preparation to meet the gap in prepared teachers, with alternate certification of engineering professionals or recruitment of undergraduate engineering majors. Some inculcated engineering content into preservice teacher education. Some projects provided support to minimize high turnover of new teachers. Industrial partners provided support to develop curricular materials or to serve as mentors.

We were surprised that so few projects created or strengthened teaching certification opportunities for engineering undergraduates. We view this as a promising practice for building capacity to support engineering in K–12. Despite arguments that engineering graduates can make much more money than teachers, demand could be surprisingly high due to the job security, geographic flexibility, and benefits afforded teachers. Similarly, we were surprised by how few projects had explicit goals to develop, archive, and distribute engineering curricula for K–12. There are notable exceptions: UTeach Engineering at University of Texas-Austin that is focusing on high school curricula, "Teach Engineering: K–12 Resources" that Duke University helped to launch, and SLED at Purdue University that is focusing on elementary curricula.

Many questions remain: Do we need separate engineering courses in K–12 or should it be embedded? If embedded, how should it be integrated? What is the required core of knowledge and how do we prepare teachers? How do we both prepare future engineering students and provide general engineering literacy? How do we promote diversity while incorporating engineering content? How will efforts be scaled-up? How will efforts be sustained?

Acknowledgements

We gratefully acknowledge the assistance of NSF MSP program officers James Hamos, Kathleen Bergin, Elizabeth VanderPutten, and Louis Everett in preparing this paper through reviewing portfolios and answering questions. We especially acknowledge the guidance of James Hamos in focusing this article. Any opinions, findings, conclusions or recommendations are those of the authors and do not necessarily reflect the views and policies of the National Science Foundation. Pamela Brown and Maura Borrego gratefully acknowledge that this material was based on work supported by the National Science Foundation, while working at the Foundation.

References

Baker, D. (2005). *An intervention on tinkering and technical self-confidence, and the understandings of social relevance of science and technology.* Paper presented at the 2004 National Association of Research in Science Teaching Annual Conference, Vancouver, Canada.

Beggs, J. M., Bantham, J. H., & Taylor, S. (2008). Distinguishing the factors influencing college students' choice of a major. *College Student Journal*, *42*, 381–394.

Custer, R.L. & Daugherty, J.L. (2011) Teaching engineering concepts in high school project. (2011). *Journal of Technology Education*. 23(1), 2–4

Fantz, T.D. & Katsioloudis, P.J. (2011) Analysis of engineering content within technology education programs. *Journal of Technology Education*. 23(1), 19–31.

Hall, C., Dickerson, J., Batts, D., Kauffmann, P. & Bosse. M. (2011). Are We Missing Opportunities to Encourage Interest in STEM Fields. *Journal of Technology Education*. 23(1), 32–46

Kuechler, W. L., McLeod, A., & Simkin, M. G. (2009). Why don't more students major in IS? *Decision Sciences Journal of Innovative Education, 7*, 463–488.

National Academy of Engineering. (2009). Exploring Content Standards for K–12 Engineering Education (Project Summary). Retrieved from http://www.nae.edu/cms/14727.aspx, (accessed December 31, 2012)

National Research Council (2011). A Framework for K–12 Science Education: Practices, Crosscutting Concepts and Core Ideas. Washington, DC: National Academies Press.

National Science Foundation. (2008). National Impact Report: Math and Science Partnership Program. Retrieved from http://www.nsf.gov/news/newsmedia/msp_impact/msp_impact_report4_08.pdf (accessed June 22, 2012)

National Science Foundation. (2012). Math and Science Partnership (MSP). Retrieved from www.nsf.gov/funding/pgm_summ.jsp?pims_id=5756 (accessed June 22, 2012)

Ohland, W. W., Sheppard, S. D., Lichtenstein, G., Eris, O., Chachra, D., & Layton, R. (2008). Persistence, engagement, and migration in engineering programs. *Journal of Engineering Education, 97*, 259–278.

Project Kaleidoscope (2006). Learning Science Volume IV: What Works, What Matters, What Lasts. Retrieved from www.pkal.org/documents/VIstudentLearningGoals.cfm%20 (accessed June 22, 2012

Silk, E., Schunn, C., & Strand C.M. (2009). The Impact of an Engineering Design Curriculum on Science Reasoning in an Urban Setting. *Journal of Science Education and Technology,* 18(3), 209–223. doi: 10.1007/s10956-009-9144-8

Engineering Design Thinking

Engineering design thinking is a topic of interest to STEM practitioners and researchers alike. Engineering design thinking is "a complex cognitive process" including divergence–convergence, a systems perspective, ambiguity, and collaboration (Dym, Agogino, Eris, Frey, & Leifer, 2005, p. 104). Design is often complex, involving multiple levels of interacting components within a system that may be nested within or connected to other systems. Systems thinking is an essential facet of engineering design cognition (Accreditation Board for Engineering and Technology, 2007; Dym et al., 2005; Katehi, Pearson, & Feder, 2009; Ottino, 2004; Schunn, 2008).

Although systems thinking has not previously played a prominent role in engineering education research, it is becoming recognized as an important engineering trait (Dym & Little, 2009; Katehi et al., 2009). Due to the nascency of systems thinking research in engineering education, there are few studies that have investigated systems thinking and its impact on engineering design, particularly with K–12 students. As a result, how high school students employ systems thinking processes and strategies is not adequately understood or identified.

This research examined high school students' systems cognitive issues, processes, and themes while they engaged in a collaborative engineering design challenge. Cognitive issues are mental activities used during a design challenge, while the processes are the ways in which the issues are approached or sequenced (Gero, 1990). Using exploratory triangulation mixed method research, the systems cognitive issues and processes were analyzed through the Function-Behavior-Structure (FBS) cognitive analysis framework. Additionally, emerging systems thinking themes and phenomena in engineering design were analyzed thematically outside of the FBS framework. Data from the different sources (verbal, video, computer movements, and sketches) were coded, organized, categorized, and synthesized for themes and patterns. Each data analysis technique yielded useful results on their own, but they were also used together to produce a broader understanding of systems thinking. The research was guided by two questions:

Matthew Lammi (mdlammi@ncsu.edu) is an Assistant Professor in Technology, Engineering & Design Education at North Carolina State University. Kurt Becker (kurt.becker@usu.edu) is Professor and Director for the Center for Engineering Education Research at Utah State University.

1. What are the cognitive issues and processes used by high school students when attempting an engineering design challenge analyzed through the FBS framework?
2. Are there emerging qualitative themes and phenomena as they relate to systems thinking in engineering design? If there are themes or phenomena, how can these themes and phenomena be analyzed and interpreted—essentially repeatedly reviewing and analyzing the data sources outside of the FBS framework looking for themes, patterns, and phenomena?

Background

Engineering design is a process that has no agreed upon definition. Nevertheless, there are multiple K–12 programs and curricula that purport to teach engineering design (Katehi et al., 2009). Although the design definitions vary, studies have shown that high school students can engage in engineering design (Apedoe, Reynolds, Ellefson, & Schunn, 2008; Brophy, Klein, Portsmore, & Rogers, 2008; Dally & Zhang, 1993; Eisenkraft, 2011; Hmelo-Silver, Holton, & Kolodner, 2000; Kolodner, 2002).

Complexity is another ambiguous term, (Davis & Sumara, 2006) yet complexity typically involves systems and their interacting phenomena. Systems thinking is a concept found in complexity, but it is also a term that has different meanings for different fields and disciplines. Engineering design often includes systems thinking facets and operations including: multiple interconnected variables, non-linearity, open-endedness, emergence, optimization, and graphical visualizations.

Complexity and Systems Thinking in Engineering Design

As the name suggests, complex systems are not easily defined and have given way to various precepts and constructs. Systems are dynamic with respect to time, with distinct variables varying along unique time scales. Complex systems have multiple interconnected variables with emerging interactions that cannot be viewed in isolation in order to understand the aggregate system (Hmelo-Silver & Azavedo, 2006). Complex systems are non-linear and unbounded (Davis & Sumara, 2006; Foster, Kay, & Roe, 2001). Most physical and social phenomena at the systems level do not follow a simple cause-effect relationship. Schuun (2008) defined optimization in complexity as balancing constraints, trade-offs, and requirements. In summary, complex systems are dynamic, adaptive, emergent, non-linear, and iterative. These systems are also influenced by multiple time scales, contain interconnected variables, and often include human activity as another variable.

Dym, Agogino, Eris, Frey, and Leifer (2005) unambiguously stated that design thinking is complex and offered the following definition of engineering design:

> Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints. (p. 104)

Dym et al. (2005) further stated, "A hallmark of good systems designers is that they can anticipate the unintended consequences emerging from interactions among multiple parts of a system" (p. 106). The American Society for Engineering Education's seminal report in the 1950s on engineering education, commonly referred to as the Grinter Report, advocates as one of their primary tenets "an integrated study of engineering analysis, design, and engineering systems" (Grinter, 1956, p. 74). The National Academy of Engineering (NAE) and Accreditation Board for Engineering and Technology (ABET) both promote systems thinking for engineers. ABET (2007) defined engineering design as follows, "Engineering design is the process of devising a system, component, or process to meet desired needs" (p. 3). NAE (2005) called for the next generation of engineers to be global, (or systems), in their thinking and practice. Support for systems thinking in engineering comes from researchers, practitioners, and preeminent national organizations alike. Katehi et al. (2009) in their work on K–12 engineering education stated, "one crucial idea that appears regularly… is the concept of *systems*" (p. 42).

Katehi and colleagues (2009) explained that a system "is any organized collection of discrete elements designed to work together in interdependent ways to fulfill one or more functions" (p. 5) and that systems thinking "equips students to recognize essential interconnections in the technological world and to appreciate that systems may have unexpected effects that cannot be predicted from the behavior of individual systems" (p. 91). Systems thinking was defined in this study as the ability to understand the components of a system and their interactions and resulting outputs.

Not all engineering requires systems thinking because not all engineering problems are complex. Structured problems and Newtonian principles are not only present in engineering practice but are also helpful in engineering education pedagogy and content. Furthermore, complex problems may be broken down into subsystems and subproblems for a more simple understanding (Schunn, 2008).

Facets of Complexity and Systems in Engineering Design

Many of the facets of complexity science are found in engineering design. Engineering designers must often consider interconnected, wide-ranging, and non-linear variables. Interconnected variables may be complicated and complex. Complicated systems are elaborate and have multiple variables. Complex systems may be complicated, but they may also have variables that interact non-linearly and yield emergent properties.

Jonassen (2000) describes design as a form of problem solving that is open-ended and complex. Engineering designs generally have multiple solutions and varying solution paths (Brophy et al., 2008; Eide, Jenison, Mashaw, & Northrup, 2002; Foster et al., 2001). In addition to containing multiple variables, the variables often vary non-linearly along unique time scales. Katehi et al. (2009) stated that aggregate behavior is qualitatively distinct from the sum of behaviors of individual components and indicates a complex engineered system, such as highways, the Internet, the power grid, physical locations of companies in a city, and many others, which are all around us.

Systems Operations Within Engineering Design

Engineering requires that the designer meet multiple, possibly conflicting, requirements or constraints through optimization (Brophy et al., 2008; Cross, 2002; Katehi et al., 2009; Silk & Schunn, 2008). Optimization is generally an iterative process that balances trade-offs. These trade-offs may include the competition of performance versus cost, robustness versus social constraints, and time versus environmental impacts. Iteration is an integral component of optimization and may occur at any point in the design process (Hailey, Erekson, Becker, & Thomas, 2005). Iteration may be understood as the process of revisiting a design for continuous improvement while balancing constraints. Although optimizing trade-offs may impose a substantial cognitive load, the concept of trade-offs can be learned through improved pedagogical and curricular strategies. These strategies may include mathematical modeling and iteration (Silk & Schunn, 2008).

Katehi et al. (2009) suggested the use of graphical visualizations can help students improve systems thinking. Sketching can be used for representation and generation of ideas (MacDonald, Gustafson, & Gentilini, 2007). Anning (1997) stated, “Drawing and the processes by which they are made give us a window on children’s cognitive processing which can be as informative as studying their language” (p. 237). Sketching can reduce the designer’s cognitive load, “The sketch serves as a cognitive support tool during the design process; it compensates for human short-term memory limitations and at the same time supplements cognitive effort by depicting the mental imagery in a concrete form” (Plimmer & Apperley, 2002, p. 9).

Methods

The Function-Behavior-Structure (FBS) framework was used in this research for representing a design process. It should be noted that Function-Behavior-Structure is also represented in literatures as SBF with different meanings and nuances. As design often involves systems or components that are part of a system, the FBS framework may be used to elucidate systems thinking. Gero and Kannengiesser (2004) offered a definition of FBS.

1. Function variables describe the teleology of the object, i.e. what it is for.
2. Behavior variables describe the attributes that are derived or expected to be derived from the structure variables of the object, i.e., what it does.
3. Structure variables describe the components of the object and their relationship, i.e. what it is (p. 374).

Kathehi et al. (2009) proffered another definition: “FBS relates the components (structures) in a system to their purpose (function) in the system and the mechanisms that enable them to perform their functions (behavior)” (p. 123). Katehi et al. (2009) further stated that the FBS framework is well suited for describing systems thinking this way: “Systems thinking involves identifying parts [Structures], determining their function [Function], uncovering relationships, discovering how they work together as a system [Behavior], and identifying ways to improve their performance” (p. 91).

FBS was first introduced by Chandrasekaran and Milne (1985) in artificial intelligence (AI) design. Gero (1990) further developed the FBS framework. Recently, Gero has applied the FBS framework to engineering students and software developers. Other researchers have expanded the FBS framework to K–12 to understand cognition within complex systems (Goel, 1997; Hmelo-Silver, 2004; Hmelo-Silver et al., 2000). “The SBF framework allows effective reasoning about the functional and causal roles played by structural elements in a system by describing a system’s subcomponents, their purpose in the system, and the mechanisms that enable their functions” (Hmelo-Silver, 2004, p. 130). FBS is not a complete theory for describing the design of systems but rather a framework that aids in the understanding of human cognition in complex systems.

Setting and Data Collection

The students and high school were selected through criterion purposeful sampling. This study included 12 student participants drawn from a high school in the Intermountain West. The high school was selected because it had a reputation for having an exemplary pre-engineering program in the region. The high school recommendation was derived from high school teachers, state administrators, and university faculty from across the region. The students were high school upperclassmen and had taken at least two pre-engineering courses. These students were chosen based on their previous coursework in pre-engineering and their interest in engineering.

Participating students were paired to perform a design challenge. The team size was chosen to maximize verbalization from the students. The engineering design challenge in this study was a double-hung window opener that assists the elderly with raising and lowering windows. This challenge has been used by Gero (2010) and other researchers to study engineering design. Double-hung windows are commonly used and most students are familiar with window operation and function, so they do not need advanced engineering knowledge or background to complete the design challenge. Additionally, the design encompasses a variety of constraints: technical, ergonomic, financial, and social. The students had access to materials to aid in their design such as a desktop computer with Internet access, engineering graphing paper, and pencils. Similar to Atman's (1998) work, the students were given a time frame, in this case one hour, to complete the design proposal. They did not completely finish the design challenge due to the limitation of time. Instead of presenting practical products by the end of design, participants only submitted design proposals as their final outcomes. There were not instructions about the form or the content of the proposals they submitted. They did not build, test, and analyze their design because of the time constraint.

While working in teams, the students communicated their thought processes through verbal and nonverbal interactions. To augment the collection of students' cognition, audio was supplemented with video (Derry, 2007; Gero & Kan, 2009). While the participants were either analyzing or gathering information independently, or even gesturing, the video helped fill potential data gaps in the audio. The study collected data mainly through protocol analysis. In the process of collaborative engineering design, the conversation naturally occurred and the participants did not need prompting or coaching to verbalize. Researchers recorded participants' conversations by audio and nonverbal interactions by video without asking questions or answering participants' questions. The audio and video data complement each other to provide richer information about the conversations and actions in the engineering design process. The computer tracking data and the participants' sketches also supplemented the protocol data. The participants would often visit a website for information gathering or point to a drawing to communicate to their team member. These non-verbal artifacts were useful for helping bridge gaps in the verbal protocol data.

Post-hoc focus group reflective interviews were administered following the challenge (Zachary, Ryder, & Hicinbothom, 2000). The verbal data from the design challenge and interview were transcribed, segmented, and coded. Additionally, the students produced a design artifact, sketches and notes, from the design challenge that was also included in the analysis. The artifact was not evaluated, but rather used as another source for data corroboration. There was also tracking software that followed and collected the students' movements while on the computer.

Data Analysis

Analysis of the quantitative and qualitative data for this mixed method triangulation research study was performed concurrently. After the audio from the design challenge and the interview was transcribed, the data were segmented and coded by two separate analysts, solicited graduate students (Chi, 1997). The video, computer movements, and sketches were also used to help the analysts reproduce the students' design process in order to segment and code the verbalizations more effectively.

The transcribed student verbalizations from the design challenge were broken down into segments. The segments were then coded using the FBS codes: requirements, function, expected behavior, structure, derived behavior, and description. Excerpts from a design challenge will serve as an illustration of the issues in Table 1.

Table 1
Examples of Design Issues from the Design Challenge

Utterance	Issue
How much do you think fishing line could hold?	Expected Behavior (Be)
The crank would raise the window by pushing it up probably	Derived Behavior (Bs)
Let's write that negative one down	Documentation (D)
That would spread the work out, make it easier	Function (F)
Get the window to go up, that's the um bottom line	Requirements (R)
Now we got to do the position of the crank and everything	Structure (S)

Within the FBS framework, the coded segments were termed design issues ,and the transition from one design issue to another was termed processes. Table 2 is excerpt from Dyad B during the design challenge that demonstrates various design processes.

Table 2
Excerpt from Dyad B Design Challenge Showing Design Processes

Student	Utterance	Issue	Process
1	*You'd have to have it down at an easy to reach level*	Be	-
1	*So you could find where the hooks are*	S	Reformulation II
1	*But then you'd have to go um over so you have like a little crank*	Bs	Analysis
1	*Like you'd have something.*	Be	Evaluation
2	*Then you'd have somebody come up over with like a pulley*	S	-
1	*Down on the hook*	S	Reformulation I

To ensure inter-rater reliability, the coding analysts received over 30 hours of training on segmenting and coding in the FBS framework. After the final training, the analysts were able to individually code segments with a percent agreement of 93.2%. Cohen's Kappa was calculated between the coders to be 0.89, exceeding an accepted reliability coefficient of 0.7 in the social sciences (Schloss & Smith, 1999).

Frequency counts and distribution of codes over time for both the issues and processes were analyzed descriptively. The processes were also analyzed using measures of centrality. The measures of centrality used were betweenness, closeness, and degree. Analysis was performed to aid in understanding the relative significance of the issues and processes.

The audio and video data from the design challenge, audio and video data from the post-hoc interview, the tracking data, and the design artifact were analyzed as a whole for evidence of systems thinking. Additional unanticipated themes or phenomena also surfaced during this process. Hmelo-Silver et al. (2000) used a similar methodology in their study. This research was also open to and sought new themes by poring over the data outside of the FBS framework and the resulting segmenting and coding. Deductive themes were derived from the literature in systems thinking. These themes included multiple interconnected variables, emergence, open-endedness, and optimization (Brophy et al., 2008; Eide et al., 2002; Katehi et al., 2009; Schunn, 2008). Inductive themes emerged from the data including graphical visualizations and analogical reasoning. These qualitative themes are discussed later in this paper.

Results

FBS Issues and Processes

The first research question of this study sought to understand cognitive issues and processes used by high school students in an engineering design problem through the FBS framework. There were 1,917 segments coded. Of these coded segments, 1,012 (52.8%) fell within the range and were coded using the FBS framework. The total FBS codes are found in Table 3 with their mean, standard error of the mean, and percentage. The percentages were calculated from the total number of FBS coded segments.

Table 3
Descriptive Statistics for Function-Behavior-Structure Coding

Code	*M*	*SEM*	%
Expected Behavior (Be)	44.83	3.63	26.6%
Derived Behavior (Bs)	28.00	8.62	16.6%
Documentation (D)	15.67	3.23	9.3%
Function (F)	2.33	0.42	1.4%
Requirements (R)	4.00	0.93	2.4%
Structure (S)	73.83	9.40	43.8%

Structure (S) was the most prevalent code at 43.8% with the lowest being Function (F) at 1.4%. Nearly one-tenth of the coding was given to the teams documenting (D) their design. This was done through sketching and list making. Note that only utterances that pertained to documentation were coded with (D). There were many instances when the students were “documenting” but they did not verbalize it. Therefore, without an utterance there was no coding attached. The processes were operationally defined as transitions from one FBS code to another. The code transitions were analyzed using descriptive statistics and measures of centrality: degree, betweenness, and closeness. The total FBS transitions are found in Table 4 (next page) with their mean, standard error of the mean, and percentage.

Table 4
Function-Behavior-Structure Transitions for All Dyads Combined

	M	*SEM*	%
Reformulation I (S→S)	37.00	4.73	36.69%
Reformulation II (S→Be)	17.50	1.95	17.36%
Synthesis (Be→S)	16.00	1.83	15.87%
Evaluation (Be↔Bs)	14.00	2.92	13.88%
Analysis (S→Bs)	11.33	4.70	11.24%
Documentation (S→D)	3.83	1.92	3.80%
Reformulation III (S→F)	0.50	0.34	0.50%
Formulation (F→Be)	0.50	0.34	0.50%

The number of design processes was highest for structures, with the majority being reformulation. Reformulation is a modification or an addition to a design based on the surface characteristics or structure. The participants synthesized their ideas transitioning from expected behavior to structure. The results from the design processes are congruent with the findings from design issues; the participants concentrated on structures and expected behaviors. The participants were able to create ideas, expected behaviors, and synthesize them into structures. However, the amount of analysis (structure to derived behavior) was low (11.24%) when compared to reformulation and synthesis.

Table 5 (next page) displays the results for all measures of centrality for all dyads. Expected behavior (Be) and structure (S) had the highest results for all measures of centrality. Although structure (S) had the highest frequency count, expected behavior (Be) had the highest degree, which is a measure of the number of links or connections to other codes.

Table 5
Mean Centrality Values for All Dyads Combined

	Degree		Betweenness		Closeness	
FBS Code	*M*	*SEM*	*M*	*SEM*	*M*	*SEM*
Be	5.33	0.33	3.53	0.97	0.16	0.01
S	4.50	0.34	3.58	0.88	0.17	0.01
Bs	4.17	0.31	1.28	0.63	0.15	0.01
D	4.00	0.37	1.64	0.66	0.15	0.01
R	2.67	0.42	1.14	0.85	0.12	0.01
F	1.50	0.22	0.17	0.17	0.12	0.01

Systems and Design Themes

The second research question sought to understand any qualitative themes and phenomena related to the students' systems thinking in engineering design. The qualitative analysis was performed by repeatedly reviewing and analyzing the data sources outside of the FBS framework looking for themes, patterns, and phenomena (Glesne, 2006). The researchers reviewed the data looking for themes. For example, one of the common practices in which the students engaged was using analogies to further understand the problem and communicate ideas to teammates. FBS was not used as a frame of reference for this analysis. Undoubtedly, the FBS framework had influenced the researcher's thinking. However, the FBS framework was not intentionally used or referenced in the qualitative analysis.

The qualitative analysis involved looking at all data sources in tandem. All of the videos were viewed to get a feel for the study. Following the viewing, the videos were analyzed along with the transcripts, the computer movements, and the corresponding sketches by dyad. The results of this analysis yielded three new inductive themes: sketching, analogous reasoning, and design challenge relevance. These themes were then identified and situated in complexity and engineering design literature. Deductive themes were also derived from the literature including: multiple interconnected variables, emergence, non-linearity, optimization, and open-endedness (Davis & Sumara, 2006; Dym et al., 2005; Schunn, 2009). With the themes identified, the data sources from all dyads were analyzed against themes listed above. This section will discuss and attempt to interpret these themes.

Multiple interconnected variables. The students considered multiple variables related to their designs. Not only was each dyad's design solution complicated with multiple interacting parts, they were complex. They were complex in that the designs included variables outside the technical design solutions. The primary non-technical variable referenced by the students was accessibility. This was followed by aesthetics, physical placement of the design solution, cost, maintenance, and manufacturability. Accessibility was frequently referenced as a design constraint among all dyads. Perhaps the students were able to relate to nursing homes and other facilities and had an idea of the end user. One of the students, Byron, even remarked how his design “would have helped her [his deceased great grandmother] out a lot” in her later years. The students not only made general mention of assistive constraints, they specifically considered arthritis, wheelchairs, and other ergonomic factors. Furthermore, the students in this study belonged to the generation raised while the Americans with Disabilities Act (ADA) was effected and implemented. Although the impact cannot be easily measured, the ADA has had at least indirect, if not direct, impacts on the students’ ways of thinking.

The students also mentioned physical placement of their design solution. Some dyads considered aesthetics and the solution’s placement in the design. Again, aesthetics could be considered another constraint in reference to the nursing home tenants. There were other variables that were only briefly mentioned. These included costs, manufacturability, and maintenance. The latter two were only mentioned once. Perhaps this is due largely to the scope of the design challenge. If the design challenge had actually included production and testing of a prototype, the students would have more likely considered a wider spectrum of variables. The students’ limited references of these diverse constraints does not imply that they were incapable of balancing them in their designs, as they were able to successfully recognize and design to the nursing home tenants’ needs and constraints.

Open-endedness. Engineering designs may be approached through multiple solution paths with varying end products (Asunda & Hill, 2007; Sneider, 2011). The students in this research investigated multiple alternatives and variations on their final design. Altogether, the students generated 14 possible design solutions. Not every dyad contributed an equal amount. Dyad F generated six unique ideas, while Dyad D produced two. Interestingly, these same dyads represented the top and bottom of the range for analogies generated, 17 and one respectively.

All of the dyads considered a pulley system in their design, with four dyads using pulleys as part of their final design solution. It is not certain why pulleys were so prevalent in their designs. Their instructor was consulted on this finding. He stated that pulleys did not receive more attention than other topics in the curriculum. Even though the students’ designs converged on pulleys, the students considered other design alternatives and compared them to each other. Eric and Eddie were a prime example as they wrestled back and forth with which of their four main ideas they would use. They finally decided upon a solution that blended their distinct ideas. Other dyads combined the ideas they generated to produce a final solution. These students demonstrated that they can generate and compare alternative ideas.

Optimization. The students optimized their designs seeking to balance competing constraints. The students had to make trade-offs between technical functionality and either costs or aesthetics. What appeared to be trade-offs often led to an improved design. Examples included a rope being traded for a transparent high strength cord or the ergonomic placement of a manual crank by Dyad B. From the data, it may be deduced that the students were continually reevaluating and improving their designs.

Within the dyads, the students had to balance the competing ideas among themselves. Each dyad had positive conflict resolution. The conflict often led to better or improved ideas. Dyad A consisted of a boisterous, outspoken senior, Anthony, and a reserved junior, Andrew. There were many instances when Andrew's suggestions appeared to be ignored. However, Andrew persisted and was eventually able to implement his ideas in the design. For example, early in the design challenge Andrew suggested the idea of a large push button. It was not until much later in the design that Andrew was able to have his idea considered. Eventually, Dyad A was able to implement the push button into their final design. This small conflict did not create contention. As a matter of fact, when the design challenge began to wind down, the one turned to the other and said, "We're a great team dude!"

All the dyads in this research study iteratively optimized their design solutions. This was evident throughout the design challenge. If the students had further personal experiences with a sash window and its construction, perhaps they would have worked with a deeper level of comprehension with the competing constraints inherent in this design challenge.

Graphical visualization. Sketching and annotation were used by all students throughout the engineering design challenge. Sketching is helpful when understanding and analyzing a system (Katehi et al., 2009; MacDonald et al., 2007). For example, Brody suggested the idea of a crank, but he recognized that there was a challenge in using a crank to move the window up and down. So, his teammate Byron attempted to tackle the problem.

Byron: Well, what I was thinking… [pause] you could… [pause] and this is a little complicated.

Brody: Okay, we just have to draw it out.

After Byron struggled to articulate his ideas, Brody realized that sketching their design would be helpful.

Sketching was not just limited to offloading cognitive effort, it was used to generate, develop, and communicate designs. Dyad C applied sketches and list making to brainstorm their ideas, see Figure 2 (page 69). Sketching was also applied to develop and optimize the students' designs. Sketching was further employed to communicate ideas and designs to each other and the "client." Sketching was the primary tool, physically and cognitively, exploited by the students. Albeit, the computer was used for information gathering and concept verification, the depth and breadth of the use of sketching was vast in the students' design process. The results of this study are congruent with the literature in that graphical visualization plays an important role in engineering design (Anning, 1997; Katehi et al., 2009; MacDonald et al., 2007). Therefore, educators might do well to use sketching and other graphical visualizations more effectively in their curriculum.

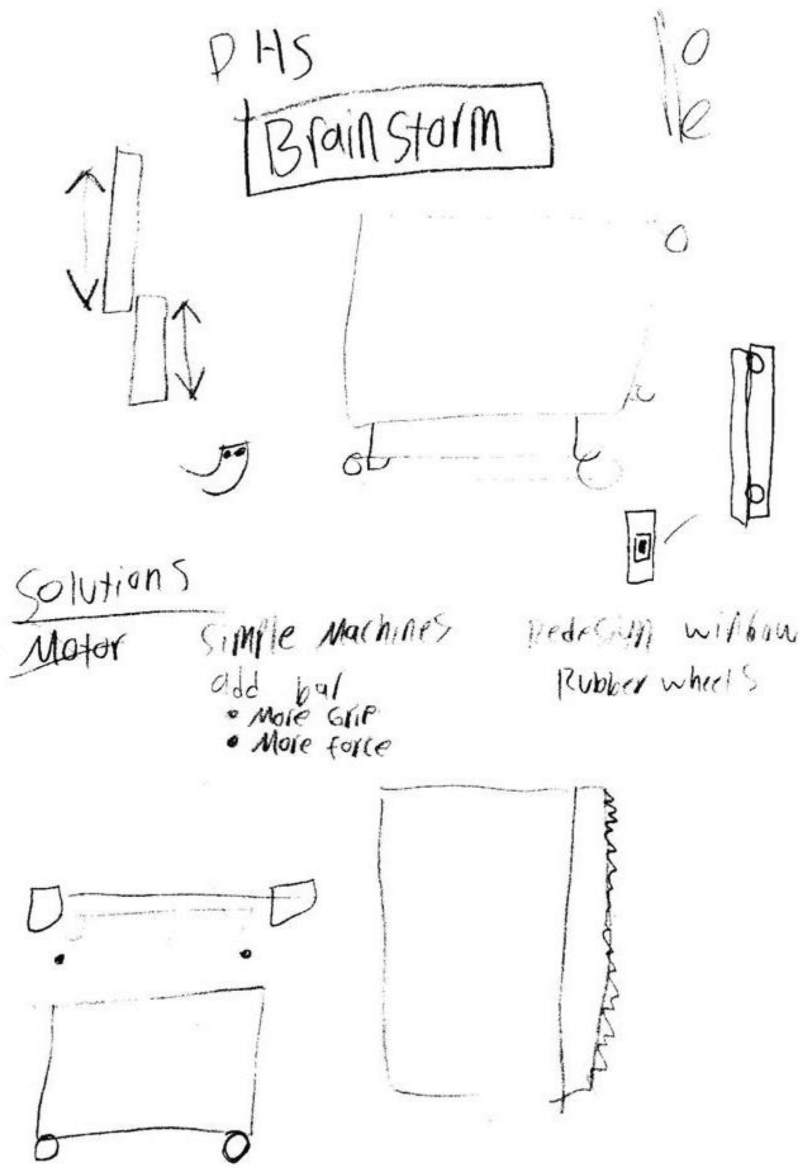
Analogical reasoning. The students used analogies to help themselves and others understand their ideas. Analogies were also used in design development. The total number of analogies used by all the students was 38. Without much technical experience with windows or assistive design, the students drew upon their experiences through analogies. In the post-hoc focus group, the students were asked how they generated different ideas.

> Fred: We tried finding examples. We used a screw driver, a crane, blinds, car jack. [We] just tried finding things that we already used.
>
> Forrest: Me and my dad go around the house—projects—we mess with stuff like that. [We] never had to mess with windows, though we have sliding windows that push up. I also got my ideas from a snow boarder binding system.

These students were explicit about drawing from their episodic memory. However, analogies do have limitations. It is possible that a fallacious analogy could be used incorrectly and in turn propagates misconceptions. Additionally, not all students have the same background or experience. Hence, an analogy that works for one student may be completely irrelevant to another. In spite of the limitations analogies pose, their use with students should be capitalized on.

Relevance. Students, particularly K–12 students, tend to be more engaged in a design activity if it is perceived to be relevant and pertains to the student's everyday life (Brophy et al., 2008; Sadler, Coyle, & Schwartz, 2000; Svensson & Ingerman, 2010). Overall, the students favorably spoke of the design challenge's relevance. Their comments included, "cool", "fun", and "interesting." The design challenge also "had real life application" that pertained to the students. Some of the students took ownership of their designs by spontaneously naming them. Furthermore, the design challenge scope was not overly restraining and was simple enough for the students to understand (Sadler et al., 2000).

Figure 2
First page of sketching by Dyad C. The figure shows the students' sketches, brainstorming, and development of ideas, such as pulleys and rack gears



Implications for Engineering and Technology Educators

This study is limited in that the participants were students from one pre-engineering program. Therefore, the reader is encouraged to reflect on how the findings from this study may be applicable to their unique situation through naturalistic generalization. From the results of this study, engineering and technology teachers may infer that systems thinking can be learned by students as it relates to the FBS framework and other phenomena. That is not to say that the instructors and students alike have to be trained in all of the details and nuances of Gero's FBS framework. Although the nomenclature of FBS may not need to be taught, the underlying concepts and thinking of the FBS framework could lend to enhanced systems thinking (Katehi et al., 2009). Hmelo-Silver and colleagues found that sixth grade students were capable of systems thinking, albeit, quite limited (2000).

Structures constituted the dominant cognitive activity in this study. Expert designers have also relied heavily on structures in previous studies (Gero & Kan, 2009; Kan & Gero, 2008). Experts often considered and employed functions and behaviors to create their designs as well. Therefore, students should be encouraged to go beyond the structures of a device or system while designing. The students did not receive explicit training in systems thinking, let alone in the FBS framework. Nevertheless, the students in this study were also able to consider behaviors, particularly when transitioning from one thought to another.

Expected behavior was pivotal in the students' cognitive processes. The participants in this study relied heavily on expected behaviors when transitioning to other FBS codes. In the FBS framework, *expected behavior* is defined as the designer's expectations for the structure; in other words, what the solution does, or what it could do. Examples of expected behavior from this study included,

(Be) So it will slide up easier
(Be) Yeah, so it's like, does it like lock and you open the window halfway or some way
(Be) Crank that one over and it will roll down

Expected behavior often includes idea generation. The students in this study often used expected behavior, suggesting that high school students from similar backgrounds might also be able to exploit this ability.

Curriculum and pedagogy with systems thinking could help the students discover the purposes (function) of a device and explore how those purposes are achieved (behavior). For example, when investigating and learning about pulleys, the teleological aspects could be addressed. The teleology may include mechanical advantage, hoisting, or rappelling. The purposes could also be made contextual, ranging from an assistive window opener to cranes or even mountaineering. Relevant behaviors, such as securing a load, reducing friction, and providing an ergonomic feel, may be examined as well. However, curricula with a systems focus are not widespread in K–12.

In addition to discussing and teaching functions and behaviors, interconnectedness of variables can be explored. The students from this study were able to consider multiple variables and also noted that these variables interacted within the design. For example, one dyad realized that a manual crank was not aesthetically attractive below the window. Moving the crank to the side of the window not only created a more attractive design, but also allowed for one less pulley and easier access for the tenants. The results of this study do not suggest that students will address all germane variables, as maintenance and manufacturability were only addressed by two separate students. Recently graduated engineers moving into industry are not expected to know every aspect and variable about their new responsibilities (Lang, Cruse, McVey, & McMasters, 1999). Even an experienced and expert engineer has to frame the problem. What then is to be expected of a high school student in engineering design with regard to multiple interconnected variables? Clearly, students will not be able to identify and design for all variables. However, the students should be taught that there are multiple factors in a design that likely interact. Furthermore, instructors could instruct the students that among all the variables there are those which are salient and those which are not.

Quite noteworthy was the finding that all students consistently recognized the human variable in their designs. Perhaps the design problem was sufficiently pertinent such that the students could relate to and visualize it. Many of the students commented on how interesting the design challenge was to them. These students had no experience with window design or maintenance and were only vaguely familiar with the intricacies involved. Yet, the students have all used a window before; albeit, not sash windows. Considering these points, the students were able to some degree relate to or imagine the end user's perspective. After Dyad A had decided on an initial design, they began to further visualize their design.

Andrew: If they're too old to even push down on it, they can just lean on it.
Anthony: Yeah.
Andrew: And if they get bored…
Anthony: Lean on it.
Andrew: If they fall asleep, guess what? They'll open the window a little bit too.
Anthony: Okay. I want to take this a little bit further. This window is not safe for elderly use.

The students are not only capable of including the human factor in their design, but they should be encouraged to extend to other non-technical variables as well (NAE, 2004).

The students engaged in sketching throughout the entire design process, with an increase toward the end of the design challenge. Students should consider the use of sketching to not only communicate ideas but to generate, develop, and optimize ideas and designs as well. The sketching does not have to be precise or expert. As Byron stated, “it's not the ability, just get the idea across.” Too often, sketching is merely used to communicate ideas (MacDonald et al., 2007), yet research has shown that drawing is integral in engineering design (Bucciarelli, 1994). Not all educational activities need a formal assessment. Sketches to aid in design could be assessed formatively without a grade assigned. Teachers may also want to increase how often sketching is performed.

Sketching is not only helpful in design; it likewise assists the students in systems thinking. The abstractness and looseness of sketching allows for adaptation and divergence. Furthermore, the sketch can offload the cognitive stresses related to complexity. Sketching is not limited to a pencil and paper drawings. There is an array of multimedia tools available to students in design; however, this research did not allow students to use computer aided drafting tools. Results from previous research were mixed in regard to the use of computer aided drafting (Denson, Lammi, Park, & Dansie, 2010).

All of the students in this study considered multiple alternatives in the design challenge. The curriculum in the pre-engineering program included the use of decision matrices; however, not one team used an annotated decision matrix in their analysis. Educators should carefully consider how to instruct students on developing design alternatives and how to make informed decisions regarding such. Perhaps the underlying principle is continuous improvement. Optimization, iteration, and evaluation of competing constraints have the end of an optimal design. There are many models of continuous improvement in industry such as Total Quality Management and Six Sigma from which instructors may draw.

Educators should help students draw from their own experience when designing. Analogous reasoning can help the students understand the many abstract science and math concepts in engineering. Analogous reasoning is often used in engineering design and should be included in engineering design curriculum and instruction (Christensen & Schunn, 2007).

Systems thinking is an important concept in engineering design (Asunda & Hill, 2007; Brophy et al., 2008; Dym et al., 2005; Katehi et al., 2009; Mehalik & Schunn, 2006). The implications for systems thinking are expansive and broad. This study was able to focus on a portion of systems thinking, particularly through the lens of the FBS framework. The implications for educators include focusing on deeper concepts and behaviors, multiple variables and their interactions, optimization, sketching, and analogous reasoning. Most salient is the finding that students in this study were capable of thinking in terms of systems.

Conclusions and Recommendations

This triangulated mixed methods research study is a viable approach for studying student thinking in terms of systems. Although there were limitations with this study, all of the data sources combined to recreate the students' design process and shed light on the students' system thinking. Hence, qualitative and quantitative themes emerged through the use of triangulated data coupled with analysis in the FBS framework.

This research attempted to collect data in an environment close to the students' everyday classroom settings. The students worked with peers in their engineering classroom while working at their computer workstations. The students were aware that they were being audio and video recorded along with their computer movements. However, when asked in the interview, the students stated that the recording equipment was not imposing or distracting. Additionally, the researcher in this study did not hover over the students. The students were accustomed to working in teams and rarely sought help. The researcher was always present for any questions, yet the researcher purposefully moved to the other end of the room from the students. The students were aware and took advantage of the freedom to move about the room. The environment where data is collected is important as it affects the students' context and attitudes as well as research validity. As a researcher, small efforts to accommodate the study participants may yield more trustworthy and valid results.

The findings from this study demonstrated that high school students are capable of systems thinking in an engineering design challenge. The students' systems thinking was demonstrated through FBS analysis and complexity themes alike. Although the high school students focused primarily on structures, they also referenced behaviors. From the analysis of the measures of centrality, it was found that expected behavior played a pivotal role in the students' cognitive transitions. These results suggest that the students looked beyond the façade of their design and delved into its anatomy and operation.

Engineering design is by definition rarely performed in isolation, i.e., isolation from other designs, networks, systems, or humans. Dym (2005) goes so far as to say that all design is systems design. If systems are so pervasive in engineering design, then what is to be taught that is unique to systems thinking and how will it be delivered? Foster et al. (2001) have been able to successfully include complexity thinking in their undergraduate engineering curriculum. However, can systems thinking be taught to high school, or even K–8 students? Jacobson and Wilensky (2006) claimed that students can learn to think in terms of complexity at some level. The findings from this research study have shown that high school students can think in terms of systems. However, this study does not claim to know how this capability was developed. This research could not only provide insight to researchers in engineering and technology education but to educational practitioners as well.

This research could provide a springboard to additional research studies, including a larger sample of students from diverse schools using distinct engineering curriculum. Qualitatively, different schools and different pre-engineering programs could be included. Undoubtedly, students from other pre-engineering curricula would have unique language, techniques, and themes. Quantitatively, a larger sample size would yield a higher statistical power. Additionally, a larger sample size would also allow for inferential statistics to be computed and analyzed. The range of students studied could also be stratified by year in school and academic performance. Questions to be answered could include: How do seniors in high school differ from freshman? How do non-engineering students in high school compare to pre-engineering students? This study could also inform experimental research that investigates system thinking interventions. Systems thinking is not unique to engineering design. Other studies outside of engineering might also benefit from the FBS framework and other systems perspectives.

Other perspectives and frameworks of engineering design could be investigated, such as collaboration, creativity, and the use of the computer for sketching and information gathering. The scope of the design challenge could also be expanded by allowing the students to build, test, evaluate, and redesign.

References

Accreditation Board for Engineering and Technology. (2007). ABET 2009 Requirements. Retrieved from http://www.abet.org/Linked DocumentsUPDATE/Criteria and PP/E001 09-10 EAC Criteria 12-01-08.pdf

Anning, A. (1997). Drawing out ideas: Graphicacy and young children. *International Journal of Technology and Design Education, 7*(3), 219–239.

Apedoe, X., Reynolds, B., Ellefson, M., & Schunn, C. (2008). Bringing engineering design into high school science classrooms: The heating/cooling unit. *Journal of Science Education and Technology, 17*(5), 454–465.

Asunda, P. A., & Hill, R. B. (2007). Critical features of engineering design in technology education. *Journal of Industrial Teacher Education, 44*(1), 25–48.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P–12 classrooms. *Journal of Engineering Education, 97*(3), 369–387.

Bucciarelli, L. L. (1994). *Designing engineers*. Cambridge, MA: MIT Press.

Chandrasekaran, B., & Milne, R. (1985). Reasoning about structure, behavior, and function. [Newsletter]. *ACM SIGART Bulletin, 93*, 4–59.

Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal of the Learning Sciences, 6*(3), 271–315.

Christensen, B. T., & Schunn, C. (2007). The relationship of analogical distance to analogical function and preventive structure: The case of engineering design. *Memory & Cognition, 35*(1), 29–38.

Cross, N. (2002). Creative cognition in design: Processes of exceptional designers. In T. Hewett & T. Kavanagh (Eds.), *Creativity and cognition* (pp. 6–12). New York, NY: ACM Press.

Dally, J. W., & Zhang, G. M. (1993). An engineering design course for freshman students. *Journal of Engineering Education, 14*(2), 20–27.

Davis, B., & Sumara, D. (2006). *Complexity and education: Inquiries into learning, teaching, and research*. Mahwah, NJ: Erlbaum.

Denson, C., Lammi, M., Park, K. S., & Dansie, E. (2010). *Methods for exploring engineering design thinking in high school student teams*. Paper presented at the 2010 ASEE Annual Conference, Louisville, KY.

Derry, S. J. (Ed.). (2007). *Guidelines for video research in education: Recommendations from an expert panel* [White paper]. Chicago, IL: University of Chicago, Data Research and Development Center. Retrieved from http://drdc.uchicago.edu/what/video-research-guidelines.pdf - page=1&view=fitV,0

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 104–120.

Dym, C. L., & Little, P. (2009). *Engineering design: A project-based introduction* (3rd ed.). New York: John Wiley.

Eide, A. R., Jenison, R. D., Mashaw, L. H., & Northrup, L. L. (2002). *Introduction to engineering design and problem solving*. Boston, MA: McGraw Hill.

Eisenkraft, A. (2011). Engineering design challenges in a science curriculum. Logan, UT: National Center for Engineering and Technology Education, Utah State University.

Foster, J., Kay, J., & Roe, P. (2001). *Teaching complexity and systems thinking to engineers*. Paper presented at the 4th UICEE Annual Conference on Engineering Education, Bangkok, Thailand.

Gero, J. S. (1990). Design prototypes: A knowledge representation schema for design. *AI Magazine, 11*(4), 26–36.

Gero, J. S., & Kan, J. W. (2009). Learning to collaborate during team designing: Some preliminary results from measurement-based tools. In A. Chakrabarti (Ed.), *Research into design* (pp. 560–567). Delhi, India: Research Publications.

Gero, J. S., & Kannengiesser, U. (2004). The situated function-behaviour-structure framework. *Design Studies, 25*(4), 373–391.

Glesne, C. (2006). *Becoming qualitative researchers: An introduction* (3rd ed.). Boston, MA: Pearson, Allyn and Bacon.
Goel, A. E. (1997). Design, analogy, and creativity. *IEEE Expert, 12*(2), 62–70.
Grinter, L. E. (1956). Report on the evaluation of engineering education. *Engineering Education, 46*(3), 25–63.
Hailey, C. E., Erekson, T. L., Becker, K. H., & Thomas, M. (2005). National Center for Engineering and Technology Education. *The Technology Teacher, 64*(5), 23–26.
Hmelo-Silver, C. E. (2004). Problem-based Learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266.
Hmelo-Silver, C. E., & Azavedo, R. (2006). Understanding complex systems: Some core challenges. *Journal of the Learning Sciences, 1*(15), 53–61.
Hmelo-Silver, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learn about complex systems. *The Journal of the Learning Sciences, 9*(3), 247–298.
Jacobson, M. J., & Wilensky, U. (2006). Complex systems in education: Scientific and educational importance and implications for the learning sciences. *Journal of the Learning Sciences, 15*(1), 11–34.
Jonassen, D. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63–85.
Kan, J. W., & Gero, J. S. (2008). Acquiring information from linkography in protocol studies of designers. *Design Studies, 29*(4), 315–337.
Katehi, L., Pearson, G., & Feder, M. (Eds.). (2009). *Engineering in K–12 education: Understanding the status and improving the prospects*. Washington, DC: The National Academies Press.
Kolodner, J. L. (2002). Facilitating the learning of design practices: Lessons learned from an inquiry into science education. *Journal of Industrial Teacher Education, 39*(3), 9–40.
Lang, J. D., Cruse, S., McVey, F. D., & McMasters, J. (1999). Industry expectations of new engineers: A survey to assist curriculum designers. *Journal of Engineering Education, 88*(1), 43–51.
MacDonald, D., Gustafson, B. J., & Gentilini, S. (2007). Enhancing children's drawing in design technology planning and making. *Research in Science & Technological Education, 25*(1), 59–75.
Mehalik, M., & Schunn, C. (2006). What constitutes good design? A review of empirical studies of the design process. *International Journal of Engineering Education, 22*(3), 519–532.
National Academy of Engineering. (2004). *The engineer of 2020: Visions of engineering in the new century*. Washington, DC: The National Academies Press.
National Academy of Engineering. (2005). *Educating the engineer of 2020: Adapting engineering education to the new century*. Washington, DC: The National Academies Press.

Ottino, J. M. (2004). Engineering complex systems. *Nature, 427*(6973), 399–399.

Plimmer, B., & Apperley, M. (2002). *Computer-aided sketching to capture preliminary design*. Paper presented at the Third Australasian User Interfaces Conference, Melbourne, Australia.

Sadler, P. M., Coyle, H. P., & Schwartz, M. (2000). Engineering competitions in the middle school classroom: Key elements in developing effective design challenges. *Journal of the Learning Sciences, 9*(3), 299–327.

Schloss, P. J., & Smith, M. A. (1999). *Conducting research*. Upper Saddle River, NJ: Prentice Hall.

Schunn, C. (2008). Engineering educational design. *Educational Designer, 1*(1), 1–23.

Schunn, C. (2009). How kids learn engineering: The cognitive science. *The Bridge, 39*(3), 32–37.

Silk, E. M., & Schunn, C. (2008). *Core concepts in engineering as a basis for understanding and improving K–12 engineering education in the United States*. Paper presented at the National Academy Workshop on K–12 Engineering Education, Washington, DC.

Sneider, C. (2011). A possible pathway for high school science in a STEM world. Logan, UT: National Center for Engineering and Technology Education, Utah State University.

Svensson, M., & Ingerman, Å. (2010). Discerning technological systems related to everyday objects: Mapping the variation in pupils' experience. *International Journal of Technology and Design Education, 20*(3), 255–275.

Zachary, W. W., Ryder, J. M., & Hicinbothom, J. H. (2000). Building cognitive task analyses and models of a decision-making team in a complex real-time environment. In S. Chipman, V. Shalin & J. Schraagen (Eds.), *Cognitive task analysis*. Mahwah, NJ: Erlbaum.

High School Students' Use of Paper-Based and Internet-Based Information Sources in the Engineering Design Process

Science, Technology, Engineering, and Mathematics (STEM) education continues to be a national concern. In the State of the Union address in January 2011, President Obama called for 100,000 new STEM teachers over the next decade. The Programme for International Students Assessment (PISA) investigated the academic achievement of 15-year-old students from 60 countries and five education systems in the areas of math, science, and reading. Results of the 2009 study indicated that the U.S. students were ranked 23rd of 60 countries involved (Fleischman, Hopstock, Pelczar, & Shelley, 2010). Published in 1983, *A Nation At Risk: The Imperative for Educational Reform* called for improvement of education at the secondary levels (National Commission on Excellence in Education, 1983). The report demanded more emphasis on science and mathematics at both the primary and secondary level, creating the academic foundation for science, technology, engineering, and mathematics education.

Technology and Engineering education (the *T* and *E* of STEM) have seen increased attention in recent years. The National Academy of Engineering commissioned a study titled "Engineering in K–12 Education," which included a review of curriculum materials related to the *T* and *E* of STEM education as well as the relationship between Science, Technology, Engineering, and Mathematics education. The National Academy's work emphasized the role of engineering in improving STEM education as it may be a "catalyst" serving to draw connections between mathematics, science, and technology education (Katehi, Pearson, & Feder, 2009).

Design is essential to the disciplines of engineering and technology. Atman, Cardella, Turns, and Adams (2005) stated that "Design is a central activity to all types of engineering. Mechanical, Civil and Electrical Engineers attempt to solve very different types of problems, but they all design some solution to the problem at hand" (p. 325). Critical to differentiating technology from other fields, such as science, is "the ability to design" according to Layton (1974, p. 37). Sheppard, Macatangay, Colby, and Sullivan (2009) stated that "engineering design involves a way of thinking that is increasingly referred to as design thinking: a high level of creativity and mental discipline as the engineer tries to discover the heart of the problem and explore beyond the solutions at easy reach" (p. 100). The National Center for Engineering and Technology Education focused its efforts on infusing engineering design into high school technology education classrooms. Through a series of research studies focused on student

Jon Pieper (Jon_Pieper@hcpss.org) is a Technology and Engineering Teacher at Howard High School in Elliot City, Maryland. Nathan Mentzer (nmentzer@purdue.edu) is an Assistant Professor in the Engineering/Technology Teacher Education Program at Purdue University.

learning and professional development, the center refined a design process emphasizing eight essential elements appropriate for high school learners (Childress & Maurizio, 2007, p. 3):

1. Identification of a need
2. Definition of the problem/specifications
3. Search
4. Develop designs
5. Analysis
6. Decision
7. Test prototype and verify the solution
8. Communication

These eight steps are generally congruent with texts describing the engineering design process for engineering students (Dym & Little, 2004; Eide, Jenison, Mashaw, & Northup, 1998; Eide, Jenison, Northup, & Mickelson, 2008; Moore, Atman, Bursic, Shuman, & Gottfried, 1995). The engineering design process, as noted by Sheppard et al. (2009), "is not linear: at any phase of the process, the engineer may need to identify and define subproblems, then generate and evaluate solutions to the subproblems to integrate back into the overall process" (p. 104). Sheppard et al. summarized the design process to include three broad areas of focus: defining the problem, generating candidate solutions, and evaluating and implementing candidate solutions. Sheppard et al. also added that communication, teamwork, time management, and project management are essential broader professional skills requisite to success.

The need to gather information is ubiquitous in the design process. Bursic and Atman (1997) stated that the step of gathering information is critical to create a successful solution of an engineering-based problem. Childress and Maurizio (2007) used the term s*earch* to mean exploring existing solutions and how they work. This search also includes parts of the solution or components that may already exist and can be combined in a novel way. Dym and Little suggested that gathering information was an essential element of the problem definition, conceptual design, preliminary design, detailed design, and design communication. The sources of information throughout the design process include literature on modern solutions, experts, codes, and regulations; competitive products; heuristics; models; known physical relationships; design codes; handbooks; local laws/regulations; suppliers component specifications; and feedback from clients/users (Dym & Little, 2004, pp. 24–25). Eide et al., suggested that after problem definition, "The team next acquires and assembles all pertinent information on the problem (Step 2). Internal company documents, available systems, Internet searches, and other engineers are possible sources of information" (2008, p. 44). In addition, Eide suggested, "Often customer requirements are not well defined. The design team must determine, in consultation with the customer, the expectations of the solution" (p.46).

Engineering design problems present an opportunity to contextualize the study of technology and engineering in authentic learning experiences where improvement of people's lives are the focus (Svihla, Petrosino, & Diller, 2012). Problem-based learning literature related to technology and engineering education suggest engaging the learner in a constructivist learning environment through design problems as a teaching methodology (Brodeur, Young, & Blair, 2002; Fosmire, 2011; Gijselaers, 1996). Creating an authentic learning environment requires that as students work through a design challenge, they have access to information relevant to their problem (Ekwaro-Osire, Afuh, & Orono, 2008; Fosmire, 2011; Wang, Dyehouse, Weber, & Strobel, 2012; Zimmerman & Muraski, 1995). Information access in classrooms may come from teacher generated documents or texts onsite, but to be authentic, should also come from access to the Internet (Katehi, et al., 2009). Engineers working on design problems use onsite resources but also access databases and search for information beyond the limits of their peers and local documents.

Teachers often present students with some information related to their design problems, but that information will be limited. Teachers have limited time to prepare and cannot explore all possible aspects of the problem at hand. To be authentic, students should engage in some problem definition which is ill-structured and open-ended (National Center for Engineering and Technology Education, 2012). Teachers inherently have a bias toward potential solutions paths, and teacher gathered information will inherently be guided by this bias therefore steering the students and potentially limiting creativity. Due to the limits of teacher prepared information resources, providing Internet access may help to address these concerns. However, not all classrooms have convenient computer access.

Though efforts to provide all students with computer and Internet access are rapidly expanding, not all students have access and not all students with access are successfully using the technology (Penuel, 2006). Studies have shown that one-to-one computing (Lei & Zhao, 2008) provides students with opportunities to engage with communication technologies, but also raises concerns about digital literacy. Mentzer and Becker (2011) and Becker and Mentzer (2012) demonstrated that high school students engaged in engineering design problems spent more time accessing information and spent more time designing when provided with Internet access. They studied high school students engaged in an engineering design challenge. The two studies attempted to apply the same research methodology as was used in previous work by Atman to facilitate comparison between high school students and experts. The 2011 study included Internet access, but the 2012 study did not. Their work showed that with Internet access, students spent an average of 137 minutes engaged in designing a playground and students allocated 47 minutes (35%) to information access. Without Internet access, similar students from the same schools on the same design problem spent an average of 92 minutes of which, 10 minutes (10%) was dedicated to information access.

With limited computer access or limited time to enable students to access a computer in some classrooms, the research questions guiding this study are:

1. What information do high school students spend time accessing during an engineering design challenge? How much information comes from paper-based resources as compared to the Internet?
2. How much time do they spend accessing information? What is the balance of time spent accessing information from paper-based sources as compared to the Internet?

Significance

Secondary education is increasingly pressured to deliver quality STEM education. Mathematics and Science education have received substantial investigation, but Technology and Engineering education are emerging as fields of inquiry related to pedagogy in K–12 environments. Little empirical research based guidance exists for teachers related to teaching engineering design in a secondary context. A variety of existing curriculums require students to engage in design thinking and specifically expect students to gather information to inform their design. Three curriculums discussed in this paper stop short of providing the teacher with details related to the information gathering effort. This investigation attempted to shed some light on student behavior related to information access, which has implications for secondary education. Answering these questions may help guide teacher and administrator decisions regarding how and when to use the Internet in design challenges by presenting information on how students are currently using the resources and for what purpose.

Treatment of Information Gathering in Curriculum Efforts

The National Academy of Engineering and the National Research Council (2009) identified 34 engineering-based curriculums or engineering resources that have been developed for implementation in the middle and high school classroom. Project Lead the Way and Engineering by Design were among the curricula reviewed and have a significant national footprint. Both curricula include a sequence of courses spanning middle and high school learning environments. Each curriculum engages the learner in a senior level capstone course, which includes a substantial focus on an engineering design problem. The smaller design problems students encounter in each course, as well as the more significant capstone design problem, present students with a need to access information.

Information gathering in these two curriculums is explicitly called for in the researching phases and is situated early in the design process, as shown in Table 1 (next page). As stated in the Standards for Technological Literacy (International Technology Education Association, 2000), “Design is regarded by many as the core problem solving process of technological development" (p. 90). Within the surveyed curricula, Project Lead the Way and Engineering by Design, each offers its own approach to a design process when solving a design challenge.

Table 1
Engineering Design Processes as Presented by Two National Curriculums

Project Lead The Way	Engineering By Design
Define the problem	Define a problem
Brainstorm	Brainstorming
Research and generate ideas	Researching and generating ideas
Identify criteria and specify constraints	Identifying criteria and specifying constraints
Explore possibilities	-------------------------
Select an approach	Selecting an approach
Develop design proposal	Develop a design proposal
Make a model or prototype	Making a model or prototype
Test and evaluate the design	Testing and evaluating the design using specifications
Refine design	Refining the design
Create or make solution	Creating or making it
Communicate processes and results	Communicating processes and results

The design processes proposed by Project Lead The Way and Engineering By Design suggest that the *research and generate idea* stage requires students to search for previously developed solutions to the problem (International Technology Education Association, 2008; Project Lead the Way, 2010), a form of information gathering. Also, in the *develop design proposal* stage, students are expected to gather information on what type of materials they will need to make their solution (Project Lead the Way, 2010). Student may need to search for prices, material strength, and other solution element characteristics to complete their design during all stages of design.

Foundational Research Efforts

Working with nine expert engineers, Kruger and Cross (2006) were able to identify four design strategies: problem driven, solution driven, information driven, and knowledge driven. Problem driven, solution driven, and information driven strategies rely heavily on the designer's ability to gather and use information. Knowledge driven design is situated heavily in prior experience and person's knowledge. An information driven designer defines the problem and then spends a majority of their time gathering information. The information found provides the basis for developing their final design. Information driven designs are low in creativity, have few solution ideas, and many of the activities are emphasized by the gathered data (Kruger & Cross, 2006).With Internet access, the time spent gathering information could increase and students have the potential to access an unlimited data set.

Though information gathering is an essential element of the design thinking process, Christiaans and Dorst (1992) discovered that during information gathering, students became stuck on the collection of information rather than progressing on to the development of their solution. This could be interpreted in a few different ways. Are students not finding the right information? Are they looking for other ideas rather than creating their own? Or are they spending too much time looking for information? Prensky coined the term *digital natives*, which is a person who has been surrounded by information technology their entire lives (Prensky, 2001). He stated that, "Our students today are all "native speakers" of the digital language of computers, video games and the internet" (2001, p. 1). Over the decade since Prensky labeled the generation as digital natives, accessibility to the Internet has only become easier and increasingly ubiquitous. Digital information access is almost instant due to the development of electronic portable devices such as smartphones, ultra-portable netbook computers, and tablet technology.

Efficient development of solutions for problems is critical in today's fast-paced economy. Though digital information is available almost instantly, the sheer volume available may be overwhelming for high school students presented with a design challenge. Given access to the Internet, they must decide what information they need to know and where to search. In engineering and technology education curriculum, paper-based and Internet-based information is often shared with students as they work through a problem. Teacher and curriculum delivered information can be focused, concise, and organized efficiently for students to quickly apply the information to their challenge. When presented with an Internet search engine in the context of a design problem, students may find the lack of structure difficult to effectively focus their efforts and the additional information access may be a hindrance to problem solving, as they might not be capable of efficiently utilizing the broad array of sources available.

In efforts to improve college-level education, previous work has focused on information gathering (Adams, Turns, & Atman, 2003; Atman et al., 2007; Atman, Chimka, Bursic, & Nachtmann, 1999; Atman, Kilgore, & McKenna, 2008; Cross, Christiaans, & Dorts, 2007). In a study by Mosoborg et al., (2005) 19 engineers with an average of 19 years of field experience were given a list of 23 words and phrases related to design activities and asked to pick which they thought were the six most important. Fifty-three percent stated that seeking information was one of the top six activities. In a similar study conducted at the University of Washington, 178 college-level engineering students were given the same list and were asked to complete the survey. Thirty percent of the students stated that seeking information was one of the top six activities of design (Morozov, Yasuhara, Kilgore, & Atman, 2008).

Several studies have been conducted in which college-level engineering students completed an engineering design task. Verbal data was transcribed and then coded using a set of eight codes related to the design process, one being information gathering (Atman, et al., 2005; Atman, et al., 1999). In one of the studies, college level engineering students were given a design task in which the main focus was to design a playground. The students that completed the design task spent 13.2% of their design time accessing information, which equates to an average of 14 minutes of the total 107 minutes spent on the design task (Atman, et al., 1999). Atman also found that after students had completed four years of engineering education, there was an increase in the amount of time spent gathering information. Freshman spent less time accessing information, while seniors and experts spent a comparable amount of time (Atman, et al., 2007).

Research Design

Methods. Students were given a design task to complete during a three hour session. The design challenge was not different from those that were used in various engineering design curriculums. The design task description can be seen in Figure 1(next page). The task was adopted from previous work implemented by research efforts put forth through the University of Washington (Adams, et al., 2003; Atman, et al., 2007; Atman, et al., 2005; Atman, et al., 1999; Atman, et al., 2008; Morozov, et al., 2008; Mosborg, et al., 2005).

Participants. The sample participants were high school students who were enrolled or had completed engineering-based classes. Although not required, the target candidate was a student who has had more than three different engineering-based classes during their academic career. Of the 12 students that volunteered to participate in the study, all were senior design students who had completed at least 4 courses related to engineering. Four of the students were female participants. All of the students who participated in the study considered themselves White or Caucasian.

Data Collected. Video data was recorded of the design performance. Students were audio recorded and asked to think out loud, consistent with verbal protocol analysis. Paper-based information requests were documented by the administrator by topic and time requested. Internet-based information requests were monitored by a software program running in the background that logged each search term and web site visited.

Figure 1
Playground Task Instructions. Adapted from Atman et al., 1999

Playground Problem Task Instructions

You live in a mid-size city. A local resident has recently donated a corner lot for a playground. Since you are an engineer who lives in a neighborhood, you have been asked by the city to design a playground.

You estimate that most of the children who will use the playground will range from 1 to 10 years of age. Twelve children should be kept busy at any one time. There should be at least three different types of activities for the children. Any equipment you design must

- be safe for the children
- remain outside all year long
- not cost too much
- comply with the Americans with Disabilities Act

The neighborhood does not have the time or money to buy readymade pieces of equipment. Your design should use materials that are available at any hardware or lumber store. The playground must be ready for use in 2 months.

Please explain your solution as clearly and completely as possible. Someone should be able to build the playground from your solution without any questions. The administrator has a lot more information to help you address this problem if you need it. Be as specific as possible in your requests.

For example, if you would like a diagram of the corner lot, some information about the lot appearance, etc, you may ask for it now. If you think of any more information you need as you solve the problem, please ask for it. Remember, you have approximately 3 hours to develop a complete solution. The administrator will tell you how much time is left while you work.

Data Analysis

Information Time Measures. Using Nvivo qualitative research software, the video of the students' performance was coded when they were directly gathering information. The software allowed the video to be played and coded simultaneously. The recording of the design session was then broken down further to compare the amount of time each participant spent accessing information from the paper-based source and Internet-based sources. The overall time spent using each source was then compared for each participant. A Microsoft Excel file was compiled of each participant's time gathering information from the two sources and group's means, and standard deviations were calculated.

Information Categorization Sources. Using the output from the Internet activity tracking software and the requests documented by the administrator, a chart was created for each participant that included the information request and source type. Using a list of 29 different information types that was developed for previous research (Mosborg et al., 2006), the students' requests were placed into one of the categories. Information requests were coded in chunks. For example, if a participant asked for several pieces of the same type of information, it would be coded once instead of how many pieces of information were found within one request. This was completed by undergraduate students who were trained and calibrated.

Calibration of the undergraduate coders was iterative and began with two students working together until they came to a general consensus on how to categorize the piece of gathered information. This was done by calculating coder inter-rater reliability. Once the training was completed, each coder was given one half of the design sessions. An overlap of 25% was coded to document reliability. An acceptable Kappa value for inter-rated reliability is above 0.75 (Orwin, 1994). The calculated Kappa values for the coder were above 0.90.

Results. The collected data provided results that were used to address each research question, refer to Tables 2 and 3 (page 68). On average, participants spent 38.8% of their total time accessing information. Of that 38.8%, participants spent 26% of their time gathering information using paper-based sources while spending 74% of their time using Internet-based sources. Of the 29 information request categories, participants only request information from 20 of the categories.

Table 2
Participant Time Allocation

ID	Total Design Time	Time Gathering Information		Paper-Based Information Gathering		Digital-Based Information Gathering	
	Minutes	Minutes	Percent of Total	Minutes	Percent of Total	Minutes	Percent of Total
1101	160	54	34	30	19	24	15
1102	177	87	48	2	1	85	47
1103	155	37	34	13	8	24	15
1104	102	51	50	20	20	31	30
1201	180	69	39	4	3	65	36
1202	161	52	32	3	2	49	31
1203	179	53	31	20	12	33	19
1204	171	58	34	14	8	44	26
1301	90	40	45	6	8	34	37
1302	63	35	57	6	15	25	41
1303	138	46	34	24	18	22	16
1304	104	39	38	8	9	30	29
Average (stdv)	140.0 (40.1)	51.7 (15.0)	38.8 (10.0)	12.8 (9.0)	10.2 (6.5)	38.9 (19.2)	28.5 (10.6)

Each participant requested 19.8 pieces of information on average with over half of those requested coming from Internet-based sources. The most sought after piece of information was material cost, being requested from Internet-based sources 5 times on average and 4.3 times from paper-based sources. Comparing the use of Internet-based and paper-based sources, participants spent nearly triple the amount of time using the Internet-based information sources when gathering information.

Using the categories that were implemented by Mosoborg et al., (2006) the information requests of the participants was categorized. Information categories that were not requested were as follows: (a) Age, (b) Facilities, (c) Legal, (d) Occupancy, (e) Park area inside the lot, (f) Utilities, (g) Supplier, (h) Supervision, and (i) Schedule. Of the categories that participants gathered information for, information on material cost was the most prevalent. On average, material cost was requested 9.3 times per participant. Of those 9.3 times, 4.3 pieces of information on material cost were accessed from the paper-based source and 5.0 pieces of material cost information was accessed from the Internet.

Table 3
Information Request Categorization

Category	Average Info Request	Average Info Request Paper	Average Info Request Internet
Material cost	9.3	4.3	5.0
Uncategorized	1.4	0.1	1.3
Dimensions	1.3	0.2	1.1
Activity	1.1	0.0	1.1
Material specs	1.0	0.2	0.8
Disability	0.9	0.6	0.3
Image search	0.9	0.0	0.9
Budget	0.7	0.7	0.0
Material type	0.7	0.5	0.2
Technical Reference	0.7	0.0	0.7
Safety	0.6	0.3	0.3
Demographics	0.3	0.2	0.1
Neighborhood Area	0.3	0.3	0.0
Neighborhood	0.3	0.2	0.1
Maintenance	0.2	0.2	0.0
Opinions	0.2	0.2	0.0
Body Dimensions	0.1	0.0	0.1
Clarity	0.1	0.0	0.1
Labor	0.1	0.1	0.0
Material cost and	0.1	0.0	0.1
Age	0.0	0.0	0.0
Facility	0.0	0.0	0.0
Legal	0.0	0.0	0.0
Occupancy	0.0	0.0	0.0
Park Area inside the	0.0	0.0	0.0
Schedule	0.0	0.0	0.0
Supervision	0.0	0.0	0.0
Supplier	0.0	0.0	0.0
Utilities	0.0	0.0	0.0
Average requests per student	19.8	7.5	12.3

Research Question 1. What information do high school students spent time accessing during an engineering design challenge? How much information comes from paper-based resources as compared to the Internet?

On average, students requested 19.8 pieces of information with 12.3 pieces requested using Internet-based sources and 7.5 pieces requested through paper-based means. The most requested piece of information was material cost. Participants requested 9.3 pieces of information that directly related to material cost. Material cost and safety information requests were balanced across Internet and paper sources, while most other information categories tended to be from either paper or Internet but not well balanced between the two sources.

Research Question 2. How much time do they spend accessing information? What is the balance of time spent accessing information from paper-based sources as compared to the Internet?

Students spent a substantial portion of their time within the design session gathering information. The data revealed that 38.8% of time was spent gathering information. Of the 140 minutes that were used during an average design session, 38.8% equated to 54 minutes gathering information.

More time was dedicated to Internet-based information sources as compared to paper-based sources. Of 140 minutes that participants spent to complete the design task, only 10% of the time was used to gather information from the paper-based source. The other 28% of the time was used to gather information from Internet-based sources. Thus, nearly 75% of the time participants spent gathering information was spent using Internet-based sources.

Search efficiency was estimated by dividing the number of minutes by the number of pieces of information (refer to tables 4 and 5). High school students found, on average, 0.38 pieces of information per minute while college seniors and experts found 1.1 pieces per minute. Students gathered, on average, 7.5 pieces of information from paper-based sources and 12.3 pieces of information from Internet-based sources. Table 5(next page) shows that, on average, 0.5 pieces of information were gathered per minute from paper-based sources compared to 0.3 pieces of information per minute when using Internet-based sources. When comparing the two sets of numbers, students did not use the Internet-based sources at an efficient rate. When comparing the efficiency rate of high school, college (freshmen and seniors), and expert engineers, there is a difference between high school engineers and the other groups, refer to Table 4 (next page).

Table 4
Comparison of Efficiency Rates

	High School (with Internet)	College Freshmen	College Seniors	Experts
Number of Requests	19.8	11.4	15.8	25.2
Amount of Time (min)	51.7	13.8	14.3	23.0
Request per Minute	0.38	0.83	1.1	1.1

Table 5
High School Student Comparison of Information Requests and Time

	Total	Paper-Based	Internet-Based
Number of Requests	19.8	7.5	12.3
Amount of Time (min)	51.7	14.8	39.9
Request per Minute	0.38	0.5	0.3

Discussion

Results showed that students spent more time on average gathering information when compared to their peers who did not have Internet access. High school students spent a total of 38.8% of the time on task gathering information. Previous studies of college students and experts used similar methodology with the exception of Internet access, which was not provided. Compared to previous studies college level freshman engineers spent 12.4% of their time, senior level college engineers spent 14.1% of their time and expert engineers spent 16.3% of their time gathering information during their design time (Atman, et al., 2007).

Past research studies have shown that as engineers move from college freshman to college seniors to experts, their time on information gathering increases. When comparing results from the current study, this trend does not hold true, as high school students spent much more time gathering information. The additional time spent accessing information may be caused by the Internet access. Access to the Internet may change the ways in which students attempt to solve engineering design problems as they spend more time on design, spend more time on information access, and access different types of information from the Internet than they do from paper-based sources.

Time is a precious resource, and time spent in high school classrooms is limited. Access to the Internet increased the amount of time spent in the design process. Most of the increase in time was invested in information access, but time spent in other aspects of design increased in addition. However, with the exception of cost of materials, results indicate that students generally searched for different types of information from the Internet as compared to paper-based sources. Students typically used the Internet to investigate dimensions, typical playground activities, material specifications, images of playgrounds, and technical information at a much higher rate than they looked for the same types of information from paper-based sources. On the other hand, students tended to access ADA information, budget, material type, and neighborhood characteristics dominantly from paper-based sources.

Implications of this Research on Student Learning

Students tended to spend more time investigating the problem with Internet access, and they access more pieces of information via the Internet than they did from paper-based sources. With Internet access limited to schools that have resources to provide computers and network connections, not all students have access to this authentic source of information. Teachers may consider scheduling time in computer labs or ensuring that students share computers in classrooms where one-to-one computing is not available. The preference of students to increase the information gathered when the Internet is available may change their design solutions.

Increases in total design time and information gathering time has a cost in the classroom. The additional time spent on one design problem is less time spent elsewhere. Teachers should prioritize their objectives such that they can justify the extra time spent on design. As students use the Internet for design thinking, they may need support developing efficient information access skills. Previous studies showed that experts access 1.1 pieces of information per minute while high school students were accessing 0.38 in this study. The difference might be related to students having Internet access, but this might also be related to a lack of information literacy skills. Teachers should closely observe student Internet use to determine levels of guidance needed to improve efficient use of the resource.

Design work includes consideration of costs, but students are spending substantial amounts of time searching, and the bulk of their searching is for material cost. They spent time looking for the cost of materials through paper- and Internet-based sources to the extent that one-half of the pieces of information accessed related to cost. This time might be more effectively used searching for other information or used for other elements of the design process. To minimize the time spent searching for costs, teachers might encourage students to estimate costs based on the stages of the design process. In the preliminary stages of design, where ideas are rough and developing, an estimate will permit comparisons to be made and feasibility to be assessed. Spending time searching for the exact cost provides little additional benefit over an estimation in this phase of the design work. In this study, it was common for students to ask for the cost of (for example) a wooden 2 x 4. After asking for the paper-based cost, they searched multiple vendors including Lowes, Home Depot, and even Craigslist for the cost of the same material, looking for the cheapest source for their bill of materials. In later stages of the design process, optimizing resources by minimizing costs are significant, but most student designs tended to be more conceptual.

Recommendations for Future Research

Data from this study suggested that students spend substantial amounts of time on the Internet with few information pieces accessed. Observations of student behavior by research administrators tended to suggest that students drifted from one website to another and accidently discovering information rather than purposefully searching for it. Additional research might differentiate between students' purposeful search activity and accidental information discovery. As an iconic example from data review, students would search for pictures of playgrounds. Frequently, students would view a website selling equipment with safety mentioned on the page; the student would then search for safety and notice maintenance issues. After noticing that wood would need to be maintained, they might add paint to the budget and ask about a budget for annual inspection. This string of events occurred regularly and may be triggered by the web-like interface of the Internet rather than purposeful forethought of the student. This leads the research team to consider the impact Internet use has on solution quality, as students might not have considered a variety of facets of the solution (such as maintenance in this example) essential in the design process.

Students rarely commented on the quality of the information source. The research team frequently thought about the validity information. There have been efforts to rate the validity of information, especially in direct relation to Internet-based sources (Wilson & Risk, 2002). Following the same procedures, data could be collected for the intent to determine whether or not high school engineering students considered information validity. Data were not rated for validity, but frequently students went to websites such as Wikipedia which may not be considered a valid website (Waters, 2007), and students often relied on commercial websites.

Information access has dramatically accelerated in recent years. Future pedagogical efforts may need to refine student information literacy skills to prepare students for applying available information in meaningful ways to the design problem at hand. Students in this study demonstrated frequent use of the Internet and made requests of the administrator for paper-based information. However, they spent a substantial amount of time searching for information with a relatively (as compared to previous research) low yield. Information literacy skills and educational efforts focusing student attention of critical missing pieces of information may increase efficiency of student research work.

References

Adams, R. S., Turns, J., & Atman, C. J. (2003). Educating Effective Engineering Designers: The Role of Reflective Practice. *Design Studies, 24*(3), 275–294.

Atman, C., Adams, R. S., Cardella, M., Turns, J., Mosborg, S., & Saleem, J. (2007). Engineering Design Processes: A comparison of Students and Expert Practitioners. *Journal of Engineering Education, 96*(4) 359–379.

Atman, C., Cardella, M., Turns, J., & Adams, R. S. (2005). Comparing Freshman and Senior Engineering Design Processes. *Design Studies, 26*(4), 325–357.

Atman, C., Chimka, J. R., Bursic, K. M., & Nachtmann, H. L. (1999). A Comparison of Freshman and Senior Engineering Design Processes. *Design Studies, 20*, 131–152.

Atman, C., Kilgore, D., & McKenna, A. (2008). Characterizing Design Learning: A Mixed-Methods Study of Engineering Designers' Use of Language. *Journal of Engineering Education, 97*(3) 309–326.

Becker, K., Mentzer, N., & Park, K. (2012). *High School Student Engineering Design Thinking and Performance.* Paper presented at the ASEE 2012 Annual Conference and Exposition, San Diego: California.

Brodeur, D. R., Young, P. W., & Blair, K. B. (2002). Paper presented at the American Society for Engineering Education Annual Conference and Exposition.

Bursic, K. M., & Atman, C. (1997). Information gathering: a critical step for quality in the design process. *Quality Management Journal, 4*(4), 60–75.

Childress, V., & Maurizio, D. (2007). *Infusing Engineering Design into High School Science, Technology, Engineering and Mathematics Instruction:An Exemplary Approach to Professional Development*. NCETE Internal Document. Utah State University. Logan.

Christiaans, H., & Dorst, K. (1992). Cognitive Models in Industrial Design Engineering: A Protocol Study. *Design Theory and Methodology, 42*, 131–140.

Cross, N., Christiaans, H., & Dorts, K. (2007). Design Expertise Amongst Student Designers. *Journal of Art and Design Education, 13*(1), 39–56.

Dym, C. L., & Little, P. (2004). *Engineering Design: A project based approach* (Second ed.). Hoboken: John Wiley & Sons.

Eide, A., Jenison, R., Mashaw, L., & Northup, L. (1998). *Introduction to Engineering Design*. Boston: McGraw-Hill.

Eide, A., Jenison, R., Northup, L., & Mickelson, S. (2008). *Engineering Fundamentals and Problem Solving* (Fifth ed.). Boston: McGraw-Hill.

Ekwaro-Osire, S., Afuh, I., & Orono, P. (2008). *Information Gathering Activities in Engineering Design.* Paper presented at the American Society of Engineering Education.

Fleischman, H., Hopstock, P., Pelczar, M., & Shelley, B. (2010). Highlights from PISA 2009: performance of U.S. 15-year-old students in reading, Mathematics, and science literacy in an international context. . Washington, D.C: National Center for Educational Studies.

Fosmire, M. (2011). *Information Literacy and Engineering Design: Developing an Integrated Conceptual Model.* Paper presented at the IFLA, Puerto Rico.

Gijselaers, W. H. (1996). Connecting Problem-Based Practices with Educational Theory. *New Directions for Teaching and Learning, 68*, 13–21.

International Technology Education Association. (2000). *Standards for Technological Literacy: Content for the Study of Technology*. Reston, VA: Author.

International Technology Education Association. (2008). *Engineering Design Course Overview*. Reston, VA: Author.

Katehi, L., Pearson, G., & Feder, M. (Eds.). (2009). *Engineering in K–12 Education*. Washington, D.C.: The National Academies Press.

Kruger, C., & Cross, N. (2006). Solution driven versus problem driven design: strategies and outcome. *Design Studies, 27*(5), 527–548.

Layton, E. T. J. (1974). Technology as Knowledge. *Technology and Culture, 15*(1), 31–41.

Lei, J., & Zhao, Y. (2008). One to one computing: What does it bring to schools? *Journal of Educational Computing Research, 39*(2), 97–122.

Mentzer, N., Becker, K., & Park, K. (2011). *High School Students as Novice Designers.* Paper presented at the American Society of Engineering Education, Vancouver, CA.

Moore, P., Atman, C., Bursic, K. M., Shuman, L. J., & Gottfried, B. S. (1995). *Do freshman design texts adequately define the engineering design process?* Paper presented at the American Society for Engineering Education Annual Conference, Ahaheim, California, June 25–29.

Morozov, A., Yasuhara, K., Kilgore, D., & Atman, C. (2008). Developing as Designers: Gender and Institutional Analysis of Survey Responses to Most Important Design Activities and Playground Information Gather Questions, CAEE-TR-07-06. Seattle: University of Washington.

Mosborg, S., Adams, R. S., Kim, R., Atman, C., Turns, J., & Cardella, M. (2005). *Conceptions of the Engineering Design Process: An Expert Study of Advanced Practicing Professionals.* Paper presented at the 2005 American Society for Engineering Education Annual Conference & Exposition, Portland, Or.

Mosborg, S., Cardella, M., Saleem, J., Atman, C., Adams, R. S., & Turns, J. (2006). Engineering Design Expertise Study, CELT Technical Report CELT-06-01. Seattle: University of Washington.

National Center for Engineering and Technology Education. (2012). Incorporating Engineering Design Challenges into STEM Courses. In D. Householder & C. Hailey (Eds.). Logan, UT: Utah State University.

National Commission on Excellence in Education. (1983). A Nation at risk: The imperative for educational reform. Washington, DC: United States Department of Education.

Orwin, R. (1994). Evaluating Coding Decision. In H. Cooper & L. V. Hedges (Eds.), *Handbook of Research Synthesis* (pp. 139–162). New York: Sage Publications.

Penuel, W. R. (2006). Implementation and Effects Of One-to-One Computing Initiatives: A Research Synthesis. *Journal of Research on Technology in Education, 38*(3), 329–348.

Prensky, M. (2001). Digital natives, digital immigrants. *On the Horizon, 9*(5), 1–6.

Project Lead the Way. (2010). Retrieved April 3, 2010, from http://www.pltw.org/

Sheppard, S. D., Macatangay, K., Colby, A., & Sullivan, W. M. (2009). *Educating Engineers: Designing for the Future of the Field*. San Francisco: Jossey-Bass.

Svihla, V., Petrosino, A. J., & Diller, K. R. (2012). Learning to Design: Authenticity, Negotiation,and Innovation. *International Journal of Engineering Education, 28*(4), 1–17.

Wang, J., Dyehouse, M., Weber, N. R., & Strobel, J. (2012). *Conceptualizing Authenticity in Engineering Education: A Systematic Literature Review.* Paper presented at the Amerian Society of Engineering Education.

Waters, N. (2007). Why you can't cite Wikipedia in my class. *Communications of the ACM, 20*(9), 15–17.

Wilson, P., & Risk, A. (2002). How to find the good and avoid the bad or ugly: a short guide to tools for rating quality of health information on the internet. *British Medical Journal, 324*(7337), 598–602.

Zimmerman, D. E., & Muraski, M. L. (1995). *The elements of information gathering : A guide for technical communicators, scientists, and engineers*. Phoenix, AZ: Oryx Press.

Disruptive Innovation in Technology and Engineering Education: A Review of the Three Works by Clayton Christensen and Colleagues

A Comprehensive Review by Vinson Carter

Christensen, C. (1997). *The innovator's dilemma*. Boston, MA: Harvard Business School Press. ISBN: *0062060244*

Christensen, C., Horn, M., & Johnson, C. (2008). *Disrupting class: How disruptive innovation will change the way the world learns*. New York: McGraw-Hill. ISBN: *0071749101*

Christensen, C. & Eyring, H. (2011). *The innovative university: Changing the DNA of higher education from the inside out.* San Francisco, CA: Wiley. ISBN: *1118063481*

As a teacher and a teacher educator, when I hear the term disruptive innovation or disruptive technologies, my thoughts are immediately drawn to the ring of a cell phone or other electronic devices that might essentially be a disturbance in the classroom. Although these devices may in fact be considered disruptive innovations, there is a deeper level that must be examined to see how disruptive these innovations might be in the future and how they might change the course of education forever.

In 1997, Clayton Christensen wrote a book entitled *The Innovator's Dilemma*. In this book, Christensen identified the differences between sustaining and disruptive technologies. He discussed how the pace of progress in business typically precedes the markets awareness of need and how the very qualities that make businesses successful may hinder their ability to predict, identify, and manage disruptive innovation.

In many ways, Christensen has reexamined progress in the business world, just as Thomas Kuhn explored change within the scientific community with his idea of paradigm shifts in *The Structure of Scientific Revolutions* (1962). Since his first book, Christensen has gone on to co-author multiple books examining disruptive innovation in health care and education as well as ways to predict and provide businesses with tools to deal with disruptive technologies.

According to Christensen, a *disruptive technology* is an innovation that results in worse product performance but is popular because of its simplification, affordability, and convenience, among other things (1997). Conversely, *sustaining innovations* happen within an existing market. Sustaining innovations typically solve problems using new technologies without creating a new market (1997). However, disruptive technologies have the ability to cause radical changes due to their availability outside of existing markets and their gentle learning curve for consumers. Given that disruptive technologies start small and with a segment of the market that is generally overlooked, they have the ability to be constantly improved upon, until they are able to overtake an existing market. Christensen (1997) gives several examples of disruptive innovations in his book, three of which follow.

In the 1980s, Digital Equipment Corporation (DEC) was leading the way in the minicomputer market with their sustaining innovations. They knew their product and their customers and were a thriving business, even "at one time regarded as among the best-managed companies in the world" (p. 8). By 1989, however, DEC was on the verge of collapse. Many in the business world were shocked that DEC had not been able to foresee the personal computer heading into the mainstream. This is the same business with the same managers that had been considered so successful just a few years previous. It wasn't that DEC was not aware that the personal computer was gaining ground quickly in the computer industry, but the personal computer did not fit their corporation's current business model. Michael Horn would say that the DEC managers probably asked themselves, "Should we build better products for our best customers for even better profits, or should we build worse products that our customers can't use and won't buy for profits that will kill our business model?" (Horn, 2010).

Personal computer companies like Apple were able to greatly disrupt the minicomputer world in the 1980s. Apple "was uniquely innovative in establishing the standard for user-friendly computing" (p. 8). Apple computers were designed for a market that did not exist. Their first computers would have been considered completely worthless to minicomputer users. Slowly, Apple was able to improve their product outside of this existing market until their product was able to fulfill the needs of those customers.

Another example of disruption is when Toyota introduced low-priced, fuel-efficient cars into the North American marketplace. The Japanese automakers were able to disrupt the American automakers as they continued to improve their vehicles by developing more sophisticated cars that competed with the American market. Entrants into the low end of the automobile market such as Hyundai are now forcing disruptive innovation of "simpler, more convenient transportation" (p. 165) upon those same Japanese companies. Christensen makes it clear that "at a deeper level …. There are times at which it is right not to listen to customers, right to invest in developing lower-performance products that promise lower margins, and right to aggressively pursue small, rather than substantial, markets" (p. 9). Often the pace of technological progress precedes the market's awareness of a need that over time might be satisfied through a disruptive innovation.

The way that a business approaches disruptive innovation can be examined through an appraisal of that organization's capabilities and disabilities

(Christensen, 1997). He has identified the three main facets or *intrinsic conflicts* that affect an organization's ability to manage change as "its resources, its processes, and values" (p. 129). All businesses have a unique set of values or company culture that may affect its allocation of resources and implementation of processes. The resources a business allocates may help managers identify how effectively changes within an organization may transpire.

> One of the dilemmas of management is that, by their very nature, processes are established so that employees perform recurrent tasks in a consistent way, time after time. To ensure consistency, they are meant *not* to change—or if they must change, to change through tightly controlled procedures. *This means that the very mechanisms through which organizations create value are intrinsically inimical to change* (Christensen, 1997, pp. 130–131).

Because of an organization's inflexibility to change its normally profitable business infrastructure, its immediate response when a disruptive technology emerges is to cram this innovation into the existing model for their current customers (Christensen, Horn, & Johnson, 2008). Christensen is clear that businesses must be mindful of the intrinsic conflicts when dealing with disruptive innovations. Sometimes the weaknesses of disruptive technologies may actually be their strengths, in that they do not have to compete in a mainstream market. In order to be successful when dealing with these disruptions, businesses "need to create a context in which each organization's market position, economic structure, developmental capabilities, and values are sufficiently aligned with the power of their customers that they assist, rather than impede, the very different work of sustaining and disruptive innovators" (Christensen, 1997, p. 174). Often, organizations that have been successful in meeting disruptive innovation head-on have had the ability to create a spin-off organization that is autonomous from the mainstream company (Christensen, 1997).

What Does This Mean for Education?

Teachers and schools in the United States have come a long way from their humble beginnings in the one-room schoolhouse. In the book *Disrupting Class*, Christensen, Horn, and Johnson suggest that as U.S. schools began this evolutionary progression, schools standardized through a process that was inspired by the "efficient factory system that emerged during industrial America" (2008, p. 35). They go on to describe and compare education to the *factory model* in which students are taught in the same fashion, noting that, "the students who succeed in schools do so largely because their intelligence happens to match the dominant paradigm in use in a particular classroom—or somehow they have found a way to adapt to it" (p. 35). Many studies have shown that teachers tend to approach teaching their students in the same manner or setting in which they feel the most comfortable (Stewart, Jones, & Pope, 1999; Orr, Park, Thompson, & Thompson, 1999). Christensen, et al. (2008) claim that "students who naturally enjoy the teaching approach they encounter in a given class are more likely to excel" (p. 36), so we must find a way to move toward … a 'student-centric' model" (p. 38).

The student-centric model of learning described in the book *Disrupting Class* is an excellent example of what may be possible "through disruptive implementation of computer-based learning" (Christensen, et al., 2008, p. 45). Often, technologies, especially computers, have been added into the classroom, but the method of instruction remains the same. The teacher is still the primary source for content delivery, and the computers are used as an addition to the factory model of traditional instruction. As the demand for computer-based learning and online classes grows, the authors feel that these disruptive tools will help students learn content in the classroom in a more meaningful way that is representative of their specific learning style or styles.

"Public education enrollments in online classes … are exhibiting the classic signs of disruption as they have skyrocketed from 45,000 in 2000 to roughly 1 million today" (Christensen, et al., 2008, p. 91). According to Christensen, et al., there will likely be a transition from the traditional teacher-led classroom where instruction is delivered through computer-based learning to a model where software will become the primary mode of delivery. In this model, the teacher will serve as a facilitator who can provide much needed one-on-one instruction for students who may be struggling. It is interesting to note that the system outlined by Christensen, et al. sounds very similar to the modular system used in technology education during the 1980s and 1990s.

According to Christensen, et al. (2008), "the data suggest that by 2019, about 50 percent of high school courses will be delivered online" (p. 98). With this in mind, educators must prepare to meet this challenge with an open mind and look to disruptions that may be taking place in the present for guidance in preparing for the future. This may involve the reinvention of our current educational system and a re-evaluation of the way that teachers develop and deliver instruction.

New Markets for Disruptive Innovations in Education

Christensen, et al. (2008) have found a major difference in identifying disruptive innovations in education as opposed to businesses. They state that "public education is set up as a public utility, and state laws mandate attendance for virtually everyone. There was no large, untapped pool of non-consumers that new school models could target" (p. 60). However, they have identified homebound, home-schooled students, students that need credit recovery, and pre-kindergarten as potential areas of non-consumption.

As schools struggle to meet the demands of No Child Left Behind, resource allocation and test scores have become a top priority. Often this means that schools must prioritize the classes that they are able to offer students.

> A casualty of this resource allocation has been many of the "nice-to-have" courses – in the humanities, languages, arts, economics, statistics, and so on. Diminishing supply in such courses means growing non-consumption in these areas. In an odd way, this is good news actually. Computer-based learning is a welcome solution when the alternative is to forgo learning the subject altogether (Christensen, et al., 2008, p. 93).

Unfortunately, technology and engineering education may fall into this "nice-to-have" category. Technology and engineering education is often overlooked as an "equal partner in general education," and its value is often scrutinized by those outside of the profession (De Miranda, 2004). Clark (1989) described the traditions of the industrial arts profession as something that may have slowed progress to a more modern, technology-based model of education. As Christensen, et al. (2008) suggest, those of us in the technology and engineering profession may have to rethink how we might make this shift through the power of disruptive innovation to deliver technology and engineering education to all students in the 21st century. Perhaps this will provide the technology and engineering education profession with a chance to redefine itself in the general education community (Sanders, 2001).

In order for disruptive technologies to be successful, they must be implemented in programs and schools "where the alternative is nothing" (Christensen, et al., 2008, p. 74). According to the authors, carefully selecting where to apply these disruptive innovations is far more important than the technologies themselves. Determining when and where these disruptive innovations should be incorporated is vital to the progress of schools as educators attempt to maintain quality instruction in today's ever-changing world.

One of the suggestions by Christensen, et al. is that student-centric, computer-based model schools be implemented in a manner that is strikingly similar to what we might know as the modular approach to technology and engineering education. They seem to believe that this modular approach will allow for the most convenient and effective means to serve the needs of students. This modular approach "opens the system to enable competition for performance improvement and cost reduction of each module" (Christensen, et al., 2008, p. 31). Although Christensen and his colleagues acknowledge that corporations, like textbook publishers, often have too much deciding power in what and how content is taught in the classroom, they do not specifically accept that the competition for modular learning models might have this same effect. As Petrina (1993) highlighted in his critique of modular approaches to teaching technology education, sometimes the "corporate values and market interests" might amount to "company views of the technological world" (p. 77). Is this what should be shaping our educational system? Petrina is adamant that these modular approaches are "no match for the practices of an imaginative and resourceful teacher with a grounding in contemporary educational theory, who can plan, design and redesign curriculum; and understands the difference between merely doing and a contextually rich educative experience" (1993, p. 78).

What Does This Mean for Higher Education?

In order for disruptive innovations to be successful in K–12 schools, the concept of these innovative technologies should be introduced in teacher education programs in post-secondary institutions. The importance of adapting to change, whether to disruptive technologies or something else, is a vital skill for educators to attain. If teacher education programs, especially in technology and engineering education, could introduce, grow, and nurture the development of disruptive technology implementation, teachers would be more willing to attempt to utilize some of these techniques. Unfortunately, there is an unfulfilled need for disruption even in higher education.

One reason for this is simply the absence of disruptive innovation. From the very beginning of post-secondary education, "learning technologies—lectures, textbooks, oral and written examinations—have remained largely the same" (Christensen & Eyring, 2011, p. 18). Several factors affect the lack of disruptive innovations in higher education, as the authors suggest that "fundamental change has been unnecessary" (p. 18). In times of financial crisis due to economic downturn, public universities have been able to weather the storms because of taxpayers, alumni support, and legislative backing. Christensen and Eyring (2011) suggest that this is no longer the case for most higher education institutions due to higher costs and new ever-emerging competitors. Even at this level, online courses are a current disruptive technology that is forcing universities to re-evaluate the traditional higher education system.

Christensen and Eyring (2011) use Brigham Young University (BYU) - Idaho as an example of an institution that might be seen as leading the way as a disruptive model in higher education. In 2000, BYU-Idaho went to a year-round academic calendar in order to serve more students throughout the year. They also eliminated their athletic programs, decided to focus on serving only undergraduate students, offering online programs of study, and changing their focus from discovery research to the scholarship of teaching. As noted in the book *The Innovative University*, this is a serious alteration "of the traditional university DNA" (Christensen & Eyring, 2011, p. 27). The traditional university student attends classes on a campus that embodies the whole collegiate experience. This experience includes peer groups, dorm life, athletics, and the specific *brand* of the college. Often this brand or image is strongly influenced by activities associated around college sporting events (Toma & Cross, 1998).

Christensen and Eyring (2011) are quick to point out these traditions may shift through the employment of disruptive innovations in higher education and that "as the diploma mill stigma of online education fades and the high end of the market becomes saturated with competitors, the premier online companies have the option of lowering price to attract even brand-conscious students" (p. 215).

Conclusion

Two opportunities that may help sustain our profession have emerged in recent years. The first of these opportunities is the increased emphasis and funding that is available in science, technology, engineering, and mathematics (STEM) education. The President's Council of Advisors on Science and Technology Executive Report (2010) details the nation's need for a strong STEM workforce with skills necessary to compete in our ever increasingly technological world. The other opportunity is in the new Framework for K–12 Science Education (2011). This framework places a heavy emphasis on technology, engineering, and design. We can look at both of these disruptions in the technology and engineering education profession as opportunities for grounding the delivery of technological literacy to a larger audience.

As we have seen, disruptive innovations have greatly influenced the course of history, from the computing industry to the automotive industry. There are disruptive innovations challenging K–12 education as well as higher education at this very moment, and the technology and engineering education profession must be proactive in our research and development of these innovations. As Christensen and his colleagues point out, we must remain flexible and be mindful of those intrinsic conflicts that may hinder our ability to effectively manage change. We must harness the potential power of our resources, processes, and values that strengthen our profession.

Additional research should be conducted to determine how the technology and engineering education profession must prepare for the inevitable disruptions in the future of education. It is also important that attention be given to how disruptive innovations might also be challenging professional societies.

References

Christensen, C. *(1997). The innovator's dilemma*. Boston, MA: Harvard Business School Press.

Christensen, C., Horn, M., & Johnson, C. (2008). *Disrupting class: How disruptive innovation will change the way the world learns*. New York: McGraw-Hill.

Christensen, C., & Eyring, H. (2011). *The innovative university: Changing the DNA of higher education from the inside out.* San Francisco, CA: Wiley.

Clark, S. C. (1989). The industrial arts paradigm: Adjustment, replacement, or extinction? *Journal of Technology Education, 1*(1), 7–21. Retrieved from http://scholar.lib.vt.edu/ejournals/JTE/v1n1/clark.jte-v1n1.html

De Miranda, M. (2004). The grounding of a discipline: Cognition and instruction in technology education. *International Journal of Technology Education and Design Education, 1*(4). 61–77.

Horn, M. (Presenter). (2010, May 26). Disrupting Class [Episode 8]. *MIT World Lecture Series.* Podcast retrieved from http://itunes.apple.com/us/podcast/disrupting-class-how-disruptive/id382420793?i=88304367

Kuhn, Thomas, S., (1962). *The Structure of Scientific Revolutions* (2nd Ed.). Chicago, IL: University of Chicago Press.

National Research Council. (2011). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas.* National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=13165

Orr, B., Park, O., Thompson, D., & Thompson, C. (1999). *Learning styles of postsecondary students enrolled in vocational technical institutes.* Journal of Industrial Teacher Education, 36 (4), 5–20.

Petrina, S. (1993). Under the corporate thumb: Troubles with our MATE (modular approach to technology education). *Journal of Technology Education, 5*(1), 72–80.

President's Council of Advisors on Science and Technology. (2010). *Prepare and inspire: K–12 education in science, technology, engineering, and math (STEM) for America's future.* Retrieved from *www.whitehouse.gov/sites/default/files/.../pcast-stemed-report.pdf*

Sanders, M. (2001). New paradigm or old wine? The status of technology education practice in the United States. *Journal of Technology Education 12*(2). 35–55.

Stewart, P. H., Jones, V. N., & Pope, J. V. (1999). *Learning styles: Charting with iconic learners*. Retrieved from ERIC Record Details - ED42840.

Toma, J. D., & Cross, M. (1998). Intercollegiate athletics and student college choice: Exploring the impact of championship seasons on undergraduate applications. *Research in Higher Education 39(*6). 633–661.

Vinson Carter (vcarter@uark.edu) is Instructor of Technology Education in the Department of Curriculum and Instruction at the University of Arkansas.

Scope of the JTE

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

Editorial/Review Process

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

Manuscript Submission Guidelines

One paper copy of each manuscript and an electronic version in Microsoft Word format on a CD, diskette, or other electronic media should be submitted to:

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

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

7. Authors for whom English is not the primary language must enlist a native English editor for the manuscript prior to submission. This person and his/her email address must be identified on the title page of the manuscript.

Subscription Information

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

Name (please print) ____

Mailing Address (please print) ___________________________________

____

Email address: ______________________________Fax: ________________

☐New Subscription ☐ Renewal Subscription

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

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

Return remittance along with this form to:

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

JTE Co-Sponsors & Membership Information

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

Journal of Technology Education

Editor
Chris Merrill, Illinois State University

Technical Editor
Amanda Fain, Illinois State University

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

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

Rodney Custer, Black Hills State University

Jenny Daugherty, Purdue University

Marc deVries, Delft University of Technology, The Netherlands

Patrick Foster, Central Connecticut State University

W. Tad Foster, Indiana State University

Brenda Gustafson, University of Alberta, Canada

Ronald Hansen, University of Western Ontario, Canada

Christine Hailey, Utah State University

Scott Johnson, University of Illinois

Oenardi Lawanto, Utah State University

Theodore Lewis, University of Trinidad and Tobago

Stephen Petrina, University of British Columbia, Canada

Philip Reed, Old Dominion University

Mary Annette Rose, Ball State University

Kay Stables, Goldsmiths University of London, England

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

John Wells, Virginia Polytechnic Institute and State University

John Williams, University of Waikato, Hamilton, New Zealand

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

The views expressed in this publication are not necessarily those of the Editor or the Editorial Review Board, nor the officers of the Council on Technology and Engineering Teacher Education and the International Technology and Engineering Educators Association.