Proceedings of the Conference on Graduate Student Research in Engineering & Technology Education

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Proceedings of
the Conference on
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Introductory Comments

Teachers' Knowledge and Disposition to STEM Curriculum and Instruction

A GLIMPSE OF THE FUTURE

Theodore Lewis
Professor, Department of Work and Human Resource Education
University of Minnesota

As part of the usual end of year meeting that has been a feature of our NCETE project we organized a conference intending to provide a forum for young voices in an outside of the Center. The basic model for the gathering was borrowed from track and field. This was to be an intellectual conference meet, to which teams of scholars and their coaches/mentors would come, drawn from university programs where scholars worked at the intersection of engineering education and technology education, to share ideas and to engage each other. The conference theme was to be Research in Engineering and Technology Education (RETE). The invitation to program leaders asked for the following:

> a. Reports on recently completed or partially completed dissertations
> b. Presentations of doctoral research proposals
> c. Presentations of issues/theory/challenges that have bearing on RETE.
> d. Reports from the field (e.g. Some students may have been working with schools, either teaching or engaged with professional development)

On the conference morning a regular campus bus drove up, having just crossed the Mississippi River that divides the main campus of University of Minnesota, and onto it climbed a quite remarkable gathering of talent, young as well as seasoned, all anxious and excited, and looking forward to the day's proceedings that would begin at the end of the short trip to the conference venue. Represented in this gathering were doctoral teams from Utah State University, The Ohio State University, Virginia Tech, Purdue, Tufts, University of Illinois at Urbana-Champaign, University of Georgia, Colorado State, and University of Minnesota, the host. Equally, this gathering included representatives from arguably the most significant Technology Teacher Education programs in the U.S., including Illinois State University, University of Wisconsin-Stout, California State University, Los Angeles, North Carolina A & T State University, and Brigham Young University. Christine Hailey, Director of NCETE, welcomed the gathering, which included Karen Zuga, NSF Project Director with responsibilities for the Center. And the program then began with Dr. David Stricker, a Fellow from the first NCETE cohort, having the honor of leading off with a presentation of findings from his recently completed dissertation.

These proceedings summarize ideas from the presentations made during the day. The reader will notice that there was clustering of ideas around themes. One group of papers focused upon exploring *teachers' knowledge and dispositions to* STEM curriculum and instruction. These can be seen in the contributions of Jenny Daugherty, Todd Fantz, Fred Figliano, Brent Holt, Morgan Hynes, and Todd Kelley. A second set of papers focused upon *dealing with ill-defined problems and complex systems.* These can be seen in the contributions of Ben Franske, Steven Rigby, and Douglas Walrath.

A third set of papers *examine problem solving predisposition in children and adolescents.* We see the issues here in the work of Katrina Cox, Michael Nehring, and Leah Roue. Cox looks at the effects of metacognitive journaling, an approach that is significant given the important role that journaling plays in the practice of engineering. Nehring and Roue examine fundamental developmental issues attending the pre-disposition to design, touching upon critical notions such as design intention, design stance, and functional fixedness. Shawn Gordon and Nathan Mentzer explore the *impact of engineering design experiences* on student motivation and learning. Gordon's approach was to have students build Rube Goldberg machines. Mentzer's approach was to engage students in design challenges.

Three of the papers explore student interest in STEM careers. Chandra Austin and Cameron Denson address the knotty question of African American students *self-efficacy beliefs regarding engineering careers*. Denson has explored whether mentoring can be a way to enhance the beliefs of these students such that engineering careers can be attainable for them. Mark Mahoney examines whether a special Metro school (in Columbus, Ohio) intended to enhance student interest in STEM-related actually achieves its purpose.

Beyond papers that cluster thematically are a few that pursue interesting lines that were influenced by cognitive and creativity considerations. They included Brian Gravel's examination of children's representation of scientific ideas; Matthew Lammi's examination of differences in the cognitive strategies and processes of expert and novice problem solvers; and David Striker's comparison of the perceptions of creativity held by art, music and technology teachers.

What can't be captured in this introduction to these proceedings is the electricity of the conference. Those of us from earlier eras developed the consensus view that what we saw and heard was incomparable in our experiences as technology educators. We saw doctoral students drawing upon theory as they framed their studies. We saw a strong focus on cognitive science and creativity ideas. Several of the presenters situated their work in classrooms and resorted to Vygtosky and Piaget as they tried to unravel what they saw. Then there were doctoral students who focused their sights on teachers--on their professional development needs, and on their pedagogical insights. Several students looked more closely at problem solving and design, in ways that suggest that, contrary to a prevailing view in technology education, these really are unsettled notions, rich in inquiry possibilities.

We old timers had caught a glimpse of the future of the field, with a completely new set of issues; a new set of conceptual frameworks; a new synergy derived from the interaction between engineers, engineering educators and technology educators; new institutions (such as Tufts and Purdue) coming into the mix; young women and minorities holding their own; and overall just the most delightful assemblage of young talent one could hope to be heirs to a field.

Engineering byDesign™ PROFESSIONAL DEVELOPMENT EVALUATION SUMMARY REPORT

Jenny Daugherty
University of Illinois at Urbana-Champaign

Abstract

Through the Engineering byDesign™ (EbD) curriculum project, professional development workshops and an online tool, eTIDEonline, were developed to create resources, provide training, and serve as a collaborative environment for EbD teachers. The EbD program is facilitated by the Center to Advance the Teaching of Technology and Science (CATTS), which is the professional development arm of the International Technology Education Association (ITEA). The EbD program is the only standards-based national curriculum model for grades K-12 that delivers technological literacy. In addition to curriculum development, the EbD program also concentrates its efforts into professional development. The goals of the professional development efforts of CATTS are to encourage and prepare teachers to implement the EbD curriculum and to develop a community of learners.

The second year of EbD professional development was undertaken at the 2007 International Technology Education Association's conference in San Antonio, Texas. The EbD professional development focused on two of the EbD courses: (1) *Engineering Design* and (2) *Exploring Technology*. This evaluation aimed to include the entire population of teachers, superintendents, or teacher educators involved in the second year of EbD professional development. The first phase of the evaluation, consisting of an online survey, gauged the value of the professional development efforts as perceived by the teachers and estimated their preparedness in implementing the curriculum. The second phase of the evaluation, consisting of a similar online survey, estimated the implementation of the EbD curriculum, challenges encountered by the teachers not addressed by the professional development efforts, and participation in eTIDEonline.

Research Questions

The following key questions guided this evaluation:

1. How well did the workshop help prepare teachers to teach the curriculum?

2. What are the strengths of the professional development efforts (the workshop and eTIDEonline)?

3. What aspects of the professional development efforts could be improved?

Evaluation Design

The overall approach that was utilized in this evaluation was a mix of a behavioral objectivist approach and a utilization-focused approach. The objectives of the professional development efforts have been clearly prescribed, including: (1) to prepare teachers to teach the curriculum, and (2) to serve as a collaborative environment for EbD teachers. The evaluation focused on providing data to gauge how the professional development is meeting these two objectives. In addition, this type of approach provides formative data to inform the decision-making processes of the primary stakeholders. This evaluation is focused on an intended use (changes to the professional development efforts) by the intended user (the CATTS director).

Data Analysis

The response rate for Survey 1 was 86%, with 24 of the 28 participants responding to the online survey. The response rate for Survey 2 was much lower (57%) with only 16 out of the 28 participants responding. The surveys were analyzed according to the type of data collected. Item 1 on both surveys provided nominal data so that frequency counts could be provided on which course the participant planed to teach or was teaching. For items 2 through 5 on Survey 1 and items 2 through 4 on Survey 2 the Likert scale data were treated as continuous variables from which descriptive statistics were analyzed. For section three of the survey (items 6-8 on Survey 1 and items 5-7 on Survey 2) qualitative data were analyzed using a method called content analysis. Themes and patterns in the data were derived, coded, and categorized in an effort to understand and explain the specific elements each question sought to answer.

Findings - Planned to Actual Implementation

There was drop between those who planned on implementing an EbD course (18) and those who were currently teaching one at the time of the second survey (13). Eight respondents planned on teaching the Engineering Design course, however, none of the respondents to the second survey were currently teaching this course. Although this decrease in planned to actual implementation cannot be attributed solely to the professional development efforts, it is important to note this finding particularly in regards to the Engineering Design course.

Research question one asked how well the workshop helped prepare teachers to teach the curriculum. Based on the majority of responses in survey 1, the workshop helped to some extent (33.3%). However, 25% of the respondents felt that they were prepared to a great extent. This finding is consistent with the results from survey 2 where 43.7% of the respondents felt they were prepared to some extent. 18.7% felt prepared to a great extent. When asked whether the workshop answered all of their questions, the respondents largely indicated that it did not or only to a little extent (45.8%). Only 29.2% said it did to some extent. However, when asked if the workshop was worth attending, 29.2% said it was to a great extent and 25% to some extent.

The second key question driving this evaluation aimed to distill the strengths of the EbD professional development efforts. With most of the participants (41.7%) indicating that the workshop was worth attending to a great extent or to a very great extent, the participants seemed to believe that the workshop was beneficial. When asked to describe the ways the workshop has provided the necessary information about the curriculum the general themes that emerged were that it: (a) provided an overview of the curriculum, (b) provided a few examples of student work and activities, and (c) made them aware of the goals and aims of the curriculum.

Exploring the weaknesses of the professional development efforts was the intent of the third key question. When asked to indicate the questions that respondents still had about teaching the curriculum, questions centered around three themes: (a) planning, (b) implementation, and (c) course content. Respondents also provided information concerning the changes they would like to see made to the workshop. One respondent indicated that he or she would like to see more specifics on the lesson plans and how to implement. Another would have liked to have seen the eTIDEonline environment. In regards to what the respondents felt they needed to teach the curriculum, the responses varied from more resources to more in-depth training. When respondents were asked what additional mathematical and science concepts were needed to implement the curriculum, responses also varied from none to a tremendous amount. One respondent stated that technology education teachers "do not have the background to teach this."

eTIDEonline

Focusing on the eTIDEonline component of the EbD professional development, the findings from both surveys indicated a desire to use the site but some obstacles to actually using the site. When asked in the first survey whether respondents intended to use the online tool, 16.7% responded to a very great extent, 37.5% indicated to a great extent, and 29.2% responded to some extent. When asked in the second survey whether respondents were participating in eTIDEonline, the responses decreased with 0% participating to a very great extent, 12.5% participating to a great extent, and 37.5% to some extent. 18.7 % were not participating at all. Asked whether respondents believed the information posted on the site to be helpful, 31.3% of the respondents indicated that it was to a great extent. When asked what would increase their use of the online tool responses included the increased participation by other teachers, more time, more participation by those piloting the curriculum, and more information to use with students.

Recommendations

When asked what advice they would give to CATTS, numerous responses were provided. A few of the respondents recommended that the professional development involve an intense examination of a unit or lesson. Another suggestion was to provide a more extensive experience with a week-long program. More structured training with more hands-on activities and examples was also a prominent suggestion. In addition to these recommendations a few other suggestions based on the professional development literature are outlined below.

As Bybee and Loucks-Horsely (2000) articulated, four key components are necessary for effective technology education teacher professional development: (a) teachers need to develop skills related to technology; (b) teachers need opportunities to learn about how to teach technology; (c) teachers need tools and motivation to continue their own learning; and (d) long-term professional development is required to support the changes required for the *STL* to be successful. In 2001 Bybee, put forth design principles for effective professional development of technology education teachers, including:

1. Student learning should be at the core;
2. Technology education pedagogical content knowledge should be developed;
3. Student learning principles should guide teacher learning;
4. Learners' current understandings should be acknowledged; and
5. Professional development must align with and support system-based changes.

Despite the lack of research on how these characteristics improve teaching and student learning, a consensus has emerged within the literature about the characteristics that differentiate "high quality" professional development (Desimone, Porter, Garet, Yoon, & Birman, 2002). Loucks-Horsely (1999) identified four clusters of variables that affect the quality of professional development including: (a) content; (b) process; (c) strategies and structures; and (c) context. Based on these clusters and respondents' suggestions, the following recommendations were provided to improve the EbD professional development.

Recommendation 1 – Content

- Focus the PD workshop on a particular lesson or activity and allow participants to work through the activity.
- Spend time educating participants on both the structure and goals of the curriculum and on the particular content knowledge needed to better implement the curriculum (i.e., math and science concepts).

Recommendation 2 – Processes

- Guide participants through an activity or unit from the perspective of a student and then through the perspective of a teacher.
- Offer deliverables from the workshop – completed activities, examples of student work, lesson hand-outs.
- Demonstrate how to login, post, and best utilize the eTIDEonline environment.
- Continue professional development experiences through eTIDEonline by scheduling online meetings with the PD facilitator to answer questions; delivering added content knowledge; providing support materials to implement particular activities, etc.

Recommendation 3 – Strategies and Structures

- Publicize workshops facilitated by curriculum specialists more broadly on EbD's website.
- Send curriculum specialists to local and state technology and engineering education conferences to present the curriculum.
- Coordinate a week-long summer PD experience that draws teachers nation-wide and is facilitated by the curriculum specialists.
- Expand the scope of the eTIDEonline tool to serve as a support to teachers by providing access to program director, curriculum developers, curriculum specialists, and field test teachers

Recommendation 4 – Context

- Market ITEA conference workshop as an informational session and strongly suggest to participants to attend a workshop facilitated by a curriculum specialist.
- Develop cohorts of teachers who first attend an informational session, then a professional development workshop, and continue collaborating on eTIDEonline.

Acknowledgement

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KNOWING WHAT ENGINEERING AND TECHNOLOGY TEACHERS NEED TO KNOW: A CONTENT ANALYSIS OF PRE-SERVICE TEACHERS' ENGINEERING DESIGN PROBLEMS

Todd D. Fantz
Colorado State University

Abstract

According to the American Society for Engineering Education, the four STEM disciplines should not be taught in isolation in a school curriculum, but interdisciplinary reinforced, and continually cross referenced, as part of a dynamic triangle that ultimately researches, designs, and creates the way we live, work and play. Therefore, it only makes solid academic and professional sense to prepare teachers who are highly qualified to deliver this integrated content in a K-12 setting. This is a powerful, yet critical, void in most public education and professional teacher preparation programs who desire to respond to the call for introducing engineering concepts into the professional teacher preparation programs that train technology education teachers.

Significant questions exist around the requisite content knowledge required of a technology teacher to infuse valid engineering concepts into the K-12 classroom. What are the appropriate mathematical and analytical levels required of pre-service teacher preparation? Can engineering trained pre-service professionals deliver instruction and teach engineering design lessons that are content and context valid? These and many more questions remain as the technology teacher preparation community begins to join with other key stakeholders in preparing teachers to respond to the national call for a stronger engineering STEM emphasis in K-12 education.

This paper will report on content analysis research of pre-service teacher/engineering science students' ability to conceptualize, design, and evaluate student design brief solutions in high school technology classes. This research is just a part of a larger challenge within the engineering and technology teacher preparation community to understand what pre-service teacher candidates need to know and be able to do to teach engineering design in a context and content valid manner. This report on the student instructional design content analysis will use a quantitative coding scheme that maps the design brief problem elements and student solutions to the engineering design process.

Introduction

Since its evolution from industrial arts, technology education has struggled to move from a curriculum based on human productive practice to a legitimate general school subject focused on technological literacy for all students. Due to this struggle, industrial arts and indeed technology education has undergone changes in its name, curriculum, instructional strategies, materials, and technical content many times over (Lewis, 2005). Some previous names of industrial arts and technology education curriculum and content framing efforts include the Industrial Arts Curriculum Project, Maryland Plan, Jackson's

Mill, and Technology for All Americans Project (Hill, 2006). The current movement in the turn to engineering involves incorporating engineering design as a focal point for technology education. Significant questions exist around the requisite content knowledge required of a pre-service technology teacher to infuse valid engineering concepts into the K-12 classroom. What are the appropriate mathematical and analytical levels required of pre-service teacher preparation? Can a professional not trained in the engineering sciences deliver instruction and teach engineering design lessons that are valid in content and context? These and many more questions remain as the engineering and technology teacher preparation community begins to join with other key stakeholders in preparing teachers to respond to the national call for a stronger STEM emphasis in K-12 education.

Why Engineering Design and Why Now?

With the high-tech boom of the 1990's, the bust of 2000-01, and the ensuing anxieties about competitiveness and national security, K-12 STEM education has commanded the attention of people far beyond the community of educators typically involved in the field. Policy-makers, industry leaders, and thoughtful leaders in the media have registered concerns and volunteered solutions regarding apparent problems with how science and mathematics are taught and learned and how technology figures as both a feature of these topics and a downstream result of their inculcation. All the while, engineering and technology has largely remained a shadowy presence in discussions about the K-12 STEM education, a spectral "T&E" quietly inserted among its more concrete complements, yielding, if nothing else, an acronym that lends itself nicely to speech and writing. In addition, the technology education community must be cautious in assuming that the "T" in STEM refers to technology education. General interpreted in the educational and professional community could reserve the "T" in STEM for information science and computing technology and not technology education. In K-12 schools this could mean educational technology.

Recent arguments in favor of defining and implementing a more substantial role for engineering in K-12 STEM education are many and strong. Starting with the most general, K-12 education, as a democratic institution, should provide meaningful preparation for its graduates, in all their representative diversity, to participate fully in the opportunities available to them in society. Among the ways that people participate in society—at home, at work, in communities, or any other context—almost every experience is shaped by a product or environment that results from engineering. Buildings, clothes, cars, clean water, indoor climate control, personal technologies, and nearly everything else people encounter in daily life comes from engineering. An education system that treats this area of activity obliquely, if at all, is failing to prepare students for the world they will enter upon completing their studies. Understanding first that the world they inhabit is engineered and second that the engineered world takes the shape it does through human choice and activity, areas in which they themselves can participate, is a fundamental precondition for full participation in twenty-first century life.

Engineering is an important national resource in efforts to keep America competitive in a knowledge- and technology-driven global economy and safe in an uncertain geopolitical climate (National Research Council, 2006). Technological innovations result from the work of people trained in engineering and technology fields. Educated across disparate areas of science and mathematics, these people translate their understanding of fundamental science and mathematics into usable objects and applications that improve our lives, create new jobs and industries, and extend the frontiers of human possibility. They also play a fundamental role in national security strategies, combating threats to a country's citizenry through research and development of technologies that can neutralize threats to civilian and military populations.

Engineering conveys practical, classroom benefits for educators and students, as well. A way to bring to life sometimes abstract, difficult topics in math and science, engineering can make the classroom exciting and relevant to lived experience. Research shows the integrative, applied nature of engineering can enhance student learning, boosting test scores and helping schools meet standards-driven education requirements (Baker 2005). 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 under-represented minorities (Guertin and Rufo 2004, Wiest 2004).

Do Technology Education Pre-Service Teachers Have the Pedagogical Content Knowledge to Teach Engineering Design?

Geddis (1993) described pedagogical content knowledge (PCK) as a set of attributes that helped someone transfer the knowledge of content to others. According to Shulman it includes "most useful forms of representation of these ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations-in a word, the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1987, p. 9).

In addition, Shulman (1987) suggests that PCK is made up of the attributes a teacher possess that help her/him guide students towards an understanding of specific content such as engineering in a manner that is meaningful. Shulman argued that PCK included "an understanding of how particular topics, problems, or issues are organized, presented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (1987, p. 8). In light of what engineering and technology education teachers should know and be able to do, Shulman argued that pedagogical content knowledge was the best knowledge base of teaching and suggests the key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students (p. 15). Therefore, the intersection of engineering science, i.e., knowledge of the scientific and mathematical knowledge needed to engage in the analytical aspects of design, knowledge of engineering design, with teaching in the technology education classroom will wholly depend on the ability of teacher educators

and pre-service teachers to transform this knowledge into adaptive instruction, with which students can engage.

The Design Processes

The underlying distinction between technology education and engineering lies with the design process. Hailey, Erekson, Becker, and Thomas, (2005) developed a comparison table of the design processes for the two disciplines .Table 1 displays the side-by-side comparison between an engineering design process and a technology education design process as listed in their manuscript.

Table 1.

Design Process Comparison

Engineering Design Process (Eide, Jenison, Mashaw, & Northup, 1997)	Technology Education Design Process (Standards for Technological Literacy, 2000)
1. Identify the need	1. Defining the problem
2. Define the problem	2. Brainstorming
3. Search for solutions	3. Researching and generating ideas
4. Identify constraints	4. Identifying criteria
5. Specify evaluation criteria	5. Specifying constraints
6. Generate alternate solutions	6. Exploring possibilities
7. Engineering analysis (applications of math and science)	7. Select an approach
8. Optimization	8. Develop a design proposal
9. Decision	9. Building a prototype or model
10. Design specifications	10. Testing and evaluating the design
11. Communication	11. Refining the design
	12. Make it – create it
	13. Communicating results

Whereas, the design processes of engineering and technology may look similar, there are distinct differences. While the technology design process is more concentrated on the building and testing aspects, the engineering design process is more focused with analysis of design. To add to this discrepancy, Hill (2006) alleged practicing technology educators do not use the steps of "identifying criteria" and "specifying constraints." In the beginning, both processes identify what the need or problem is, and who will benefit from a solution. Both processes also search for solutions from various sources and identify what restrictions will be placed on the design. However, the next step is drastically different between the two. The technology design process jumps to selecting an approach to follow what will hopefully lead to a solution. The engineering design process is not yet ready to settle for an approach. Instead, the engineering design process generates many possible approaches for the solution. With many approaches, an engineering analysis and/or a mathematical analysis must be used to decide which approach would yield the optimal result. After a rigorous analysis involving all the

previous steps in the design process, an approach is selected. The technology design process does not need to perform this analysis because there is only one approach from which to select.

As identified by Hailey et al (2005), the end goals of the design processes are different. The engineering design process is more concerned with developing and specifying the optimal design than the actual creation of it. This contrasts the technology design process that is more focused on the "hands-on" aspect of building the design than the optimization and specification of the design.

Purpose of the Investigation

Colorado State University has recently developed a joint education-engineering degree program. Students who complete the program receive a nationally accredited Accreditation Board for Engineering and Technology (ABET) engineering degree in engineering science and a nationally accredited National Council for Accreditation of Teacher Education (NCATE) technology teaching license. Some objectives of this program include: improving secondary education by placing highly qualified technology education teachers in the classroom; encouraging a more diverse population to study engineering at an early age by having engineering-trained teachers in the secondary classroom; and creating programs to better prepare secondary students to study science, technology, engineering, and mathematics (STEM) disciplines in a college undergraduate program (De Miranda, Troxell, Siller, & Iverson, 2008).

Graduates of the Colorado State University education-engineering model develop an engineering design philosophy throughout their engineering and K-12 classroom teaching experience. One aspect of this philosophy involves using the engineering design process to solve problems. When the students enter the secondary classroom, it is likely they will teach students to solve problems in the same manner.

Prior to the education-engineering model at Colorado State University, technology teachers were licensed through traditional technology and education studies. During this time, there was less emphasis on using the engineering design process to solve problems. The pre-service teachers would be taught less mathematical problem solving without consideration of optimization in their design. One can assume that a student from this program would be likely to teach with less mathematical rigor and less likely to use the engineering design process.

Problem

This project was focused on what differences exist between traditionally-trained technology teachers and engineering-trained technology teachers. In particular, any differences between the teaching methods that each group is using in the classroom. We also would like to know how the two groups differ in their knowledge and performance when preparing to teach in the technology classroom. To perform an analysis of content and delivery methods, we need to be able to understand and compare the design lessons

for traditionally-trained and engineering-trained technology teachers. The overall research question for this project was the following: How does traditionally-trained technology instruction differ from engineering-trained technology instruction?

Method

To better understand the differences between traditionally-trained technology teachers and engineering-trained technology teachers, the content and delivery methods must be examined. The most efficient way to accomplish this task is by collecting artifacts that demonstrate typical teaching lessons from both groups. A common task of the technology teacher is to develop lesson plans for class projects. These lesson plans are commonly referred to as "design briefs" or "design problems." Through a national appeal, design briefs from traditionally trained practicing technology teachers were acquired. For comparison, similar design briefs were collected from technology pre-service teachers who completed Colorado State University's education-engineering program. Due to the fact that this program is still in its infancy, there were only three design briefs to compare. Therefore, caution should be used when interpreting the data due to the small amount of available data.

A rubric was created around the eleven-step, engineering design process as defined by Eide et al. Each component of the process was detailed with four levels of adequacy. The top score of a 3 for a component of the process demonstrated complete integration of that component into the design process. On the other hand, a score of 0 indicated either a lack of use of that component or inadequate integration into the design process. The engineering design scoring rubric is shown in Appendix A. The two groups of the design briefs were scored according to the defined levels on the rubric. Each design brief was scored four times by four different reviewers to lessen the bias of the reviewer. To further lessen possible bias, the reviewers were unaware of which design briefs were created by engineering-trained teachers and which by technology-trained teachers.

Findings

An independent samples t-test between engineering-trained and technology-trained teacher-generated design briefs was performed for each of the ten engineering design steps. Table 2 displays the means and standard deviations for each step of engineering design process.

Table 2.

Means and Standard Deviations for Steps of the Engineering Design Process by Teacher Training

Engineering Design Step	Engineering Trained			Technology Trained		
	M	N	SD	M	N	SD
Identify the Need	2.25	12	0.87	2.17	12	1.03
Define the Problem	2.33	12	0.78	1.83	12	1.03
Search for Solutions	1.83	12	1.03	1.42	12	1.00
Identify Constraints	2.25	12	0.87	1.42	12	1.00
Specify Evaluation Criteria	2.58	12	0.67	1.08	12	0.67
Generate Alternate Solutions	1.58	12	1.08	1.75	12	0.87
Engineering Analysis	2.17	12	1.03	0.17	12	0.39
Decision	2.00	12	1.04	0.75	12	0.45
Design Specifications	2.21	12	0.94	0.08	12	0.29
Communication	2.25	12	0.97	0.50	12	0.52

Once again, due to the small sample size, caution should be used in interpreting the results. When evaluated at the alpha level of 0.01, the tests produced statistically significant differences for the engineering design steps of Specify Evaluation Criteria, Engineering Analysis, Decision, Design Specifications, and Communication. Table 3 presents a summary of the independent t-test results. For each of the statistically significant outcomes, the engineering-trained teachers produced higher results. This indicates that these five steps of the engineering design process are utilized more by engineering-trained teachers than by traditional technology-trained teachers.

Table 3.

Independent Samples t-test for Utilization of the Engineering Design Process by Teacher Training

Engineering Design Step	M diff	T	Df	p
Identify the Need	0.08	0.22	22	0.83
Define the Problem	0.50	1.34	22	0.19
Search for Solutions	0.42	1.01	22	0.33
Identify Constraints	0.83	2.19	22	0.40
Specify Evaluation Criteria	1.50	5.50**	22	< 0.001
Generate Alternate Solutions	0.17	0.42	22	0.68
Engineering Analysis	2.00	6.29**	14.08a	< 0.001
Decision	1.25	3.80**	22	0.001
Design Specifications	2.13	7.48**	13.06a	< 0.001
Communication	1.75	5.52**	22	< 0.001

aThe t and df were adjusted because of unequal variances
**Statistically significant at the $\alpha = 0.01$ level

Conclusions/Recommendations

It should be noted that this is a very preliminary investigation with limited information. Since institutions such as Colorado State University produce more engineering-trained technology teachers, the analysis should be repeated to check for consistency of results. However, the findings from this investigation indicate that engineering-trained teachers are more likely to incorporate engineering design into the secondary technology classroom. With technology education moving toward infusing more engineering design, these results indicate that the training of technology teachers should be examined carefully to align with the desired outcomes to teach and become proficient in engineering design. This preliminary investigation points to the importance of providing technology teachers with engineering science content in order to support them in infuse the engineering design process into technology education classrooms.

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Appendix A
Engineering Design Brief Scoring Rubric
Design Brief _____   **Reviewer's Initials** _____

	3	2	1	0	SCORE
Identify the need	Objectives are **clearly** identified. Acknowledged who will benefit and how.	Some objectives are listed. Acknowledged who will benefit and how.	Only one objective is listed **or** beneficiary is not identified.	No need is identified	
Define the problem	Broad definition of the problem with multiple solutions possible. Objectives are clearly defined. User requirements are established. Functions are established.	Somewhat defined problem with a couple of possible solutions. Objectives are listed.	Highly defined definition of the problem with only one possible solution. Objectives are vague.	No definition of the problem is given. No objectives are stated.	
Search for solutions	Many different pathways are researched. Less efficient paths are eliminated. Use of past problems or experiences to solve this type of problem. Use of creativity for new ways to solve the problem. Search findings are recorded for future reference.	A few different pathways are researched. Less efficient paths are eliminated. No use of past problems or experiences to solve this type of problem or no use of creativity for new ways to solve the problem.	At least one alternate pathway is researched. No use of past problems or experiences to solve this type of problem or no use of creativity for new ways to solve the problem.	Only one solution. No opportunities for searching for alternate solutions.	
Identify constraints	All possible physical and practical limitations are identified. Limitations are not overly restrictive to innovation. Examples include cost, codes, accommodations and rules.	Some physical and practical limitations are identified. Limitations restrict some innovation.	At least one limitation is identified. Innovation is highly restricted by the limitations.	No constraints are identified.	

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	3	**2**	**1**	**0**	**SCORE**
Specify evaluation criteria	Many desirable characteristics of the solution are known. Easy to qualitatively judge alternate solutions based on criteria. Students determine importance of each criterion. Four to six primary criteria are listed. Examples include cost, reliability, weight, appearance, ease of use, effectiveness, feasibility.	Some desirable characteristics of the solution are known. Sufficient to qualitatively judge alternate solutions. Students determine importance of each criterion. Two to four primary criteria are listed. Examples include cost, reliability, weight, appearance, ease of use, effectiveness, feasibility.	At least one desirable characteristics of the solution is known. Alternate solutions are based on at least one criterion. Examples include cost, reliability, weight, appearance, ease of use, effectiveness, feasibility.	No evaluation criteria are specified.	
Generate alternate solutions	Many Detailed alternative solutions or designs to the problem are developed. High use of creativity for new solutions. Use of checkoff lists or brainstorming. Determination of most valid approach.	Some alternative solutions or designs to the problem are developed. Some use of creativity for new solutions. Use of checkoff lists or brainstorming. Determination of most valid approach.	At least one alternative solution or design to the problem is developed. Limited use of creativity for new solutions. No use of checkoff lists or brainstorming.	Only one solution is generated.	
Engineering analysis and optimization	Alternative designs are compared and evaluated. Each design is looked at objectively. **Heavy** use of math and engineering principles to determine performance of each design. Mathematical models/graphs are generated to compare results. Results are	Alternative designs are compared and evaluated. Each design is looked at objectively. **Some** use of mathematical and engineering principles to determine performance of each design. Mathematical models/graphs are generated to compare results. Results are	Alternative designs are compared and evaluated. Each design is looked at objectively. **Little** use of mathematical and engineering principles to determine performance of each design. No Mathematical models/graphs are generated to compare results.	Alternative designs do not exist or are not compared and evaluated mathematically and through engineering principles.	

	3	2	1	0	SCORE
	judged for reasonability.	judged for reasonability.			
Decision	Final design is carefully chosen based on trade-offs of each solution. Engineering analysis of alternate solutions is used to determine optimal solution. Priorities of evaluation criteria are considered before a decision is made.	Final design is chosen based on trade-offs of each solution. Engineering analysis of alternate solutions is not used to determine optimal solution or priorities of evaluation criteria are not considered before a decision is made.	Final design is chosen. Engineering analysis of alternate solutions is not used to determine optimal solution or priorities of evaluation criteria are not considered before a decision is made.	No decision is made or the decision is made without considering previous steps in the design process.	
Design specifications	Details of the chosen design are described in great detail. Drawings of the design are developed. Sizes, shapes, notes, standards, specifications, and a bill of materials for the project are stated. Others could easily replicate the design through the design specifications.	Details of the chosen design are described in some detail. Drawings of the design are developed or sizes, shapes, notes, standards, specifications, and a bill of materials for the project are stated. With effort, others could replicate the design through the design specifications.	Details of the chosen design are described. Either drawings of the design are developed or a bill of materials for the project are stated. Others could not replicate the design through the design specifications.	Little to no documentation of the design is developed.	
Communication	Conveying information and ideas for the chosen design. A very detailed written report and oral presentation are generated to communicate to other interested parties.	Conveying some information and ideas for the chosen design. A written report and oral presentation are generated to communicate to other interested parties.	Conveying little information and ideas for the chosen design. A written report or oral presentation is generated to communicate to other interested parties.	No communication of the design to others.	

STRATEGIES FOR INTEGRATING STEM CONTENT: A PILOT CASE STUDY

Fred Figliano
Virginia Tech

Abstract

Science, technology, engineering, and mathematics (STEM) literacy is a critical component of 21st century education (AAAS, 1989, 1993; NCTM, 2000; ITEA, 2000). America's current educational reform agenda is spurred by an urgent need for a more STEM literate population. The central tenet of STEM literacy is the preparation of people who are knowledgeable of the connections between the content and practices of the STEM fields. When conceived as an integrated curriculum model designed around teamwork and problem-solving environments, STEM education is the ideal pathway for achieving such literacy.

A goal of STEM education is developing interdisciplinary thinkers. Interdisciplinary instruction is the act of consciously applying methodology and language from more than one discipline to make connections in content that cuts across subject areas (Pring, 1973, Jacobs, 1989, Drake, S., & Burns, R. 2004). Pring (1973), in his analysis of the term 'integration' concluded that "the very notion of 'integration' incorporates the idea of unity between forms of knowledge and their respective disciplines." For developing interdisciplinary thinkers, integrative instruction is the requisite approach.

The research presented in this document was designed to identify and describe successful teaching strategies revealed by studying an exemplar of integrative instruction. The results provide a clearer, deeper understanding of the instructional practices found effective in delivering integrative instruction and promoting more STEM literate students.

Research Questions

This study was guided by the following research question:

> How are teaching/learning strategies, as reflected in exemplars of integrative instruction, used to promote the purposeful integration of STEM content?

The data needed to answer this question were gathered through the following set of sub-questions.

1. What strategies are used in lesson plans to integrate purposefully STEM content?

2. What instructional strategies do teachers use, based on self-reflection, to purposefully teach integrative STEM content?

3. What collaborative teacher strategies are used in planning for purposeful integration of STEM content?

4. What strategies are used to evaluate student recognition of multidisciplinary connections?

Research Design

The design of this research calls for the analysis of exemplar programs featuring integrative instruction. To accomplish this analysis, a pilot case study design was implemented. The specific type of case study used was a "single case: embedded" design. The single case comes from the use of only one participating site. It is embedded because data were collected from three different instructor perspectives: Biology, History, and English. The four research sub-questions were individually applied to each of these perspectives and then analyzed as a whole through a process of convergence.

Selection of Subjects

The types of participants needed for this study were those exemplar practitioners practicing integrative instructional strategies. The review of relevant literature provided many sites as being exemplar models of integrated instruction. *Meeting Standards Through Integrated Curriculum* (Drake and Burns, 2004) was the primary source used for these identifications. Once these sites had been identified, the list was narrowed down to only those in Virginia, this being done because the research institution was in Virginia. From that final list, a selection was made based on the relative proximity to the research institution.

Data Collection and Analysis

To address research question 1, "What strategies are used in lesson plans to integrate purposefully STEM content?" lesson plans were collected and analyzed from the three subject area teachers (Biology, History, and English). The method of analysis to determine if lesson plans indeed reflected integrative teaching/learning strategies was a theme analysis.

To address research question 2, "What instructional strategies do teachers use, based on self-reflection, to teach purposefully integrated STEM content?" data were collected through the use of a 14 item open-ended questionnaire. The questionnaire was designed to better understand what instructional strategies were used by practitioners to create collaboratively lessons using integrative instruction.

To address research question 3, "What collaborative teacher strategies are used in planning for purposeful integration of STEM content?", data were collected through the recording of one planning session that occurs every six weeks. Dual tape recorders were used to insure the voices where properly recorded. The recording was then transcribed in

preparation for coding. A theme analysis was conducted on the transcription to identify common threads across the three disciplines.

To address research question 4, "What strategies are used to evaluate student recognition of multidisciplinary connections?", data were collected in the form of student artifacts. Students' final interdisciplinary projects for several 6 week units were collected with help from the instructors. A theme analysis was conducted on this data source to determine whether students were making interdisciplinary connections.

Convergence of Data Sets

Following the analysis of the four sets of data, they were examined further to identify points of convergence. These points of convergence allowed for the creation of a three-dimensional picture of integrated instruction.

Conclusions

The 15 strategies, as revealed through analysis of data collected in this study, are guidelines for instructors wanting to design and implement integrative STEM units. To organize these strategies, a sum of frequencies was calculated. These frequencies related to how often a particular theme was identified during the coding process which specifically related to how often a theme was discussed by participants.

A careful review of these 15 strategies found there were several broad strategy categories: Planning, Implementation, and Evaluation. These strategy categories were gleaned from the topics discussed and terms used within each strategy statement. In this way, each strategy could be shown to relate to specific aspects of the overall integrative instruction process. Organizing strategies in this manner allowed for a logical sequence that could be followed by practitioners.

Six strategies were found to address Planning (see Table 1). From the review of these six strategies, eight concepts emerge: standards, themes, connections, group work, time, trust, support, and brainstorming.

Table 1

Strategies for Planning Integrative Units

	Planning Strategies	*f*
1	Lessons are driven by state content standards and are based around primary and secondary themes that are agreed upon by all instructors involved, and allow for connections to be made among other disciplines.	64
2	Lessons are designed to allow student to work in cooperative groups where they produce some product.	33
3	Instructors must arrange for time to meet outside of school to develop integrated units.	32
7	All the instructors involved in the integrated unit must trust each other enough to give up control of the planning and implementation of the unit.	12
9	During the planning of an integrated unit, it is helpful, though not necessary, for faculty to gain the support of school administration.	9
11	Planning for integrated units occurs through brainstorming which is driven by state content standard requirements, teacher interest, and teacher experiences.	6

Implementation is another key category, with strategies identified in all four data sources (see Table 2). On close review of these four strategies, four concepts emerge: intentional connections, methods of teaching, attention to connections, keeping track of connections.

Table 2

Strategies for Implementation of Integrative Units

	Implementation Strategies	*f*
4	As a team, teachers intentionally make connections in content across disciplines.	30
8	Methods of teaching can include lecture / discussion, Internet research, practice activities, and group work.	9
14	Instructors specifically call attention to connections between disciplines.	2
15	Instructors encourage students to use methods such as graphic organizers to keep track of connections.	2

Five strategies were found to address Evaluation, the third category (see Table 3). From the review of these five strategies, five concepts emerged; holistic grading, alternative assessment, unit assessment, formatively assess students, and formatively assess units.

Table 3

Strategies for Evaluation of Integrative Units

	Evaluation Strategies	*f*
5	Presentations are watched and graded by the entire instructor team and a single holistic score is awarded. This score counts in each participating course.	29
6	Students are assessed for their knowledge of multidisciplinary connections through project presentation and class discussion.	20
10	Based on student recognition of multidisciplinary connections units should be continually assessed and constantly revised.	8
12	Student research on topics are formatively assessed to identify cross disciplinary connections.	5
13	Teachers constantly should be meeting with teachers in other disciplines to be sure to make appropriate connections to other disciplines.	4

The 15 strategies reflect a complex iterative process that will take a significant amount of time, perhaps years, to fully implement. Practitioners who might use this list as a framework for initiating integrative units of instruction in STEM education must recognize the complexity and the amount of time needed for implementation. These complexities and time requirements were echoed by participants, who, at a collaborative planning meeting, stated that if they were asked to give advice to a new teacher who wanted to use integrative techniques to teach a unit, they would advise them to start small. These 15 strategies, as organized in categories revealed through this study, provide a mechanism for faculty to start small.

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**HIGH SCHOOL STEM EDUCATORS' SELF-EFFICACY BELIEFS AT
VARIOUS CAREER STAGES**
Brent Holt
Virginia Tech

Abstract

The concept of self-efficacy originated from Bandura's social cognitive theory, which stated that individuals could control their behaviors and thoughts and promote change by their own efforts (Bandura, 1982). Bandura (1997) defined self-efficacy as, "the beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments." This definition refers to the concept that individuals who believe they can control an outcome or situation through their actions and abilities will tend to be more persistent and place more effort in achieving the outcome. Individuals who do not believe they can control a desired outcome or situation will tend not to be focused or motivated to implement strategies to achieve the outcome. Teacher self-efficacy has been found to influence several student outcomes such as achievement (Armor et al., 1976; Ashton & Webb, 1986; Moore & Esselman, 1992; Ross, 1992), motivation (Midgley, Feldlaufer, & Eccles, 1989), and students' own sense of efficacy (Anderson, Greene, & Loewen, 1988). Teachers who have a higher sense of self-efficacy produce increases in student achievement when working with struggling students for longer periods of time and create learning environments that are more responsive to students (Woolfolk, Rosoff, & Hoy, 1990). Ashton and Webb, (1986) found that teachers with higher self-efficacy were more inclined to maintain positive learning environments that were student focused. Teachers with low self-efficacy tended to have more rigid and controlling classrooms (Woolfolk & Hoy, 1990) and ignored or criticized students who answered questions incorrectly (Gibson & Dembo, 1984).

Variations in Teachers' Sense of Self-Efficacy Across Time

Even with a broad research base in self-efficacy, little has been done to study the development of teacher self-efficacy and whether these beliefs remain stable over time. Tschannen-Moran, Hoy, & Hoy (1998) found that very little evidence exists as to how self-efficacy beliefs solidify across a teaching career. It appears to be unclear as to whether teacher self-efficacy changes or stabilizes across a career. Brown & Gibson (1982) found that teachers at later stages in their careers had lower sense of self-efficacy, while another study found that outstanding teachers had no differences in their self-efficacy across career stages (Pigge & Marso, 1993). While it might be reasonable to assume that teacher self-efficacy will change over time, predicting the nature of the change, one has to consider the two components of teacher self-efficacy, personal self-efficacy and teaching self-efficacy.

Changing Self-Efficacy Beliefs

Teacher self-efficacy is a very important construct related to numerous behaviors found in teachers as well as students. Even though a higher sense of self-efficacy produces

higher measures of student achievement (Ashton & Webb, 1986), teacher beliefs appear to be quite stable and resistant to change (Brousseau, Book, & Byers, 1988). Making a transition to a new conceptual understanding or the application of a new pedagogical approach is difficult because preexisting beliefs are tenacious even in the face of contradictory evidence (Kagan, 1992). Bandura (1997) cautioned that positive changes in self-efficacy only come through "compelling feedback that forcefully disrupts the preexisting disbelief in one's capabilities" (p. 82). Teacher self-efficacy has been shown to have the potential to change over time. DeMoulin (1993) noted a fluctuation in teaching self-efficacy levels from pre-service and novice teachers to experienced teachers presented with similar tasks. As teachers become more experienced, modifying self-efficacy beliefs becomes more difficult. Even if teachers are exposed to new workshops or presented new teaching methods, there is a resistance to this change. Guskey (1988) confirmed that change is gradual and difficult after intervention, and programs requiring change need to be accompanied by encouragement, support, and feedback to be effective (Stein & Wang, 1988).

Method

Quantitative and qualitative research methods were employed in the study of STEM teachers' sense of self-efficacy. An online survey was administered to selected STEM teachers in Virginia to obtain demographic data and data relating to their levels of self-efficacy and factors associated with self-efficacy. From the results of this survey, a selected sample of participants was interviewed with the goal of increasing an understanding of self-efficacy beliefs.

Participants

Participants were selected from among the population of Virginia secondary STEM educators. Specifically, participants (teachers) were recruited from the various high school programs across the State of Virginia, including urban as well as rural school districts. Lists of superintendents' and high school principals' e-mail addresses were compiled from Virginia high school Web pages. Superintendents were contacted through a personal email requesting permission to survey teachers under their jurisdiction. After obtaining those permissions, the researcher asked school principals via email to forward an email note provided to them by the researcher to each of the STEM teachers in their school. In accordance with the policies of Virginia Tech's Institutional Review Board, this email asked STEM teachers to participate in the study, and directed them to the online survey instrument.

Eight participants were purposefully identified for follow-up interviews based upon their teaching self-efficacy scores as measured in the quantitative component of this study. More specifically, they were selected randomly from four "pools" of STEM teachers identified with high and low self-efficacy in rural and urban schools.

Instrumentation Design and Development

Data were gathered using an online survey conducted via the Internet. The survey consisted of two sections. The first section asked participants to provide demographic information, including gender, age, education, educational major, county in which present school is located, type of community (rural or urban) in which the school is located, years of teaching experience, years of teaching in a STEM program, enrollment level of existing school, and type of community in which the teacher grew up. If the teacher had five or fewer years' experience, they were also asked: utilization of a mentor, perceived support of mentor, perception of first year teaching experience, perception of student teaching experience, and perceived quality of teacher preparation.

The second section of the survey consisted of 24 questions using the *Teachers' Sense of Teacher Efficacy Scale* (TES) (Tschannen-Moran& Woolfolk Hoy, 2001). This instrument measured teacher self-efficacy based on 24 items obtained from Bandura's (1997) efficacy scale. Each item was measured using a 9-point Likert-type scale.

Quantitative Research Design

The quantitative approach used in this study is descriptive in nature in that variables were not manipulated and that the sole purpose of this study was to gain more information about STEM teachers' self-efficacy. Analysis was done on a number of factors to determine the degree of correlation between the factors and teacher self-efficacy.

Qualitative Research Design

To acquire more in-depth information of teachers' perceptions, open-ended interviews were conducted with STEM teachers whose self-efficacy values fell outside of the norm for their demographic or experience level. The rationale for the use of a qualitative approach was to conduct research in the teachers' natural setting attempting to interpret phenomena in terms of the meanings that teachers could articulate. It was hoped that this approach could add further evidence regarding factors that affect teacher self-efficacy over teachers' careers. A qualitative, phenomological methodology was chosen because it seemed well suited for encouraging teachers to tell their stories, to reflect on and describe their human experiences, and explore their perceptions within their STEM field. These data were elicited through personal interviews and were tape recorded.

Research Questions

1. Do self-efficacy measures for classroom management, instructional strategies, and student engagement differ among novice and experienced STEM teachers across the STEM disciplines?

2. Which factors contribute significantly to variations in novice and experienced STEM teacher self-efficacy across the STEM disciplines?

3. Does STEM teacher self-efficacy show a point of stabilization and does this point vary across the STEM disciplines?

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INVESTIGATING MIDDLE-SCHOOL TEACHERS' ENGINEERING SUBJECT MATTER AND PEDAGOGICAL CONTENT KNOWLEDGE

Morgan Hynes
Tufts University

Abstract

Including engineering education in the K-12 setting is a relatively recent initiative. Engineering is a rich field of study that allows students to see the value of what they are learning, apply interdisciplinary knowledge to contexts that make sense to them, and to create and explore the world around them. As industry, organizations, and school systems transition into including engineering education into the K-12 classroom, educational research in the subject area of engineering will require greater attention. The research proposed here grew out of the need to understand the nature of the task teachers face and what they need to know when teaching engineering. The proposed dissertation study aims to examine middle-school math, science, and computer teachers' use and development of subject matter and pedagogical content knowledge as they teach an engineering unit focused on the engineering design process (see Appendix A). The proposed qualitative study involves observing and interviewing a small (~5-8) cohort of teachers as they implement the same engineering unit in the Boston Public Schools.

Introduction

The research proposed here grew out of the need to understand the nature of the task teachers face and what they need to know when teaching engineering. The central research questions centered on this need and focus on the knowledge that teachers use and develop as they teach an engineering unit.

Research Questions

1. What subject matter knowledge do middle school math and science teachers use and develop as they teach an engineering unit focusing on the engineering design process?

2. What engineering pedagogical content knowledge do middle school math and science teachers know, use, and develop as they teach the said engineering unit?

3. How do math and science teachers connect their subject matter and pedagogical content knowledge the same and differently when teaching the said engineering unit?

Three constructs are at the core of these questions—*subject matter knowledge*, *pedagogical content knowledge*, and *expertise*. The first two constructs contribute to the knowledge base of teaching. Subject matter knowledge and pedagogical content knowledge are both content-specific, meaning that, for each subject (e.g., engineering),

they may contain different knowledge. The third construct, *expertise*, considers how teachers develop towards expertise in their engineering subject matter and pedagogical content knowledge.

Subject matter knowledge (SMK) entails the mix of math, science, and engineering content, concepts, principles, process skills, and fundamentals along with knowledge of engineering design—which usually involves the application of the aforementioned principles. Previous research in other subjects (e.g., math) has shown that a teacher's depth of SMK impacts their ability to teach (Ball & McDiarmid, 1990; Ma, 1999) as well as their teacher self-efficacy (Hoy & Davis, 2006) or belief in their ability to impact change with their students.

Pedagogical content knowledge (PCK) can be thought of as a teacher's knowledge of *how* to teach a specific subject (Shulman, 1986). PCK includes knowledge of students (i.e., their misconceptions and understandings), teaching strategies (i.e., real-world examples, probing questions), and lesson management. Previous research has illustrated the importance of teachers knowing and understanding their students backgrounds and conceptions (Driel, Verloop, & Vos, 1998; Magnusson, Krajcik, & Borko, 1999; Peterson, 1988; Veal, Tippins, & Bell, 1998). While PCK is commonly thought of as knowledge teachers develop through their experience and practice (Veal, Tippins, & Bell, 1998), others have shown that PCK can be developed with focused study outside the classroom (Carpenter, Fennema, & Franke, 1996). The proposed research hopes to capture the development of teachers' engineering PCK.

The construct of expertise considers what makes someone an expert in a particular domain. In terms of teaching, expertise considers what knowledge, skills, and strategies teachers develop to be more effective as a teacher (Berliner, 1986, 1994). Since the goal is to capture what PCK teachers use and develop, it will be important to consider what knowledge, skills, and strategies are developed in the pursuit of engineering teaching expertise.

Methodology

Six grade 5-8 teachers will be selected to participate in this study and will all be teaching the same LEGO robotics engineering curriculum (see Appendix B) developed by the researcher and collaborators. Each of the teachers will have previously participated in a summer teacher professional development workshop led by the researcher or collaborators. Data from these teachers will be collected in the form of: (1) semi-structured interviews, (2) videotaped classroom observations, (3) hands-on think-aloud tasks, and (4) student projects. Each of the six teachers will be interviewed and observed a minimum of four times over the course of the study.

Within specified interviews, the teachers will be presented with hands-on, think-aloud tasks that will aim to elicit both their subject matter knowledge and pedagogical content knowledge related to engineering. These methods of data collection are intended to allow the teachers to both verbalize what they are doing and experiencing, and allow the

researcher to then confirm what the teachers were doing in the classroom (Appleton, 2003; Dawkins, Dickerson, & Butler, 2003; Veal, Tippins, & Bell, 1998). Veal, Tippins, and Bell (1998) highlighted the success of using vignettes or teaching scenarios for teachers to work through during interviews. The hands-on think-aloud tasks will include an example LEGO artifact along with the teaching scenario to best represent what a teacher using the LEGO robotics curriculum would encounter. These tasks were developed out of the need to identify the subject matter knowledge the teachers were using as they approached teaching situations, which was seen as a shortcoming in a prior pilot study (Hynes, 2007). Finally, the students' final projects will be assessed using two methods. First, the teacher will assess their students' projects to reveal how well the teacher can identify the SMK addressed in the design as well as the PCK they may have used to assist the students in getting to their final project. Then the researcher will assess the student projects from each class to serve as a cross-case comparison of the teachers. These two methods will highlight both the teacher's ability to recognize the SMK incorporated into the projects and the success the teacher had in teaching their students (PCK) to implement the subject matter into their designs.

Miles and Huberman's (1994) qualitative data analysis approach will be applied in the analysis of the interview, task, observation, and student project data. The approach incorporates different types of data into displays and matrices to help reduce and organize data for analysis. The data is then analyzed by noting patterns and themes, clustering data, making comparisons, and noting relationships and then organizing the data into conceptually ordered matrices and charts, which help tell the story. A complete content analysis of the curriculum and results from the previous pilot study (see Hynes, 2007) provided the basis for the coding scheme that has been developed to this point (see Appendix C). Both within-case analysis for each teacher and cross-case analysis among the teachers will be used to examine the data.

Implications

The results from this study may help inform engineering educators prepare teachers, develop teacher resources, and create curriculum that will foster students' knowledge and interest in engineering. The research may also provide valuable insight into methods of analyzing teacher knowledge and how it can be researched further. If nothing else a small handful of teachers and their students will experience the excitement of engineering with LEGO!

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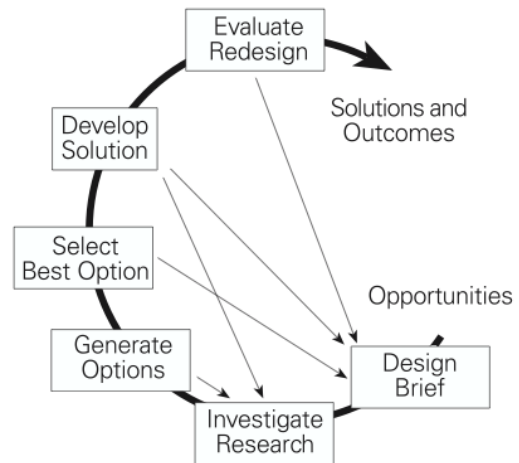
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Appendix A - Engineering design process models that act as the basis of the middle-school engineering curriculum.

[Graphic Unavailable for Reproduction]

(Massachusetts DOE, 2001)   (Newfoundland and Labrador DOE, 2007)

Appendix B – Robotics curriculum outline

Challenge (estimated time)	Description
Spatula design (1-2 hours)	Students will build a spatula out of LEGO that must be long and strong. The students will test the spatulas as a group, discuss design strategies that made them strong, then redesign the spatulas, and retest them. The teacher and students will then discuss the Engineering Design Process (EDP) and how they worked through the process in their challenge.
Wheelchair design (1 hour)	Students will build a LEGO wheelchair that must be able to hold a bottle of water, be at least 8 inches tall, be able to roll freely, and survive a drop test. The teacher will begin the challenge with a discussion about constraints and design criteria and their role in the EDP.
Design selection (1 hour)	This is a multi-part challenge. The discussion at the beginning and throughout the class revolves around selection and design criteria and how they play a role in the EDP and product development. First, the students have to select the "best" LEGO wheelchair drive train based on a number of criteria.
Design selection continued (1 hour)	The discussion for the second part of the challenge revolves around using orthographic drawings, learning how gears work, and constructing the model. The students use a set of orthographic drawings to construct the model they chose. Each model incorporates gears, and the teacher presents information on how gears work as they complete the challenge.
Design selection continued (1 hour)	Finally, the students, with the constructed models, test and evaluate the models. They find out how fast they go, how well they travel up an inclined ramp, how well they turn, and how well they traverse terrain. The teacher then has the students discuss and compare all the different models that were tested.
Programming (1-2 hours)	The programming challenge begins with the teacher introducing the students to the concept of computer programming and, specifically, the ROBOLAB programming language. After this brief introduction, the students use the models they built in the previous challenge to complete simple programming challenges (e.g., program the wheelchair to go forward for 2 seconds and stop). The challenges progress in difficulty.
Programming with sensors (1-2 hours)	The teacher begins this challenge discussing how sensors work. The teacher relates sensors to both the human senses and to the LEGO sensors. Students are then given programming challenges that incorporate the LEGO light and touch sensors (e.g., program the wheelchair to go forward until it crosses a black line).
Assistive device final project (4-8 hours)	The final design challenge asks the students to create an assistive device using the LEGO toolset with a minimum of 1 sensor, 1 motor, and the RCX brick. The students research a need or problem that they will propose to design a solution for. They then determine the criteria they will address and use the EDP to create, test, redesign, and finally market their solution to the class.

Appendix C – SMK and PCK coding schemes

Subject Matter Knowledge Codes

Math	Concept	Description
M1	Graphing	Using data and plots to estimate and optimize
M2	Measurement	Measuring physical dimensions, speed
M3	Estimation	Estimating measurements, weights, speeds, etc
M4	Symmetry	Identifying symmetry in design (balance and stability)
M5	Statistics	Statistics as selection and reporting criteria
M6	Percentage	Percentages as selection and reporting criteria
M7	Ratios	Calculating and using ratios in gears
M8	Scale	Identify and use scale in engineering drawings
M9	Other	
Science		
S1	Static forces	Gravity, load, structural forces
S2	Torque	Rotational force about a point (force x distance)
S3	Moment of Inertia	"Angular mass", resistance to angular motion
S4	Trusses	Transfer of forces
S5	Bending moment	Resistance object has to bending
S6	Friction	Resistance to motion
S7	Speed	Rate at which an object moves
S8	Simple machines	Screw, gear, wheel and axle, wedge, lever
S9	Kinetic forces	Forces in motion, kinetic frictional forces
S10	Other	
Engineering		
E1	Eng. Design	Eight steps of the engineering design process
E2	Testing	Evaluating design features and constraints using systematic tests
E3	Tradeoffs	Design features and constraints and their pros and cons
E4	Constraints	Criteria or limitations that apply to the design of an artifact
E5	Prototypes	Functional model of a product to test certain features
E6	Eng. Drawings	Orthographic, isometric, views
E7	Specifications	Set of requirements to be satisfied
E8	Comm. System	Source, encoder, transmitter, decoder, storage, retriever, receiver
E9	Comp. Programming	If/then, while, loops, iterations, etc.
E10	Control	Using sensors/feedback to control a robot or device
E11	Electronics	
E12	Other	
LEGO/ROBOLAB		
L1	Connections	How to connect different LEGO pieces together
L2	Stability	Sturdy and stable construction
L3	Gears	How to use the various types of LEGO gears (connections, applications, orientations)
L4	RCX	How to operate and connect to the RCX
L5	Motors	How to operate and connect to the motors
L6	Sensors	Function, operation, and connection of sensors
L7	Programming	Fundamentals of programming with ROBOLAB

Pedagogical Content Knowledge Codes

Real World Examples

RW1	Physical in-class example
RW2	Talk about example
RW3	Demonstration/video example
RW4	Other

Strategy for student understanding

SU1	Question/Inquiry
SU2	Demo/Physical
SU3	Instruction/Direction/Suggestion
SU4	Other

Knowing students

KS1	Student misconception
KS2	Student background education
KS3	Student background/culture
KS4	Did not know student background (education or culture)
KS5	Other

EXAMINATION OF ENGINEERING DESIGN IN CURRICULUM CONTENT AND ASSESSMENT PRACTICES OF SECONDARY TECHNOLOGY EDUCATION

Todd R. Kelley
University of Georgia

Abstract

This descriptive study examined the current status of technology education teacher practices with respect to engineering design. Participants were drawn from the current International Technology Education Association (ITEA) membership database. A survey instrument gathered data about the extent to which engineering design concepts are incorporated into the curriculum content and assessment practices employed by secondary technology educators. Moreover, the survey identified challenges faced by technology educators when seeking to implement engineering design. Current curriculum content that addresses engineering design concepts consisted of the following seven subsets: (a) engineering design, (b) engineering analysis, (c) application of engineering design, (d) engineering communication, (e) design thinking, (f) engineering and human values, and (g) engineering science. The instrument was developed from current research in technology education (Asunda & Hill, 2007; Rhodes & Childress, 2006; Smith, 2006; Gattie & Wicklein, 2007).

Introduction

The field of technology education has a history of experiencing curriculum reforms that generate new program titles with little curriculum changes (Akmal, Oaks, & Barker, 2002; Clark, 1989; Sanders, 2001). Considering the history of resistance to change in the field of technology education, questions arise about the current curriculum shift to move to engineering design as a content focus.

Recently, there have been new curricula designed to infuse engineering content into technology education such as *Project ProBase, Principles of Engineering*; *Project Lead the Way, Principles of Technology*; *Engineering Technology*; and *Introduction to Engineering* (Dearing & Daugherty, 2004.) Certainly, research was needed to determine to what degree engineering design content was being presented in technology education. Moreover, a need to understand where technology educators are in practice regarding an engineering design focus was expressed by leaders in technology education (NCETE meeting report, Oct, 2006). It was clear that a descriptive study could better identify the depth of implementation of engineering design content infused into technology education.

Purpose of the Study

This descriptive study examined the degree to which technology educators are implementing elements of engineering design in their curricula. A full sample was taken

of all secondary technology educators who were members of the International Technology Education Association (ITEA) as of September 2007. The sample consisted of all high school technology teachers regardless of whether they indicated they taught engineering design in their classrooms. The survey instrument gathered data about the degree to which engineering design concepts were incorporated into the curricula content, assessment practices employed by secondary technology educators, and challenges to implementing engineering design concepts in the secondary technology education curriculum.

Research Questions

1. To what degree does the current curriculum content of secondary technology education programs reflect engineering design concepts?

2. To what degree do current assessment practices of secondary technology educators reflect engineering design concepts?

3. What selected challenges are identified by secondary technology educators in teaching engineering design?

Methodology

This descriptive study examined the degree to which technology educators were implementing elements of engineering design in their curriculum. This descriptive study sought to describe the current engineering design content and assessment practices using the results of four recent research studies (Asunda & Hill, 2007; Childress & Rhodes, 2008; Smith, 2006; Gattie & Wicklein, 2007) to create items for the survey instrument.

Instrumentation

The first section of the survey instrument gathered data about degree to which engineering design concepts were incorporated into technology education curriculum content. The curriculum content items were created from the results of Childress and Rhodes study (2008) and Smith's study (2006) to create the framework for defining engineering design curriculum content in seven categories, see Table 1. Participants were required to respond to each curriculum content item twice, for *frequency of use* and for *time per typical use*, using a six-point Likert scale, see Table 2.

The second section of the survey instrument consisted of identified assessment practices for evaluating engineering design activities (Asunda & Hill, 2007). Participants rated their level of agreement regarding their assessment practices of engineering design activities with the identified assessment practices presented in the instrument.

A third section of the survey instrument identified teacher challenges relative to implementing curriculum changes to infuse engineering design into technology education curricula. Participants used a five-point Likert scale to rate their levels of experience

identifying teacher challenges. The five-point Likert scale was as follows: Never = 0, Rarely = 1, Sometimes = 2, Very Often = 3, and Always = 4 (Lodico, Spaulding, & Volegtle, 2006). One question was open-ended allowing participants to identify any other challenges faced. The final section of the survey instrument collected general demographic information of each participant.

Results

Using the Krejcie and Morgan (1970) method for calculating sample size for a given population size, the appropriate sample size for this study was determined to be 285. The final results of the study yielded a total of 226 respondents, therefore, the results of this study cannot be generalized to the entire population.

The results of this research yielded a 0.982 Cronbach's Alpha for internal consistency. *Engineering Communication* was the highest ranked category with a group mean score of 2.80. In the Engineering Design category was the highest-ranking individual item (measured by time per typical use) *use of computer-aided design to construct technical drawings* with a mean score of 3.35. Also, the item *use technical drawings to construct or implement an object, structure, or process* (mean score of 3.30), was high ranking. The emphasis of CAD in technology has been discovered in other status studies (Dearing & Daugherty, 2004; Sanders, 200; Warner & Mumford, 2004).

Another result of particular interest is that the second highest ranked item measured by time per typical use was *develop basic student skills in the use of tools* with a mean of 3.32. It appears that the field of technology education has not moved far from its industrial arts roots. As a matter of fact, a similar survey item, *developing skill in using tools and machines,* was the highest ranked item in the SfIAP project (1979) and Schmitt and Pelly study (1963) according to Sanders (2001).

The lowest ranking categories based on composite scores for total instructional time were, *Engineering and Human Values* (6.21 hours for traditional schedule; 6.06 hours for block schedule), *Engineering Science* (7.06 hours for traditional schedule; 8.88 hours for block schedule), and *Engineering Analysis* (14.41 hours for traditional schedule; 14.16 hours for block schedule); see Figure 1 and Figure 2. These results reveal that there is less emphasis on the use of math to predict design results and a low emphasis on optimization techniques. Some might question if engineering design is being properly taught when these are key engineering design elements (Hailey, Erekson, Becker, & Thompson, 2005; Hill, 2006; Gattie & Wicklein, 2007). Similar results were obtained in the assessment practice and teacher challenges section. See appendix for those results.

Conclusion

Current research reveals that technology education teachers believe there are potential benefits of an engineering design focused curriculum (Gattie &Wicklein, 2007). However, those benefits may never be realized unless our field is properly informed as to the status of its practitioners regarding the implementation of engineering design into the

technology education classroom; this study sought to provide such information. The evidence from this study reveals that technology education curriculum content currently emphasizes career and technical education skills such as CAD and general tool skills providing rationale for the field to develop an engineering career pathway for high school students. This would end the argument that dates back to Dewey and Prosser of vocational education versus general education and would provide a clear mission for the field as suggested by some (Wicklein, 2006).

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Table 1
The Seven Categories of Engineering Design Content

Seven Categories of Engineering Design Content
Engineering Design
Engineering Analysis
Application of Engineering Design
Engineering Communication
Design Thinking as It Relates to Engineering Design
Engineering and Human Values
Engineering Science

Table 2
Teaching Style Scale Conversion

How Often? (Frequency)				How Many Minutes? (Time)			
Likert	Wording	Traditional (meets 5 days a week)	Block	Wording	Traditional (50 minutes per period)	Block (90 minutes per period)
0	**Never**	0	0	**None**	0 min.	0 min.
1	**A few times a year**	5 days	5 days	**A few minutes per period**	5 min.	9 min.
2	**1 or 2 times a month**	14 days (1.5*9.1)	7 days (1.5*4.6)	**Less than half the period**	15 min.	30 min.
3	**1 or 2 times a week**	55 days (1.5*36.8)	28 days (1.5*18.4)	**About half**	25 min.	45 min.
4	**Nearly everyday**	129 days (3.5*36.8)	64 days (3.5*18.4)	**More than half**	37.5 min.	67.5 min.
5	**Daily**	184 days	92 days	**Almost all period**	50 min.	90 min.

  Assumptions: Traditional schedule meets 5 days a week, 50 minute period, 184 day school year. Typical A/B and 4x4 block scheduling meets for 92 days for 90 minutes.

Table 3
Engineering Design

Engineering Design Content	Mean Frequency	SD Frequency	Mean Time	SD Time
understand engineering design is an iterative process	3.03	1.21	2.27	1.20
understand creativity is an important characteristic for engineers to apply in design	3.33	1.21	2.51	1.34
recognize that there are many approaches to design and not just one design process	3.26	1.32	2.42	1.28
recognize engineering as a potential career option	3.05	1.31	2.12	1.22
are able to identify good and bad design	2.96	1.19	2.40	1.16
believe in his/her ability to design a solution to a technological problem	3.27	1.19	2.58	1.31
Average Group Mean / Std Dev	3.15	1.24	2.38	1.25

Table 4
Engineering Analysis

Engineering Analysis Content	Mean Frequency	SD Frequency	Mean Time	SD Time
understand that knowledge of science and mathematics is critical to engineering	3.44	1.20	2.61	1.25
apply engineering science principles when designing solutions	3.15	1.25	2.59	1.29
use measuring equipment to gather data for troubleshooting, experimentation, and analysis	3.09	1.25	2.69	1.26
use physical and/or mathematical models to estimate the probability of events	2.12	1.42	1.93	1.35
use optimization techniques to determine optimum solutions to problems	2.09	1.41	1.82	1.38
use models or simulations to study processes	2.82	1.40	2.58	1.40
Average Group Mean / Std Dev	2.79	1.32	2.37	1.32

Table 5
Application of Engineering Design

Application of Engineering Design Content	Mean Frequency	SD Frequency	Mean Time	SD Time
apply knowledge for manufacturing products to the engineering design	2.62	1.22	2.39	1.28
identify problems that could be solved through engineering design	2.82	1.23	2.48	1.24
understand no perfect design solution exists	2.91	1.41	2.24	1.31
conduct reverse engineering to analyze product design	2.02	1.34	2.26	1.51
organize and manage design process for optimal use of materials, processes, time, and expertise	2.50	1.33	2.39	1.34
design, produce, and test prototypes	2.89	1.34	3.15	1.39
apply research to designing products, processes, and materials	2.65	1.24	2.62	1.32
develop skills to use, manage, and assess technology	2.94	1.29	2.65	1.31
demonstrate the ability to handle open-ended/ ill-defined problems	2.79	1.30	2.50	1.33
develop basic students' skills in the use of tools	3.46	1.26	3.32	1.34
understand design often requires tradeoffs	2.86	1.24	2.44	1.25
Average Group Mean / Std Dev	2.77	1.29	2.59	1.33

Table 6
Engineering Communication

Engineering Communication Content	Mean Frequency	SD Frequency	Mean Time	SD Time
communicate design ideas orally, through presentations, and graphics	2.96	1.35	2.94	1.29
communicate through writing technical reports	2.03	1.29	2.25	1.39
use technical drawings to construct or implement an object , structure, or process	3.34	1.26	3.30	1.25
visualize in three dimensions	3.26	1.31	3.19	1.32
develop and maintain an engineering design portfolio	2.54	1.87	2.07	1.71
use computer-aided design to construct technical drawings	3.39	1.52	3.35	1.49
apply the rules of dimensioning	3.09	1.49	2.98	1.51
apply rules of manufacturing tolerance	2.10	1.35	2.00	1.37
use basic computer applications such as word processors, spreadsheets, and presentation software	3.27	1.39	3.15	1.36
Average Group Mean / Std Dev	2.89	1.42	2.80	1.41

Table 7
Design Thinking Related to Engineering Design

Design Thinking Related to Engineering Design Content	Mean Frequency	SD Frequency	Mean Time	SD Time
think critically	3.65	1.10	3.15	1.22
synthesizes simple parts into complex systems	2.73	1.25	2.61	1.29
Apply systems thinking - understanding and considering the multiple facets of a design solution result in positive and negative impacts	2.58	1.42	2.34	1.34
apply brainstorming and innovative concept generation	3.24	1.20	2.98	1.30
have the ability to approach open-ended/ ill defined problems	2.80	1.41	2.62	1.44
Average Group Mean / Std Dev	3.00	1.28	2.74	1.32

Table 8
Engineering and Human Values

Engineering and Human Values Content	Mean Frequency	SD Frequency	Mean Time	SD Time
understand how engineers put ethics into practice	1.75	1.23	1.76	1.32
are aware of social, economical, and environmental impacts on design solutions	2.31	1.24	2.21	1.24
understand that the solution to one problem may create other problems	2.47	1.28	2.23	1.30
consider cost, safety, appearance, and consequences of design failures	2.47	1.34	2.25	1.33
take human values and limitations into account when designing and solving problems	2.27	1.33	2.07	1.31
apply knowledge of basic ergonomics to engineering design process	2.04	1.32	1.95	1.35
Average Group Mean / Std Dev	2.22	1.29	2.08	1.31

Table 9
Engineering Science

Engineering Science Content	Mean Frequency	SD Frequency	Mean Time	SD Time
apply math and science to the engineering design process	3.15	1.26	2.84	1.24
apply knowledge of basic mechanics to the engineering process	2.88	1.33	2.69	1.29
apply knowledge of basic statics and strengths of materials to engineering design process	2.02	1.28	1.98	1.32
apply knowledge of dynamics to the engineering design process	1.81	1.40	1.76	1.39
use of algebra to solve problems or predict results to design solutions	2.19	1.47	1.98	1.35
use geometry to solve problems or predict results to design solutions	2.60	1.35	2.30	1.32
use trigonometry to solve problems or predict results to design solutions	1.65	1.37	1.58	1.34
apply knowledge of material process to engineering design process	2.37	1.35	2.19	1.37
Average Group Mean / Std Dev	2.33	1.35	2.16	1.33

Table 10
Engineering Design Category Rankings for Frequency of Use

Rank	Engineering Design Content Category	Total Group Mean Frequency	Total Group SD Frequency
1	Engineering Design	3.15	1.24
2	Design Thinking Related to Eng. Design	3.00	1.28
3	Engineering Communication	2.89	1.42
4	Engineering Analysis	2.79	1.32
5	Application of Engineering Design	2.77	1.29
6	Engineering Science	2.33	1.35
7	Engineering and Human Values	2.22	1.29

Table 11
Engineering Design Category Rankings for Time Per Typical of Use

Rank	Engineering Design Content Category	Total Group Mean Time	Total Group SD Time
1	Engineering Communication	2.80	1.41
2	Design Thinking Related to Eng. Design	2.74	1.32
3	Application of Engineering Design	2.59	1.33
4	Engineering Design	2.38	1.25
5	Engineering Analysis	2.37	1.32
6	Engineering Science	2.16	1.33
7	Engineering and Human Values	2.08	1.31

Table 12
Assessment Practices for Engineering Design Projects

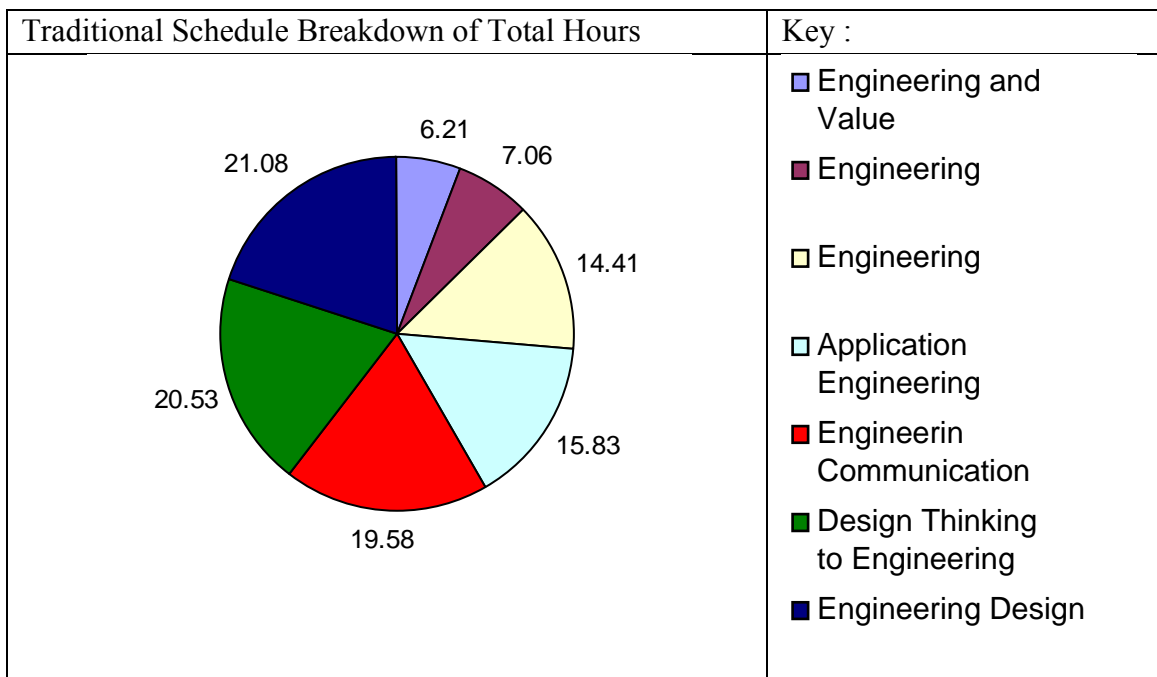| Assessment Practices	Mean Frequency	SD Frequency	Mean Time	SD Time
use support evidence / external research (research notes, illustrations, etc)	2.32	1.38	2.25	1.37
provide evidence of formulating design criteria and constraints prior to designing solutions	2.33	1.45	2.19	1.43
use design criteria such as budget, constraints, criteria, safety, and functionality	2.45	1.34	2.31	1.39
provide evidence of idea generation strategies (e.g. brainstorming, teamwork, etc.)	2.92	1.46	2.69	1.50
properly record design information in an engineer's notebook	2.01	1.76	1.78	1.64
use mathematical models to optimize, describe, and/or predict results	1.72	1.43	1.62	1.39
develop a prototype model of the final design solution	2.69	1.43	2.87	1.55
work on a design team worked as a functional inter-disciplinary unit	2.53	1.50	2.79	1.60
Average Group Mean / Std Dev	2.37	1.47	2.31	1.48

Traditional Schedule Breakdown of Total Hours	Key :
	☐ Engineering and Value
	☐ Engineering
	☐ Engineering
	☐ Application Engineering
	■ Engineerin Communication
	■ Design Thinking to Engineering
	■ Engineering Design

Values shown on pie chart: 6.21, 7.06, 14.41, 15.83, 19.58, 20.53, 21.08

Figure 1. Composite Score for Traditional Schedule.

Block Schedule Breakdown of Total Hours	Key :
	☐ Engineering and Value
	■ Engineering
	☐ Engineering
	☐ Application Engineering
	■ Engineerin Communication
	■ Design Thinking to Engineering
	■ Engineering Design

Values shown on pie chart: 6.06, 8.88, 14.16, 14.72, 17.75, 19.11, 19.44
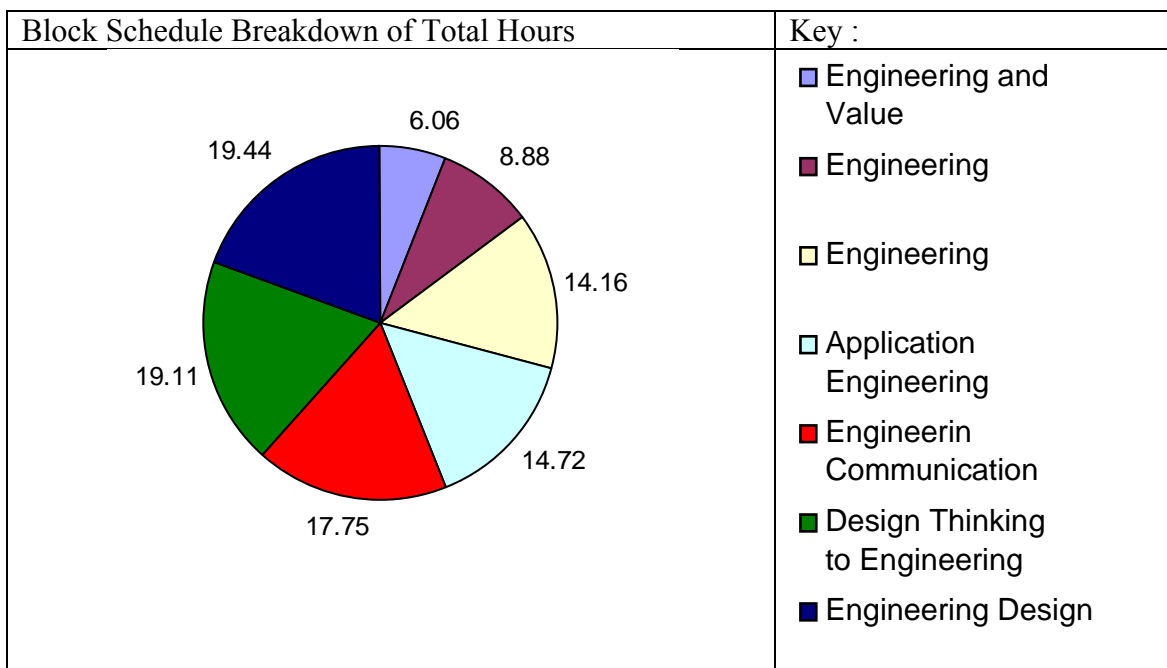
Figure 2. Composite Score for Block Schedule .

Total Hours Per Assessment Strategy	Key :Assessment Strategy
	■ use support evidence / external research (research notes, illustrations, etc) ■ provide evidence of formulating design criteria and constraints prior to designing solutions □ use design criteria such as budget, constraints, criteria, safety, and functionality □ provide evidence of idea generation strategies (e.g. brainstorming, teamwork, etc.) ■ properly record design information in an engineer's notebook ■ use mathematical models to optimize, describe, and/or predict results ■ develop a prototype model of the final design solution ■ work on a design team worked as a functional inter-disciplinary unit

Figure3.   Composite Score for Assessment Strategies for Traditional Schedule.

Total Hours Per Assessment Strategy	Key :Assessment Strategy
	■ use support evidence / external research (research notes, illustrations, etc)
	■ provide evidence of formulating design criteria and constraints prior to designing solutions
	□ use design criteria such as budget, constraints, criteria, safety, and functionality
	□ provide evidence of idea generation strategies (e.g. brainstorming, teamwork, etc.)
	■ properly record design information in an engineer's notebook
	■ use mathematical models to optimize, describe, and/or predict results
	■ develop a prototype model of the final design solution
	■ work on a design team worked as a functional inter-disciplinary unit

Figure 4. Composite Score for Assessment Strategies for Block Schedule.

COMPARING QUESTION POSING CAPABILITY ACROSS HIGH SCHOOL CURRICULA: A RESEARCH PROPOSAL

Benjamin Franske
University of Minnesota

Rationale

Our lives and world seem to be teeming with problems: how to save on gasoline; how to keep food from spoiling; how to maintain our ability to feed a growing population; how to protect endangered species. We live in a world which seems defined by problems. For all of recorded history, we, as a society, have relied on science and technology to help address problems such as these. From the earliest methods for farming to the invention of the wheel, sail and ship and, more recently, the advances brought about by electronics, computers and the Internet, we see the importance of technology as a method for addressing a growing number of problems. Still, all of these advances in science and technology would remain purely intellectual curiosities were it not for people who can see a practical value to the knowledge and who have an ability to apply it to solve problems. As with most useful and productive services, over time, a profession of people who use science and technology to solve real world problems has emerged. Many of those involved in this type of problem solving are identified by themselves or others as engineers.

The U.S. Department of Labor describes an engineer as someone who applies the principles of science and mathematics to solve technical problems economically (2007). Thus, when we talk about solving real world problems using technology and scientific discoveries in a systematic way, we are really talking about engineering problem solving. It naturally follows, then, that engineers who are most familiar and most successful with problem solving and have the required skills will develop the highest quality solutions to the problems they examine. As we do not live in an ideal world, it is not enough for engineers to design the best possible solution to problems. Even in the definition provided by the Department of Labor, we can see the influence of commercialization and economics. The solutions devised by engineers must not only be technically and scientifically feasible, but must also be economically feasible. This wrinkle in engineering problem solving which requires that a solution be economical can add significant complexity to the problem solving process and necessitates that the best and most desirable engineers have superior problem solving skills.

Although the success of an engineer is largely determined by their ability to solve complex and ill-structured "real world" problems, engineering schools often do a poor job of teaching students how to deal with these types of problems (Jonassen, Strobel & Lee, 2006). The solving of problems with unclear goals and unlisted constraints is not something that students are able to learn through the structured problem solving to which they are most commonly introduced in engineering classes (Jonassen et al., 2006). The problems discussed in school are typically designed to have a correct, or at least apparently optimal, solution to which the students' solutions can be compared. In the real

world, problems often have more than one appropriate solution and can require the balance of conflicting goals and other complex issues.

More recent research has suggested that even the word or story problems that engineering students might be exposed to do not appear to provide adequate transfer to the solving of complex, ill-structured problems (Jonassen et al., 2006). It is not just engineers who benefit from the practical application of science and technology to solve problems. As our daily lives have evolved and become more complex, we have exposed ourselves to an increasing number of technological problems. For example, the majority of Americans living today take for granted the ability to control the climate in their homes through heating and cooling systems. The function of a building has evolved from a simple shelter from the elements to something expected to keep us comfortable year around, but the increasing cost of energy is slowly causing us to re-think our living habits. Thus, the homeowner must now balance the desire for a comfortable home with the reality of the costs for maintaining such a home. These seemingly contradictory goals might be achievable, or the situation improved, through the application of scientific and technological principles in a problem solving process, and the better that process, the more satisfactory the end result.

Problems

It may not seem necessary to define what is meant by a problem. After all, we frequently use the term and nearly everyone has experienced a problem of some kind, but when embarking upon a study of problems, it soon becomes evident that "problem" is not a universal term and can have multiple meanings which must be differentiated. Psychologist Karl Duncker (1945) begins his work on problem solving by describing problems as what occur when someone has a goal but does not yet know how to meet that goal. This description of a problem as something which blocks the move from an existing state to a desired state is echoed by Simon and Newell (1972). Along these lines, it is possible to describe what blocks this transition as a difficulty. The *Oxford English Dictionary* describes the most common uses of problem to be "a difficult or demanding situation; a matter or situation regarded as unwelcome, harmful or wrong and needing to be overcome; a difficulty" (2008) a description which clearly fits those provided by Duncker, Simon and Newell.

It is not merely enough though to describe a problem as a difficulty. Those problems faced by engineers and designers, while they may be difficult, are more than a difficulty. *Merriam-Webster's Dictionary* defines a problem as "a question raised for inquiry, consideration, or solution" (2008) which is a more appropriate definition in this case. Getzels (1982) suggests that in these cases, instead of being a difficulty, developing the problem is itself the primary goal and what remains then is execution. Furthermore, it becomes possible to classify problems based on whether the problem exists or is created, whether the problem is suggested by the solver or another and whether a known solution exists or must be devised. This method for classification of problems led Getzels (1964; 1982) to describe ten common types of problems, revolving around whether the problem exists or is to be discovered, or whether there are known steps to solutions.

Jonassen (2000) takes a slightly different tact and suggests two critical attributes for an issue to be a problem. First, there must be a situation with an unknown described as a discrepancy between a current state and goal state. This is similar to the definition used by Simon and Newell (1972). Secondly, there must be some social, cultural or intellectual value to finding or solving the unknown. The value could be either intrinsic or extrinsic, but the key component is that someone feels that it is worth finding the unknown.

Jonassen (2000; 2006) believes that there are thee essential types of problems which form the basis for problem classification. Puzzle problems are characterized by having a single correct solution which reached using a specific procedure (Jonassen, 1997). Although multiple methods may accomplish the same end result, only the single most efficient method is deemed to be the correct one. These are problems which have most commonly been associated with the study of cognitive problem solving, for example, by Simon and Newell (1972), and include the Tower of Hanoi, water jug problems and the nine dot problem. Jonassen (1997) suggests that, while these are interesting from an initial research perspective, they map poorly onto complex real-world problems and, as such, are not relevant to school learning or everyday practice.

Well-defined or well-structured problems are those to which people are most conditioned to solve and are most familiar, especially in the school setting. For example, when a math or science teacher writes problems for an exam or assigns "homework problems", they are most frequently well-defined problems. This is likely because well-defined problems have a definite solution process which requires the application of concepts, rules and principles from a given knowledge domain (Jonassen, 1997). In other words, well-structured problems are good for checking basic understanding and facts which is often the desired outcome of homework and exams. Jonassen (1997; 2000) describes well-structured problems as having a well-known initial state, a defined goal and known method for arriving at a solution. Although not explicitly identified as well-structured, the first and second type of problems identified by Getzels (1964; 1982) are really examples of well-defined problems. These are given problems with standard methods for solving the problem, and solutions can be compared to determine correctness.

One common misconception about well-defined problems which Jonassen (Jonassen, 1997) wishes to dispatch is the idea that skills learned in solving them will easily transfer to real world, ill-structured problems. The third problem category is the ill-structured or ill-defined problem. Unlike puzzle problems and well-structured problems, this category of problem is frequently tied to a specific context, and the information required to solve the problem is not all available in the problem statement (Jonassen, 1997; Jonassen, 2000). Many, if not most, of the problems encountered in daily life are of the ill-structured variety (Jonassen, 1997). For example, problems found or given to engineers and designers do not often contain all of the information required to solve the problem in the problem statement. There is also significant room for creativity in these types of problems as more than one correct solution may exist. The problem will often require the application of multiple domains of knowledge, and judgment calls must be made by the problem solver (Jonassen, 1997). The problem types Getzels (1964; 1982) identifies as

three through ten could be described as ill-structured problems in that multiple solutions might exist, and the problem and/or the method for solving it is not fully understood.

For the purposes of this study, the problems of interest are ill-defined questions raised for inquiry, consideration or solution. This is undoubtedly the most frequently encountered type of problem in the real world and that which is faced by designers and engineers on a daily basis. Although designers and engineers are often asked to "fix a problem" or are given what initially appear to be problems, they are often more accurately described as dilemmas or issues. There is usually no immediately apparent path to solution, and devising a solution will require the application of critical thinking skills and creativity. The dilemma or issue must also be somehow turned into a problem which can be solved.

Problem Posing

The study of problem solving and the desire to utilize it in schools and workplaces is not new. Educational researcher John Dewey (1910) proposed a five-step problem solving process which included: (1) felt difficulty, (2) problem clarification, (3) identification of possible solutions, (4) testing of solutions, and (5) verification of results. The four step heuristic model for problem solving proposed by mathematics researcher George Polya (1957) is similar to that of Dewey as it includes: (1) understanding the problem, (2) devising a plan, (3) carrying out the plan, and (4) looking back on all of which can be seen in Dewey's five steps. One problem with models such as these is that they make the complex task of problem solving appear to be deceptively simple and can hide some of the processes which result in the most desirable solutions. In his seminal study of problem solving, psychologist Karl Duncker (1945) suggests that the process of finding a solution is more accurately seen as the continual reformulation of the problem. Over time, this problem reformulation leads to the discovery of "essential" properties of the solution which, given knowledge of the domain, will, in turn, dictate an appropriate solution to the problem.

It may initially seem like a radical suggestion that the formulation of the problem is more essential than the solution, but Duncker is not alone in this belief. Scientists, Albert Einstein and Leopold Infeld, noted the importance of problem formulation in their discussion of the evolution of physics: The formulation of a problem is often more essential than its solution which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science (1961, p. 92).
Einstein illustrates the importance of problem formulation by discussing the problem of determining whether light travels instantaneously or whether it occupies time, as sound does, a question posed by Galileo. Although the crude instruments of Galileo's time prohibited him from answering this question once he had formulated the question, he was able to discern an experimental procedure which could be used leaving the work to be done a matter of technical and experimental skill (Einstein & Infeld, 1961). Clearly, the experiment itself is not the most difficult part of this problem. Instead, the formulation of the problem is the true challenge, and if we are to be good at the solving of problems, we must be good at finding problems.

Sometimes, when the topic of problem finding comes up, it is asked "why do we need to seek out more problems when our world is already full of them?" It is certainly the case that our world has many issues, dilemmas and quagmires, but for these there is no immediately apparent path to solution (Getzels, 1979). They are not solvable in their current form. Returning to our earlier discussion of problems, this can further complicate the categorization of problems as the initial dilemma may be presented to the problem solver, but the problem to be solved remains to be found. Take for example early prairie farmers who were able to harvest an abundance of grain on their remote but fertile ground. Someone may consider the problem to be that we did not have enough roads to transport grain to markets and ponder how to get roads built in these remote areas. Taking this view, the problem domain has already been narrowed to building roads. As it turns out, roads are not the only way to transport grain and may not be the most efficient for a specific situation. If a river is nearby, or a number of farmers deposit grain in an elevator near them to which a railroad could be built, these may be better solutions. Solving the problem for these farmers is aided by the finding or formulation of an underlying problem, the transportation of grain from farm to market, and the posing of questions such as the feasibility of centrally collecting grain prior to shipment or the proximity of a navigable river which may provide a better solution.

If the ability to solve complex and ill-structured problems is a critical skill, and the formulation of problems or problem posing a critical and early step in the process of solving these types of problems, should we not focus attention upon problem finding as a desired outcome of technology and engineering education? Unfortunately, problem finding has been largely neglected by researchers, as a whole, (Getzels, 1979) and in the field of technology education (Lewis, Petrina, & Hill, 1998). It is the goal of this study to identify the state of problem finding in the high school classroom as it relates to the solving of technological problems and to compare the problem finding abilities of students from a wide variety of backgrounds.

Problem Solving

Once a problem has been found, devising a solution to the problem can begin. The most basic description of problem solving comes from the seminal work of Newell and Simon (1972) which describes problem solving as the transition from an initial situation to a goal state by a narrowing of the problem space. The initial state, sometimes referred to as the problem state, encompasses the understanding of the situation as it exists. Take, for example, the dilemma of energy efficiency given above. In this case, the problem state could include the thickness of walls, amount of insulation, price of energy, type of heating and cooling system, area climate and other similar factors. The goal state is the desired result and embodies the solution to the problem. In our example of home energy efficiency, this could be the replacement of the heating system, additional insulation, use of passive solar design or other solutions to reduce climate control costs while improving efficiency. The link between the problem state and the goal state is the search for solutions through the narrowing of the problem space. This narrowing occurs as the problem solver searches through the information to which they have access seems

relevant to the problem including things in their memory and any research they conduct. Eventually, the problem solver narrows the problem space enough to determine the solution to the problem (Newell & Simon, 1972).

Even in the example of home energy efficiency, we can begin to see deficiencies in Newell and Simon's description of problem solving. The problem has more than one solution, and the problem space cannot be systematically narrowed until a solution becomes obvious. Complex and ill-defined problems such as those most commonly faced by engineers and designers cannot be solved in Newell & Simon's simple problem space model (Middleton, 2005).

Recognizing the deficiencies in the simple problem space model as well as the extensive use of design in Australian technology classrooms, Middleton (2005) modified Newell and Simon's simple problem space model to account for the characteristics of design problems including the ill-structured nature and potential existence of multiple solutions. The revised model replaces the problem state with a "problem zone" which enables starting with an ill-defined and complex problem about which little is known. The goal state is replaced by a "satisficing zone" indicating an understanding that more than one competing goal may exist, and a balance may need to be struck as well as the understanding that multiple solutions may exist. Finally, the simple narrowing of the problem space by searching is replaced by a complex search and construction process where numerous procedures are used which may be constructed or emerge. Another critical aspect of the revised model is that it is not a linear one. There remains a vacillation between the problem zone and the search and construction space as well as between the satisficing zone and the search and construction space (Middleton, 2005). This vacillation allows the problem to be redefined and the solution reexamined as the problem solving continues.

A Focus on Design and Engineering

Technology education in the United States, like industrial arts and manual training before it, has traditionally focused on domain knowledge and production skills rather than on intellectual processes. In 1983, the landmark government report *A Nation at Risk* was published. Among other indicators that the American system of public education was on a dangerous path, it was reported that high school students were lacking in intellectual skills, such as problem solving, which should be expected of them (The National Commission on Excellence in Education, 1983). The concerns identified in *A Nation at Risk* were reiterated in 1991 with the publication of *What Work Requires of Schools: A SCANS Report for America 2000*. Again, intellectual skills and problem solving were identified as lacking in American students (The Secretary's Commission on Achieving Necessary Skills, 1991). Taking note of this shift in the workplace, Johnson (1992) wrote in the *Journal of Technology Education* about the critical nature of intellectual skills and suggested that the field adopt a curriculum emphasizing intellectual skills such as problem solving through ill-structured, design oriented problems.

In 2000, the International Technology Education Association published the *Standards for Technological Literacy*, a set of content standards for the study of technology in schools. Out of the twenty standards, four are entirely focused on the design process, and several others make note of the importance of design (International Technology Education Association, 2000). Since many cognitive scientists consider design to be a special case of problem solving (Newell & Simon, 1972), the inclusion of design in standards such as these can be interpreted as an explicit inclusion of problem solving. Although technology educators in the United States have been slow to include explicitly design in their curriculum, other parts of the world have truly embraced design as a foundation for technology education. The British, too, were concerned about the gap between education and industry, but their wake up call came with the release of the *Crowther Report* in 1959 (Gradwell, 1996), several decades before *A Nation at Risk* and the *SCANS* report were released in the United States. Beginning in 1963, British researcher Gerd Sommerhoff opened the Technical Activities Centre at Sevenoaks School in Kent (Gradwell, 1996). This center was designed squarely to address the gap between education and the workplace, especially the field of engineering, through student designed projects requiring creativity and problem solving skills (Gradwell, 1996).

From the late 1960s through the 1970s, the ideas promoted by Sommerhoff were propagated to other schools in Great Britain, and design based problem solving slowly became a regular part of the curriculum (Gradwell, 1996). The late 1980s and early 1990s saw the introduction of a national curriculum in the United Kingdom aimed at ensuring that all students learn essential knowledge and skills. One of the subjects selected for inclusion in this curriculum was Design & Technology, a subject heavily influenced by the ideas of Sommerhoff almost thirty years earlier (Atkinson, 1990; Gradwell, 1996). The advent and subsequent revisions of the national curriculum in the United Kingdom have firmly entrenched the idea of design and problem solving within their technology curriculum while the United States continues to struggle with the idea though some progress is being made.

In recent years the field of technology education in the United States has been moving toward a more engineering and design focused curriculum. Articles by respected technology education researchers (Lewis, 2005; Wicklein, 2006) as well as the inclusion of design standards in the ITEA *Standards for Technological Literacy* (2000) indicate the increasing interest in engineering and design as content for the study of technology. As engineering and design curriculum continue to propagate through American schools, there will need to be continued research to promote understanding student problem solving both in how problem solving can be nurtured in students as well as appropriate methods for the assessment of problem solving.

Problem Statement

Complex and ill-structured problems such as those commonly found within the design and engineering fields require that solvers have the ability to define and question the problem itself through a process of problem finding, but the research on problem finding

in technology and engineering education has not been extensive, and we do not know whether high school engineering curricula support this critical skill in problem solving.

Guiding Research Questions

    1. What can we say about the types of problems found by students?

    2. How do students who have taken high school engineering coursework compare on measures of problem finding ability and the types of question posed to those with traditional technology education coursework and those without any kind of engineering or technology coursework?

    3. How do students in rural, exurban, suburban and urban areas compare on measures of problem finding ability and the types of questions posed?

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THE EFFICACY OF CROSS-DISCIPLINE REPRESENTATIONS
FOR ILL-DEFINED IAS CONCEPTS

Steven Rigby
Purdue University

Abstract

A universal problem in our society is the dramatic increase in the number of security threats, risks, and vulnerabilities to our nation's computer systems, data, and infrastructure. Our future depends upon the problem solving and thinking abilities of professionals entering the Information Assurance and Security (IAS) field. These professionals will be faced with many problems that are complex, ill-defined, and multidisciplinary in nature. But how do we, as educators, prepare these professionals to be successful? Are traditional approaches sufficient for the complexity they will face? Providing complex, ill-structured learning activities increases problem solving abilities of the learner and increases expertise, however, most of the research that has been done to date has been specific to domains of knowledge that could be classified as well-defined and not multidisciplinary. Much is not known especially in domain areas that are complex, ill-defined, and multidisciplinary such as information assurance where the knowledge domain is dynamic, complex, multidisciplinary, and rapidly changing with many concepts being ill-defined. The purpose of this study is to investigate how inner and cross-discipline representations affect learners' conceptual understanding of ill-defined IAS concepts. More specifically, this study investigates the efficacy of presenting cross-discipline representations of ill-defined concepts to learners to improve conceptual understanding.

Introduction

The demand for professionals able to solve IAS problems is steadily increasing, and academia is now faced with the challenge of preparing these professionals for the complex, ill-defined problems that await them (PITAC, 2005). While some institutions are experimenting with case study approaches to teaching problem solving, others are developing laboratory exercises to develop troubleshooting skills. Although instruction can take many forms, it is worth reevaluating how we think about IAS instruction and the nature of thinking skills. The knowledge required to solve the complex problems of IAS involves many well-defined and ill-defined concepts. Well-defined concepts are those considered "concrete" and are clearly defined with described features and characteristics (Smith & Ragan, 1999). In mathematics terminology, a "well-defined" concept is one in which the input will always provide the same answer (Hall, 1959). For example, the exclusive or (XOR) logical operation would be considered a well-defined concept because performing this operation on the same two operands will always produce the same results. Ill-defined concepts are those that are less structured and "abstract" with no single clear characteristic and are usually based on situations and the understanding of other related concepts (Smith & Ragan, 1999). When discussing ill-defined concepts, the discussions usually begin with "it depends". The attributes and relationships between ill-

defined concepts are of key importance for solving "real-life" problems. Academia is currently teaching well-defined and ill-defined IAS concepts to students through educational experiences with the hope that concepts learned in school will transfer to the everyday problems they will face professionally, but are these educational experiences successful?

Research suggests that providing complex, ill-structured learning activities increases problem solving abilities of the learner and increases expertise, however, much of the research done to date has been specific to domains of knowledge that could be classified as well-defined and not multidisciplinary, such as mathematics. There is much that is not known especially in domain areas that are complex, ill-defined, and multi-disciplinary. In fields such as information assurance, the knowledge domain is dynamic, complex, multidisciplinary (see definition of terms), and rapidly changing with many concepts being ill-defined. This is not to say that IAS does not include well-defined concepts, rather that the well-defined concepts have connecting relationships with ill-defined concepts and, oftentimes, both are needed in order to solve problems.

Of central importance for educators of IAS disciplines is what factors influence transfer (see definition of terms) of these well-defined and ill-defined concepts. According to Mestre (2002):

> Cognitive research has converged on the conclusion that transfer is better if people have learned initially in a way that fosters deep, abstract understanding of central principles of a field…. One method for achieving such deep, abstract understanding is to involve students in multiple examples illustrating a central principle drawn from an equivalence class where the surface characteristics of problem vary as widely as possible.
> (p 10)

This suggests that cross-discipline representations foster deep learning of abstract concepts which enhances transfer and increases expertise (see definition of terms). One unexplored area is to what extent inner-discipline representations and cross-discipline representations affect the learning of ill-defined concepts such as those found in the field of IAS. Up to this point, research has mainly focused on well-defined concepts while the problems faced most by IAS professionals will require conceptual understanding of ill-defined concepts. This presents a need to research how inner and cross-discipline representations affect learners' mental models or schemata of ill-defined concepts. Of particular interest is to what extent cross-discipline representations increase a learner's conceptual understanding of an ill-defined concept. The closer the learner's conceptual understanding is to that of experts, the better the learner will be able to approach new problems in a meaningful way.

Research Question

 The question this study is to examine is whether cross-discipline representations are more effective than inner-discipline representations in increasing students' conceptual

understanding of complex, ill-defined concepts like those found within the knowledge domain of technology and IAS.

1. Are representations of ill-defined concepts within the same discipline as effective as cross-discipline representations in increasing expertise in learners?
2. To what degree do additional cross-discipline representations of ill-defined concepts increase the conceptual understanding of learners?

Methodology

Previous research suggests that multiple representations are an important factor to increase conceptual understanding with cross-discipline representations increasing expertise more than inner-discipline representations. It is expected that this will also apply to ill-defined concepts. The hypotheses of this study will investigate the effect inner and cross-discipline representations have on students' learning of ill-defined concepts. The following hypotheses indicate the expected outcomes of this study.

1. Cross-discipline representations are more effective than inner-discipline representations in increasing conceptual understanding of an ill-defined concept.
2. Each additional cross-discipline representation increases conceptual understanding of an ill-defined concept at a functional rate.

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COMPLEX SYSTEMS IN ENGINEERING AND TECHNOLOGY EDUCATION: A MIXED METHODS STUDY INVESTIGATING THE ROLE SOFTWARE SIMULATIONS SERVE IN STUDENT LEARNING

Douglas J. Walrath
Utah State University

This research will determine if students receiving complex systems instruction recognize patterns and underlying elements of complex systems more effectively than students receiving traditional instruction. Complex systems were investigated with an analytic (reductive) approach in a control group and with a synthesis approach in the treatment group. Exploration of this top-down approach to learning complex systems counters traditional bottom-up methodologies, investigating systems and sub-systems at the component level. The hypothesis was that students experiencing complex systems scenarios in a computer-based learning environment would outperform their counterparts by constructing a greater number of explanations with emergent-like responses.

A mixed method, experimental, pretest/posttest, control group Triangulation Design research study was designed for high school students enrolled in an *Introduction to Technology and Engineering* course. A pretest consisting of one open-ended near transfer problem and one far transfer problem was administered, investigating the generation of reductive (clockwork) and complex (emergent-like) mental models. Following treatment, an analysis of covariance failed to reveal statistically significant evidence supporting the hypothesis. However, qualitative data in the form of student transcriptions, daily lab reports, and data entry worksheets revealed evidence of emergent-like response and behaviors.

It is important for high school students to be able to synthesize information from disparate courses (Frank, 2005; Jacobson & Wilensky, 2006). The American education system tends to teach core classes in separate rooms and seldom explains how concepts from both disciplines can be used to solve real problems (Thode & Thode, 2002). "For nearly a century, Western society in general and American society in particular, has been dominated by a form of thinking and an approach to life that is narrowly reductive and deeply analytical" (Pink, 2006, p. 2). Frank (2005) explains this analytical focus as, "the traditional approach in engineering and technology teaching [which] is bottom-up, i.e. component to system" (p.20). However, Pink (2006) states that "what's in greatest demand today isn't analysis but synthesis – seeing the big picture, crossing boundaries, and being able to combine disparate pieces into an arresting new whole" (p. 66).

An alternative approach capitalizing upon interdisciplinary connections, which may be effective in technology education, is that of complex systems teachings (Charles, 2003; Jacobson & Wilensky, 2006). Exploration of a top-down approach to learning complex systems counters traditional bottom-up methodologies, investigating systems at the component level. This approach provides students with a holistic perspective exploring scenarios with cultural, environmental, economic, political and societal interactions.

Engaging students in complex systems teaching aligns with technology education standards four through seven, focusing on technology and society relations.

Complex systems approaches have not been researched in Engineering and Technology Education (ETE) programs. Complex systems thinking has its roots anchored in scientific domains, which, due to their compulsory nature, make them well suited for complex inquiry. However, ETE programs are particularly well suited to investigate complex systems as "technology education teachers are in a unique position in that their curriculum is often more flexible, and they have the opportunity to present the 'big picture' to their students by tying the other areas together in realistic activities" (Thode & Thode, 2002, p.15).

Therefore, an experimental study was conducted with high school students enrolled in a technology education class, utilizing a stratified sampling method for control or treatment groups. The study addressed the research question: Can high school students' exposure to complex systems scenarios within a software simulation enhance the generation of emergent framework mental models, as demonstrated by the ability to create emergent-like explanations as they are applied to near and far transfer problems?

The site for this study was Mid-Western High School (MWHS). With an enrollment of 1767 students (2007-08), MWHS is located in a suburban community of a Midwestern city of 200,000. Eighteen students enrolled in a freshmen-level *Introduction to Technology and Engineering* class were randomly assigned to groups.

The dependent measures for this study were complex responses in the form of Emergent Framework Metal Models (EFMM) and reductive responses, in the form of Clockwork Mental Models (CWMM). An alternative for EFMM and CWMM was a lack of understanding, identified as No Model (NM). The independent variable was the method of complex systems instruction. Control group students received reductive instruction focusing at the subsystem and component level during the construction of a robot. Treatment participants received synthesis instruction within a global warming simulation (CO2FX) with embedded complexity concepts.

A pretest and posttest was administered with one open-ended near transfer problem and one open-ended far transfer problem coded and analyzed with Charles' (2003) Ontological Mental Model Taxonomy to measure group differences. A concurrent form of analysis was selected for this mixed methods Triangulation Design research study. A one-way analysis of covariance (ANCOVA) was conducted for each of the three dependent variables: Emergent Framework Mental Models (EFMM), Clockwork Mental Models (CWMM) and No Models (NM). A qualitative analysis was completed on the three primary forms of data collected: worksheets from the software simulation intervention, student's daily lab reports, and nine sets of transcriptions from teams of three students working within the intervention.

Quantitative and qualitative evidence tend to support one another in this research. ANCOVA results do not provide statistically significant evidence of emergent-like

understanding following the intervention. Qualitative data reveal a predominance of student statements, actions, and behaviors within the simulation displaying reductive characteristics. Not surprisingly students relied upon a trial and error problem-solving approach typifying strategies frequented in technology education. However, over the course of the month-long treatment, students provided examples displaying emergent-like characteristics across all three qualitative data forms (see Appendix A). Verbal exchanges, between students working in teams of three, tended to indicate that through repetitive trial and error approaches students exhibited a novice-level complex systems understanding. Revelation of underlying complexity elements was demonstrated in spoken and written form, but most often through a pattern of decisions revealed on CO2FX data entry worksheets (Appendix B).

Penner's research (2000) into emergent phenomena found that students lack the cognitive capacity to represent accurately emergent-like concepts: "that is, even though students might possess considerable domain knowledge, they do not necessarily possess the ways of thinking that can help them analyze phenomena appropriately" (p. 804). It is possible treatment participants' intuition led them to believe certain emergent-like happenings were occurring in the CO2FX simulation. However, failing to possess the tools to analyze independently, their answers subsequently lacked sufficient evidence to be coded as EFMM. Therefore, no differences were found at posttest.

Beyond learning complexity terminology and concepts, the challenge is one of demonstrating complex systems understanding over time. Transferring information to a new domain with emergent-like component beliefs would serve as a practical demonstration. However, that did not occur in this study. This could partially be due to the treatment group's repeated exposure in a single complexity scenario. Gick and Holyoak (1983) found that a single analogous event failed to provide adequate abstract representation transferring to new settings. However, transfer increased when two or more analogs sharing similar characteristics were used. Utilizing several simulations embracing similar complexity concepts could provide complementary abstract representations facilitating transfer, whereas, a single unit failed to demonstrate statistical significance in this research.

Clearly, the need exists for more research in this area. Complex systems and student learning research is still in its infancy within science domains. As technology education represents a natural, multidisciplinary learning environment for presenting the "big picture" research, this domain would be a logical extension of current efforts in science. Recommendations for future research would include studies pertaining to pedagogy, curricular materials, and learning tools. Many important questions need to be addressed, to include: How does students' conceptual understanding change over time? What strategies are appropriate based on age? What role can longitudinal studies play?

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Appendix A – Qualitative Data Source Findings
Table 1

Qualitative Triangulated Data Sources: Coded Themes Across Three Trials

Data Forms:	Trial 1	Trial 2	Trial 3
CO2FX Student Transcripts (Themes)	Singular Causality Trial and Error Tradeoffs Big Change = Big Effect **Change Over Time** **Additive Effects**	Singular Causality Trial and Error Tradeoffs	Singular Causality Trial and Error (or) Experimentation
CO2FX Student Worksheets (Mean Responses)	Large Input = 17.67 **Small Input = 15.67** **No Change = 5**	Large Input = 12 **Small Input = 18.33** **No Change = 8**	Large Input = 12.33 **Small Input = 26.33** **No Change = 10.33**
Daily Lab Reports (Themes)	Singular Causality Trial and Error Rational **Small Change = Big Effect** **No Change**	Singular Causality Emphasis Upon Controllable Events **Averages/Small Input** **Circular Causality**	Singular Causality Tradeoffs Applied Knowledge **Balance Variables**

Note. Words identified in bold letters represent emergent-like characteristics. Regular text represents reductive traits.

Emergent-Like and Reductive Decisions in CO2FX Simulation
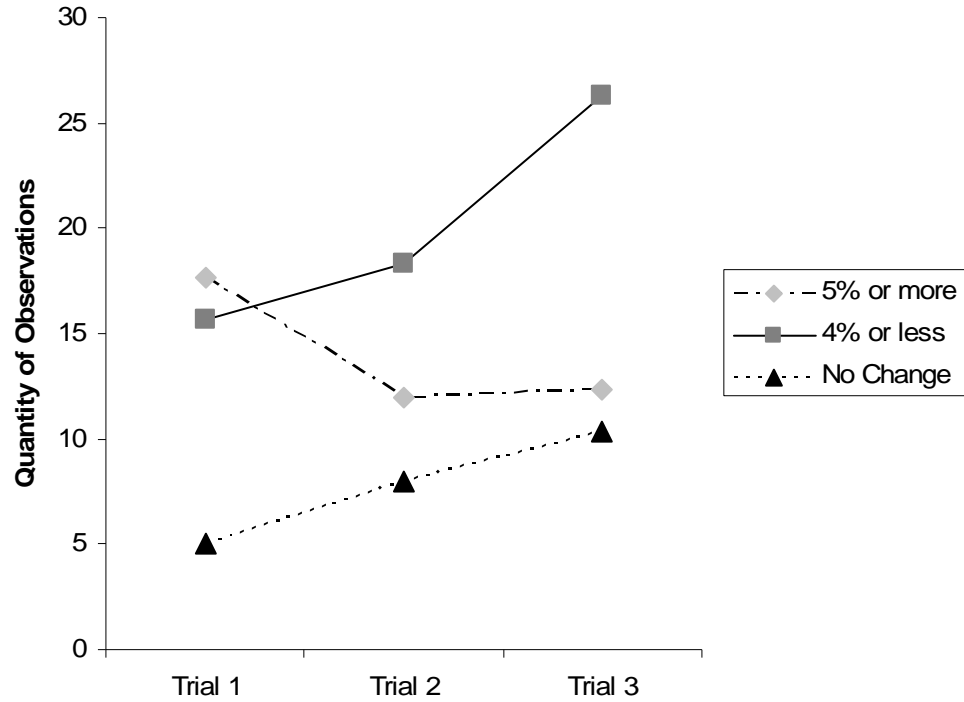

Figure 1. CO2FX data decisions over three or more decades. No change line displays an emergent-like pattern with values held consistent across a minimum of three decades. 4% or less line displays emergent-like characteristics with minor changes of 0% to 4% inputted between three or more consecutive decades. 5% or more line represents attributes of reductive-type behavior with data input decisions varying decade-to-decade between 5% and 99%.

EFFECTS OF METACOGNITIVE JOURNALING ON ACADEMIC ACHIEVEMENT OF HIGH SCHOOL STUDENTS

Katrina M. Cox
Utah State University

Abstract

Learning Journals have been used and proven effective for undergraduate college students and for ninth graders in increasing grade performance and general comprehension in a variety of fields of study. A limited number of studies have shown that Metacognitive Journaling, a form of Learning Journals, is more effective. Three studies that researched Metacognitive Journals have weaknesses in study design. Additionally, no study has been found testing the effects of journaling with students in grades 10 through 12. It would be beneficial to determine if Metacognitive Journals are better than the other forms of Learning Journals since teachers could have a new, more effective tool for improving student grade performance and comprehension that is no more time consuming than other Learning Journals. Therefore, a study will be done among students grades 9 through 12, using three comparative groups: (1) Control, (2) Metacognitive Journal, (3) Learning Journal (Scientific/Experimental), to test Metacognitive Journals' effect on course grade performance and final exam scores.

Learning Journals

A Learning Journal's main focus is on the learning experience (Park, 2003). From this, a variety of journal forms have appeared such as Reflective/Reading (Thomas & Barksdale-Ladd, 2000), Experimental/Scientific, Cognitive, Affective, and Metacognitive Journaling (McCrindle & Christensen, 1995; Smith, Rook, & Smith, 2007) and are a positive influence for undergraduate college students and 9th graders in that:

> It has been welcomed as a learning tool, and …offers an autobiographical approach to learning, a way of improving knowledge and learning, a way of developing reflective practice, and a help to developing the course of one's own learning (Park, 2003).

They also improve student grades, understanding, and feelings of capability in such fields as English (Mannion, 2001, O'Rourke, 1998), Algebra (Pugalee, 2004), Biology (McCrindle & Christensen, 1995), Psychology (Connor-Greene, 2000), History (Smith, Rook, & Smith, 2007), Geography (Park, 2003), and Reading Comprehension (Thomas & Barksdale-Ladd, 2000). No negative effects beyond student complaints of completion time and initial understanding of the use of journals were found (Park, 2003). Metric and verbal analysis showed positive effects of their use in learning and teaching for students' perceptions and performance and teachers' methodologies.

Metacognitive Journals

Metacognitive Journaling, defined by an ability to induce self metacognitive awareness or "…one's knowledge concerning one's own cognitive process and products or anything related to them, e.g. the learning of relevant properties of information or data" (Flavell, 1976) and the ability to maintain executive control over those faculties, must incorporate predicting, planning, revising, selecting, classifying and checking (Smith, Rook, & Smith, 2007; McCrindle & Christensen, 1995; Thomas & Barksdale-Ladd, 2000; Pugalee, 2004; and Chester, 2007) and must also address Flavell's three domains of metacognitive awareness: 1) Person, 2) Task, and 3) Strategic (McCrindle & Christensen,1995, pp.169-170). All of these recommendations are best exemplified by McCrindle and Christensen's questions for use in Metacognitive Journals (1995):

1. What did you do? (*Strategic/Task*) (p. 173)

2. How did you learn the content? (*Task*) (p. 173)

3. Explain as fully as you can what strategies you used to comprehend, learn, and recall the information… [with] Reflection on the strategies used, how effective they were, evaluations or recommendations for their future use, and other reflections on their personal learning process (*Strategic/Person*) (pp.173-174).

Metacognitive Journaling has been found by a limited number of studies to be better than other Learning Journals. McCrindle and Christensen (1995) showed that students who used the Metacognitive Journals (M=29.4 vs. M=25.25) in the college undergraduate biology scored an average of 4.15 points higher on the final exam, used more metacognitive strategies,… [had] acquisition of greater metacognitive knowledge, … gave richer, more detailed accounts of their learning process,…articulate[d] their understandings with greater clarity, [and] …demonstrated greater awareness of cognitive strategies as well as greater control in implementing strategies effectively (p.182) than students using the Experimental/Scientific Journals, "despite the fact that the [this] group had more opportunities to interact directly with the course content" (p.184) and had similarly ranked and acknowledged the importance of various metacognitive strategies.

Smith, Rook and Smith (2007) found that ninth grade History student course grades were consistently higher over a 12-week period with those using a combination metacognitive journal than those using cognitive journals or not journaling. This shows the metacognitive addition "support[s] content learning to a much greater degree than just cognitive or text-related" styles (p.46).

Study Flaws

Only three studies found tested Metacognitive Journals directly: Thomas and Barksdale-Ladd (2000); McCrindle and Christensen (1995); Smith, Rook and Smith, (2007). Smith, Rook and Smith (2007) tested cognitive (A), affective (B), and metacognitive (C) writing

styles in an X, A, ABC style with no capability of comparing the effects of the metacognitive element alone, rather, comparisons could only be made between the ABC treatment, A, or none at all (X). This study also fails to distinguish between the various forms of questioning/journaling they tested with no examples of what questions looked like, how they were used, or even formed.

The Thomas and Barksdale-Ladd (2000) study, while providing detail in what the journals were composed of, also, used combination treatments, but no control group. The combinatory effect of all three treatments was discussed in a case study description of behavior, but not in a comparison of any kind via internal or external controls. They also fail to address major aspects of Metacognitive Journaling by monitoring, predicting, hypothesizing, and judging/evaluating reading materials and text, not the manners in which they learned or monitored their cognitive behaviors.

The McCrindle and Christensen study of 1995 did not use a control group. Although it claimed that the Experimental/ Scientific Journaling group was a control, it is still a Learning Journal, and, thus, affected student performance on many measures. Without the incorporation of a non-journaling control group to compare any result "would not be conclusive in itself without comparison to a control group…Moreover, a significant difference for the control group would alert you to the possibility of extraneous factors affecting your independent variable" (Cohen, 2001, p.305).

Benefits of Metacognitive Journals

If Metacognitive Journaling were found more effective, it would produce increased student performance using means that are no more time consuming than traditional Learning Journals (Thomas & Barsdale-Ladd, 2000; McCrindle & Christensen, 1995). They would theoretically "provide[s] a mechanism to increase metacognition" (McCrindle & Christensen, 1995) "an essential element of comprehension" (Thomas & Barsdale-Ladd, 2000) "central to the development of 'expert learners'," improve student grade performance and comprehension, and "potentially be seen to provide a sound framework for the development of 'capable' [students]" (Phelps, Ellis & Hase, 2001).

These issues lead to the conclusion that a better study needs to be designed that tests and analyzes the singular effects of Metacognitive Journaling, uses a control group absent any journaling, single treatment groups, and uses proper statistical measures, not simply a verbal analysis and description of effects. In total, "Further research is necessary to investigate those factors that provide for the successful implementation of a writing program designed to develop metacognitive behavior" (Pugalee, 2004, p.44).

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ASPECTS OF PROBLEM SOLVING IN CHILDREN PRE-KINDERGARTEN TO NINTH GRADE: FOCUS ON FUNCTIONAL FIXEDNESS.

Michael Nehring
University of Minnesota

Introduction

Technology as defined by the International Technology Education Association (2000, p.2) is "…[a] diverse collection of processes and knowledge that people use to extend human abilities and to satisfy human needs and wants." According to the American Heritage College Dictionary (1993), the word technology is derived from the Greek word, tekhnologia, meaning systematic treatment of an art or craft: "teché" meaning skill, and "ology" defined as science, theory, or study.

Historical Perspective

The formal education of technology has evolved over the centuries from apprenticeships to high-tech laboratories in colleges and universities. Much of the evolution can be attributed to the original formal education programs of the late 1800s, such as Manual Training, Sloyd, and Manual Arts.

Following the European Industrial Revolution, the philosopher, Johan Heinrich Pestalozzi, began advocating for a reconnection of the mind and hand in education. Pestalozzi advocated for teaching words and meanings through the manipulation of objects and models (Cochran, 1970; Hostetter, 1974). Influenced by Pestalozzi, Friedrich Wilhelm Augustus Froebel developed the first kindergarten, where children learned through the manipulation of three-dimensional objects. Through his study of children, Froebel recognized differences in individual learning development and encouraged individual education (Hostetter, 1974).

Following a similar philosophy on education, Victor Della Vos developed the Russian system of manual activity at the Russian Imperial Technical School of Moscow (Phillips, 1985). Della Vos developed a new educational program for engineers based on "an analysis of operations, processes, and manipulative work" (Cochran, 1970, p. 2). Around the same time in Scandinavia, Uno Cygnaes, influenced by Pestalozzi and Froebel, modified the Russian system to develop the Elementary Education system in Finland. Otto Salomon, director of a Sloyd school in Naas, Sweden, after visiting with Cygnaes in 1877, returned with his own modification of the Russian system.

In celebration of the centennial of the United States, the Centennial Exposition was held in Philadelphia in 1876. During the exposition, educational systems from around the world were on display, including the Russian and Sloyd systems. Two of the most influential people to learn about the Russian and Sloyd systems were Calvin Woodward and John Runkle. Woodward developed the Manual Training School of Washington University in St. Louis based on the Russian system, and Runkle developed the School of

Mechanic Arts at the Massachusetts Institute of Technology based on the Sloyd system (Cochran, 1970; Hostetter, 1974; Phillips, 1985).

Woodward believed, when combined with literature, science, mathematics, and theoretical mechanics, manual training would raise the machinist to the level of a professional, an accomplished mechanical engineer. Woodward argued this combination of the traditional liberal arts and mechanical arts creates a perfect balance of knowledge needed for inventiveness (Woodward, 1890). Woodward and Runkle advocated for manual training or manual arts to be a new approach to general education, not as a new form of trades development. Runkle (1882) writes that, although not opposed to the idea of trade schools' being included in public schools, there needs to be substantial justification of how it will provide special educational value. Runkle further writes the role of general education is to educate students generally, and the specific technique of their future trade should be learned in after he leaves school.

Throughout the end of the 19th century and into the 20th century, the philosophies of the Manual Training schools and Mechanic Arts schools continued to spread across the United States. Charles A. Bennett, professor and head of the manual arts department at Bradley Polytechnic Institute, argued with the rapid development of industry and industrial products the schools must assume in the role of educating the members of society about the materials, principles, and processes of industry. Bennett (1917) advocates for all schools to include the five areas of industrial arts: graphic arts, mechanic arts, plastic arts, textile arts, and bookmaking arts. It is also evident in Bennett's writings of the discussion within U.S. society about whether manual arts is intended to be vocational or general and whether it is a method of teaching or a subject of its own.

After the turn of the century, there was great debate over the role of vocational education in manual training/arts and its role in public education. In 1914, the Commission of National Aid to Vocational Education was established as a result of the U.S. Congress being split on the debate over vocational education. The commission recommended federal aid for vocational education, which later would lead to the passage of the Smith-Hughes Act in 1917 (Cochran, 1970). After the passage of the Smith-Hughes Act, vocational education programs were being developed throughout the country.

While congress was debating federal funding for vocational education, the debate continued within academia. In response to the absence of educators on the Commission of National Aid to Vocational Education, Dewey (1914/1977) argued public schools should not be turned into pre-factories where the tax levy subsidizes the burden of skill development for employers. Dewey argues public schools should be developing industrial intelligence instead of skill development for the trades. Snedden (1915; 1977), in response to Dewey, argues that publicly supported vocational education is needed to insure that everyone can receive the training needed to be employed. Dewey responds to Snedden in kind, arguing that education is, by nature, vocational. However, Dewey objects to the idea of the limited scope of vocation used by vocational education advocates. Dewey argues that the type of vocational education targeted at children under

eighteen or twenty is a narrowly focused view of vocation, focused on manual labor skills at the expense of high order knowledge.

With the success of the Smith-Hughes Act and the increase in vocational education programs, the National Society of Vocational Education merged with the Vocational Association of the Middle West to form the American Vocational Association in 1926 (Cochran, 1970). Although there was a division within the American Vocation Association, the advocates for general industrial education were unable to organize their own voice until 1947, when the first annual American Industrial Arts Association conference.

Throughout the 50s, 60s, and 70s, a number of researchers and educators attempted to develop curriculum guides to define what should be taught in Industrial Arts. In 1981, the American Industrial Arts Association published its first set of standards, Standards for Industrial Arts Programs. In 1983, the American Industrial Arts Association officially changed its name to the International Technology Education Association (ITEA). In 1985, the standards were revised and renamed: Standards for Technology Education Programs. In 1994, the ITEA began working on Technology for the All Americans Project, in an effort to develop standards for technological literacy. In 2000, ITEA published the Standards for Technological Literacy: Content for the Study of Technology, with a large emphasis on design and problem solving (Dugger, 2008).

Problem Solving in Education

Problem solving, the process of developing a plausible solution to an encountered obstruction, is an important cognitive ability used throughout a person's life. The importance of problem solving is recognized by teachers of English, Mathematics, Science, Social Studies, and Technology as evidenced by its inclusion in their professional association standards (International Reading Association and the National Council of Teachers of English, 1996; International Technology Education Association, 2000; *National Council for the Social Studies, 1994;* National Council of Teachers of Mathematics, 2000; National Research Council, 1996). Despite the apparent importance of the development of problem solving abilities, research on problem solving within the educational community is limited (Petrina, Feng, & Kim, 2007).

The lack of research on problem solving within technology education requires the study of research in other disciplines, particularly cognitive development. One of the areas of problem solving in cognitive development that has received much attention is the area of fixedness. According to Duncker (1935; 1945), functional fixedness is a condition where an individual's problem solving ability is impaired due to a fixation on the common or intended function of an object. Brown (1989) concluded some forms of learning during analogous problems can create a situation of functional fixedness or negative transfer in children as young as two. While other forms of learning are the same, analogous problems can create flexible thinking. Contrary to Brown's (1989) findings, German and Defeyter (2000) concluded that children younger than six have immunity to functional

fixedness. Chrysikou (2006) in a study on insight problems concluded that the use of an alternative categorization task could reduce the effect of functional fixedness.

Purpose of the Study

The purpose of the study is to understand the differences in children's thought processes as they develop solutions to technological problems. The specific aspects of problem solving the study will focus on are: the existence of functional fixedness in technological problem solving, understanding how functional fixedness affects children's development of solutions, and the differences of functional fixedness in children pre-kindergarten to ninth grade.

Statement of the Problem

In general, little is understood concerning the cognitive and developmental dimensions of technological problem solving and, more specifically, there is a debate within the literature on the role of functional fixedness in problem solving.

Research Questions
  1. Are children impacted by functional fixedness when solving technological problems?

  2. How does functional fixedness affect children's solution development?

  3. Is there a difference in functional fixedness in children from pre-kindergarten to ninth grade?

Contributions to Technology Education

The significance of the study is to improve pedagogy and curriculum development within the field of technology and engineering. By having a deeper understanding of the cognitive development of problem solving, educators will be able to improve instructional strategies for teaching students how to be better problem solvers. Secondly, by having a deeper understanding of the cognitive development of problem solving, educators will be able to improve the development of curriculum used to instruct students on problem solving. Finally, by having a deeper understanding of the cognitive development of problem solving, educators will be better prepared to assist individuals in improving their problem solving strategies.

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DIVERGENT THINKING SKILLS IN SCIENCE AND ENGINEERING: INFLUENCE OF GENDER AND GRADE LEVEL

Leah C. Roue
University of Minnesota

Introduction

The current shortage of skilled workers in science and engineering makes it imperative that young students from all segments of our diverse society, particularly those currently least engaged, be attracted into these fields. Accelerating technological advancements and global competition create a demand for a full workforce of creative scientists and engineers. During this time of significant shortage, women are underrepresented in science and engineering. Women constitute a large untapped resource that has the potential to ease the urgent need for skilled workers. This study will examine whether the shortage of females in science and engineering is linked to possible gender-based differences in school-aged children's divergent thinking, an important characteristic in science and engineering and a direct measure of creativity. Such an investigation has the potential to fill a research gap and serve as an aid in teaching and learning about gender-based differences in divergent thinking.

Creativity

Creativity is an essential skill for scientists, technologists and engineers who are at the cutting edge of solving problems and developing new innovations vital to industry and society as a whole. Creative persons and organizations are admired. Martin (2006) describes creativity as discovering or inventing something new, valuable, and purposefully made. Runco (2003) defines creativity as problem solving or thinking that involves the construction of new meaning. According to Guilford (1950), creativity is the ability to be creative and the trait most characteristic of creative people. Creative abilities establish whether an individual has the power to produce creative behavior to a mentionable degree. The study of creativity spans multiple disciplines, making its definition more complex. The field of psychology focuses on the individual and the important components within creativity such as cognitive and personality traits that are native to creative people. Creativity within the realm of sociology has focused on creativity as an environmental task (Tornkvist, 1998). Social psychology has studied the creativity process and its interaction within a given context. The field of psychology focuses on the individual and the important components within creativity such as cognitive and personality traits that are native to creative people. Past research on creativity has focused on enhancement, problem-solving, social influences, education, and personality. The sheer amount of research in creativity has, in turn, increased the rigor behind its evaluation (Runco, 2003). Years of research has brought more agreement and greater quality control, which helps to insure the reliability and validity behind the measurement of creativity leaving less room for bias and speculation.

Creativity is currently high in national priorities, generating summons for support from national science research boards (National Academy of Sciences, 2003; National Science Foundation, 2006). Companies are increasingly aware of the need for creative solutions in order to maintain their competitive edge and respond quickly to market challenges (Baillie, 2002). The products of creative science, engineering, scholarship, art, and design can bring immense benefits to society, as well as give satisfaction to their discoverer. Society is willing to invest in projects and programs that promise creative outcomes (National Academy of Sciences, 2003). History reflects a gender difference in significant creative accomplishments. There have been far more accomplishments, particularly at the highest level, by males in science, literature, arts, music, and technical development than women (Eysenck, 1995). Many researchers have determined factors that influence creativity, but the inconclusive nature of the current collection of research emphasizes the fact that more research is needed to understand gender differences in creativity.

Creativity in Science and Engineering

Creativity is associated with the highest levels of achievement in many fields, and certainly this is true in science and engineering. Creativity has enormous importance in science and engineering (Martin, 2006). Creativity is a key attribute of talented scientists and engineers; people are the engines of creative practice. In the fields of engineering and science, new systems, tools, processes, and equipment are the concrete result of creative acts (Tornkvist, 1998). Engineers develop numerous innovative and creative business solutions today (Fogal,1998). In science and engineering, creativity can result in new predictive theories, new materials, more efficient energy sources, and safer products. The list is endless. Research has shown that creative ability is held in high regard in science and engineering and that constraints may discourage creativity, such as the demand for productivity, competitiveness, and the various external pressures of resources such as time and money.

Mowry (2004), in his article, *The Power of Creativity*, states that creativity is of vast importance to our economy. Creative individuals want to make breakthroughs in their discipline and strive to be inventive. Therefore, creativity serves to advance the disciplines in which a person is creative. Creativity carries the added importance of enhancing one's sense of individual fulfillment. It provides engineers and scientists with a sense of meaning and self-fulfillment, therefore, creativity in science and engineering is a revolving win-win cycle that benefits industry and the individual. Mowry has praised our country's development of and future plans for promoting the creative sector as an important step in the right direction.

Divergent Thinking

Divergent thinking is a direct measure of creativity and an important characteristic in successful advancements in science and engineering. Divergent thinking is defined as an idea-generating process wherein an individual is faced with problems or questions for which there is not just one answer (Guilford, 1950; Runco, Dow & Smith, 2006). It is the opposite of convergent thinking where ideas are eliminated to arrive at a single correct

answer, as in multiple choice questions. Charles and Runco (2001) stated that divergent thinking is indicative of one's potential for creative performance. Integrating creative thinking into professional knowledge to create new ideas is of major importance (Hsiao & Liang, 2003).

The concept of divergent thinking was developed in the 1950s by J. P. Guilford (Gale Group, 2001). According to Guilford, divergent thinking is a key factor in creativity, and he associates it with four main ingredients. The first is elaboration, the ability to think through the details and carry them out. The second is flexibility, the capacity to think about a variety of approaches simultaneously. Third is fluency, the capability to produce a large number of ideas rapidly. The fourth is originality, the expertise to develop ideas different from most people's ideas. There are many possible factors that may influence divergent thinking. Runco, Dow and Smith (2006) identified memory, information, and experience as factors. Thomas and Berk (1981) reviewed the possibility of environment influencing divergent thinking. Reese, Lee and Cohen (2001) and McCrae, Arenberg, and Costa (1987) published research on divergent thinking and age differences in test results. Anxiety has also been shown to influence divergent thinking (Feldhusen, Denny, & Condon, 1965; Wadia & Newell, 1963). Gluskinos (1971) and Russo (2004) studied the influence of grade point average (GPA) and intelligence quotient (IQ) on creativity. The 1960s and 1970s brought about an increased interest in non-cognitive (creativity) tests in an effort to identify gifted and talented students. With this effort came the need for a standardized testing method. Many researchers have created tests, the most popular of which is the Torrance Tests of Creative Thinking (TTCT) (Hsiao & Liang, 2003). This and other tests will be discussed in the literature review in the following chapter.

Tests of divergent thinking use open-ended problems in order to allow the individual to come up with a variety of answers. Researchers use variations in testing instruments and in the scoring methods. One example of scoring measurements is the grouping of responses into three aspects (Runco, Dow & Smith, 2006; Guilford, 1950). Originality is measured by the number of unique ideas presented. Flexibility is the number of categories or themes presented in the ideas. Ideational fluency is the number of ideas.

Shortage of Scientists and Engineers

Success in a global economy is highly dependent on the education and employment of the best pool of workers in the areas of science and engineering. The current shortage is well documented. The number of engineers produced in the United States per capita is proportionately low compared to developing high-tech countries, such as India and China. The population of the United States is about 300 million people, and it produces 60,000 engineers each year (Wei, 2006). India has a population of 1 billion (or about three times that of the United States), and India produces 350,000 engineers annually, or six times that of the United States. China, with a population of 1.4 billion (or about four times that of the United States) graduates 600,000 engineers a year. That is 10 times the number of graduates in the United States (Wei, 2006). Japan trains twice as many engineers and scientists as does the United States (Beech, 2000). Failure to produce

qualified workers means that the United States would be left in a position where it must compete abroad for qualified workers.

Isidore (2007) reports that economists and labor market experts say that job growth and the economy overall would be significantly stronger if employers could find the skilled workers they desperately need. The deficiency of scientists, engineers, and technologists is likely the chief constraint on economic growth. The lack of workers skilled in these areas, in addition to the projected retirement of baby boomers, makes this an urgent problem that, without immediate attention, is certain to compound in the years to come. The workforce shortage in science and engineering would be problematic if needs remained fixed, but the huge growth in these fields compounds the difficulty. Marcus (2000) said that the Bureau of Labor Statistics anticipated that, during the years 2000-2006, the number of computer engineers needed would double. Marcus cited the National Science Foundation, which predicted jobs in engineering would grow at a rate triple that of other jobs. Numerous studies provide statistics proving that women are underrepresented in science and engineering.

Women comprise approximately 50% of the population, yet, according to Science and Engineering Indicators (2008) women held only 26% of non-academic science and engineering occupations in 2005. DeBartolo and Bailey (2007) point out that women comprise fewer than 20% of engineering majors and stress that it is essential for our nation's high-tech industries to increase the diversity of engineering graduates. As business leaders and policymakers seek to address talent shortages, it is becoming increasingly urgent to close this gap and leverage the talents of men and women.

Reed-Jenkins (2003) states that females remain underrepresented in science, technology, engineering, and math careers. Female enrollment in technology-related fields is at the lowest level since 1985 (Treyvaud & Rounds, 2003). "Balancing the Equation" (1998), a press release by the National Council for Research on Women, stated that the United States workforce was comprised of 45% women in 1996 but only 12% of them held science and engineering jobs. The press release also stated that in 1999, women earned less than 20% of computer science degrees, and in 1996, they earned only 18% of engineering degrees. Today's homogeneous male engineering teams are no longer able to deal with the increasingly diverse needs of the customers (Ihsen, 2005). The lack of diversity and the issue of women in engineering holds more and more political and economical relevance worldwide. To survive and thrive, science and engineering must draw from the broadest and most diverse pool of candidates to attract and retain the best skilled workers. A diverse workforce blending genders, cultures, and ages has the advantage of representing a wider customer base in order to translate customer requirements into new and useful products. Another factor in the scarcity of female scientists, engineers, and technologists is the dropout rate of women already employed in the field. Women tend to abandon full-time work at a higher rate than men, but this phenomenon is far greater in these fields (Hewlett, Luce & Servon, 2008). Many factors such as confidence, interests, social influences, perceptions, efficacy, desire to help others, physical abilities and characteristics, have been identified as potential negative influences on women and their lack of participation in these fields and the reasons they

are leaving these fields after entering them (Jacklin 1989; Linn & Hyde, 1989). Identifying these factors has proved beneficial, but we are still struggling toward increased diversity in many fields, particularly science and engineering.

Current research points to perceptions and stereotypes as the greatest obstructions to young females becoming interested and entering the fields of science and engineering. Perceptions have obvious implications that have contributed to low numbers of female participation in technology and engineering. Research shows that females view engineering and scientific fields as "geeky" (Muller, 2002).

> Many girls are turned off by the thought of a career in technology. They are haunted by the image of nerdy male co-workers drinking Red Bull, eating Twinkies and having meaningful relationships with their computers. Sure, we know it's a cliché, but to kids--and especially young girls--image is everything. (Woodka, 2001, Introduction section, ¶ 1)

Based on the current research helping to identify the shortages in science and technology, many programs have been developed to reduce this insufficiency.

President Bush's American Competitiveness Initiative and the Democratic Innovation Agenda are two programs assembled to increase female participation through school funding, scholarships, and grants in science, technology, engineering, and math (STEM). Hundreds of programs, publicly and privately funded, have been implemented in response to this national deficit. Despite the wide recognition of the problem and the programs to intervene, participation of women in STEM is still an issue. Further investigation is necessary to understand the fundamental reasons. Are there other factors beyond stereotypes and societal norms that restrain women's involvement? Do innate differences between males and females play a larger role than is currently understood?

Statement of the Problem

There is a shortage of scientists and engineers at a crucial time when technological innovation depends on the involvement of our nation's best and brightest, representing all segments of our diverse society. Women comprise approximately 26% of the college educated workforce in science and engineering occupations (Science and Engineering Indicators, 2008). Sanders (2005) stated that women's lack of participation can only be measured in jobs not filled, problems not solved, and technology not created. Engineering must attract young people who are seeking stimulating and creative work (Wulf, 1998). "Diversity is the gene pool of creativity" (Wulf, 1998, p. 23). Creativity is at the heart of engineering and science and is essential to scientists and engineers who are responsible for developing many of our most innovative and creative business solutions today (Fogal, 1998). Divergent thinking is a well accepted component of creativity (Charles and Runco, 2001) and is central to its measurement. Understanding creativity and divergent thinking has the potential to shed light on the underrepresentation of women in science and engineering. Few studies have been conducted which analyze creativity in underrepresented groups and most have revealed contradictory findings (Matud,

Rodrıguez, & Grande, 2007). Limited research has been conducted to determine whether there are fundamental differences between boys and girls in the area of creativity and its key component, divergent thinking. Divergent thinking is a critical dimension of inventiveness in science and engineering related creativity.

The Study

This study will compare gender and age differences in divergent thinking among middle school and high school students in the Midwest using the figural Torrance Test of Creative Thinking (TTCT). Approximately 100 students from middle and high school, a total of 200 participants, will participate. Results will be scored and analyzed by the researcher. The middle school students and the high school students attend public schools where they are engaged in the engineering curriculum option offered at the schools. The middle school acts as a feeder school for the high school pre-engineering program. Participants will be given the Figural Torrance Test of Creative Thinking, a measurement of divergent thinking. Results will be analyzed in an attempt to determine whether there exist gender-based or age-based differences in divergent thinking:

Research Questions

1. Are there gender differences in:
  a. Originality of responses?
  b. Fluency of responses?
  c. Abstractness of titles in the responses?
  d. Elaboration of the responses?
  e. Resistance to premature closure?

2. Do age differences exist in:
  a. Originality of responses?
  b. Fluency of responses?
  c. Abstractness of titles in the responses?
  d. Elaboration of the responses?
  e. Resistance to premature closure?

Variables and Their Measurements

Five main independent variables are present in this study of divergent thinking. *Originality*: Responses are measured for originality using norm referencing. The tested individuals' responses are compared to their peers. For example, if a response has been given by only 5% of the participants, it receives one point. If the response has been given by less than 1% of all respondents, the answer gets 2 points. The points are then totaled, and the higher the score, the more creative the individual. *Fluency*: Fluency is rated as the overall number of responses given to a question. Previous research has pointed out that there have been cases in which a participant's responses could be considered repeats. Some answers that are expressed differently can have the same translation. In scoring the responses, the rater must pay close attention to avoid counting duplicate answers more

than once in order to comply with the TTCT streamlined scoring guide. ***Abstractness of titles:*** In order to measure the abstractness of titles, also referred to as flexibility, all responses are categorized. The number of categories measure one's flexibility. To clarify, if a participant is asked to name things with wheels, and their responses were a car, a truck, a bike, and your mind, they would get a flexibility score of two. One point is for responses that fit into the category of transportation, and the second point is for the non-transportation category, "your mind". ***Elaboration:*** This is the level of detail presented. The responses will be given no points for no detail and one or more points for details within the response. ***Resistance to premature closure:*** This variable measures whether the respondent kept an open mind while processing information, a requirement of divergent thinking. It should be pointed out that the nature of creativity and the reliability of current measurements are still under debate by many, even after 50 years of work in the area (Russo, 2004). The lack of agreement in this area is often attributed to the multidimensional nature of creativity. It is thought, however, that divergent thinking and its measures, originality, fluency, abstractness of titles or flexibility, elaboration, and resistance to premature closure, are vital to the study of creativity (Torrance, 1981). Chapter 3 will provide more information on each of the factors and the measures used in scoring.

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DESIGN TWICE, BUILD ONCE: TEACHING ENGINEERING DESIGN IN THE MIDDLE AND HIGH SCHOOL CLASSROOM

Shawn Jordan and Nielsen Pereira
Purdue University

Abstract

Hands-on learning experiences and interactive learning environments can be effective tools for teaching K-12 students. Design, in essence, is an interactive, hand-on experience. Engineering design can be taught in the classroom using hands-on projects, such as designing and building Rube Goldberg-style machines that complete a task in complex ways. Rube Goldberg activities serve to teach design, promote creativity, and prove opportunities for hands-on problem solving, in addition to giving students experience working in cooperative teams. In turn, these experiences could encourage students to consider engineering as a possible future career.

This paper explores preliminary findings from data collected during the authors' recent experience teaching a group of fifteen gifted and talented students in grades 4-6 enrolled in a 6-week Saturday enrichment program to design and build Rube Goldberg machines. A scaffolded engineering design process was used to guide groups of 3-4 students through the project. Students took on defined roles in order to promote teamwork. This paper will present both aspects of the course that worked well and areas for improvement, in addition to surprises encountered along the way. Finally, thoughts on migrating the class to high school students will be discussed.

Introduction

Rube Goldberg activities have been used in classrooms throughout the country for many years. Despite their use, little research has been done to understand how they should be used for maximal benefit. The class described in this paper as a "report from the field" and the associated research in progress are unique because they apply an engineering design process to the teaching of Rube Goldberg machines. In the education space, this study incorporates participants who have ADHD, anxiety disorders, and mild autism.

Class Background

Saturday enrichment programs can be an alternative strategy for gifted children who need more advanced content in a specific field. Children are usually taken to programs outside of regular schools, such as university camps. This type of programming offers several benefits to gifted students, such as exposure to advanced content in diverse subject areas, highly qualified instructors, and interaction with like-ability peers in a learning environment where the students feel safe to be themselves (Davis & Rimm, 2004). Special gifted programs can also provide affective gains in participants' self-esteem, self-efficacy, and academic motivation and these gains may lead to success in school after attending such programs (Olszewski-Kubilius & Grant, 1996).

Super Saturday is an enrichment program for children in grades P-8 that takes place at Purdue University's main campus, in West Lafayette and is sponsored by the Gifted Education Resource Institute (GERI). Super Saturday and similar programs meet some needs of gifted children that schools do not usually deal with and those include achievement of basic concepts and skills to their maximum; adequate pace and level of activities; improvement of self-awareness and of the understanding of one's own ability level, interests, and needs; increase in independence; self-direction and discipline in learning (Feldhusen & Wyman, 1980). Parents of students in the class are informed that the classes are challenging and that students who do not show high-ability or interest in the topic of the class may not be able to benefit as much from the program.

Class Goals

This class sought to teach engineering concepts and meet the needs of high-ability students. Our first specific goal was to have students work together in small groups in an effective way. The students' second goal was to understand and be able to apply an engineering design process to a problem. Their third goal was to understand the science and engineering concepts used in Rube Goldberg machines. The last goal was to build the machine they designed.

Class Outline

The course had a total of eighteen hours divided in six different Saturdays. During the first class, we had a brief introduction of the class, and students filled out a brief pre-assessment and an interest inventory. We had an introduction to mechanics concepts and some brainstorming aimed to encourage students to exchange ideas freely and to learn to work in groups. Students, also, worked on the design of the first module. We initially had the goal of having a structure for the class so that groups of students would work on a module at a time and would integrate their modules and test them before final presentations. Our initial plan was to have them create one module in about 3-4 hours and always to follow an engineering design process, that is, students would have to first, design, then build, and, finally, test their modules. During classes 2 and 3, students worked on the design of the first module, built, and tested this module. We had a brief introduction to electricity, magnetism, fluid mechanics, some brainstorming and design for the second module.

The fourth class was used to finish the design, build, and test the second module. Most of the groups could only finish their second module by the end of class 4, so they had to use class 5 for building and working on the integration of modules and testing of their machines. During class 6, groups had to reassemble their machines and test them again before final presentations to family members and classmates.

Participants

The participants in this study were fifteen students in a Saturday enrichment class in grades 5-6. Students in the program, typically, attend local schools in the greater Lafayette area, but some come from other cities in Indiana. Four of these students were part of a GERI initiative to bring low-SES children to gifted programs, Project HOPE, and that made our sample even more diverse and representative of the different types of communities in Indiana, such as rural, suburban, and urban locations. There were twelve boys and three girls.

Research Questions

This study seeks to explore the following research questions:

1. How effective is teaching an engineering design process to 5th and 6th grade gifted students?

2. How do group interactions influence design process outcomes?

3. How can an engineering design process be taught to 5th and 6th graders?

4. How do design ideas generated by 5th and 6th graders evolve across different stages of the design process?

5. What effect do design artifacts have on final products?

Methods of Data Collection

A variety of data was collected during the class. A student interest inventory, conducted on the first day of class, provides a glimpse into what the students like to do. A pre-assessment, also conducted on the first day of class, was used to determine the background each student had with Rube Goldberg and related activities. The brainstorming processes had artifacts in the form of written lists and sketches that were collected. Design sketches were also collected, as well as the final posters that teams made including sketches of the final machine design and a written sequence of steps. Pictures were taken throughout the class, and videos of the final demonstrations were made. Finally, the two instructors kept reflective teaching journals. These data were collected and electronically stored (e.g., the sketches were scanned) in a master file during the class.

Preliminary Results

Formal analyses of the data are in progress. An early look at the reflective teaching journals reveals some interesting trends. First, teamwork was a challenge for the students. Gifted children often prefer working alone than with others, and this class was no exception. The notion of individual roles in teams was introduced in order to facilitate

better teamwork, but the students did not adopt the roles well and usually fell back into each person working independently.

Second, the design process was difficult for the students to use. The students wanted to come in and build the entire time without doing any design work. They, also, did not want to document anything they did before, during, or after they built it.

Finally, maturity of the children was an issue throughout the class. Many of the students had trouble focusing on the activities for long periods of time without getting distracted. This did not appear to be due to a lack of interest, but rather a lack of attention span. Additionally, structure was a problem. The environment was reasonably structured, but the students had trouble remaining within the structural bounds of the class.

Recommendations and Remarks

For those considering implementation of a hands-on project like this in a high school environment, we definitely recommend a strong connection between research and practice, with an emphasis on informing each from the other. Long term goals do not seem to hold the attention span of kids as much as shorter, moderated goals. Checkpoints can help give students something to work toward. An engineering design process may be somewhat tedious for students to use but can be motivated by using problems that are too difficult to solve without design.

The Next Iteration

The class will be offered in a summer residential program for high-ability learners in the summer of 2008 with some improvements based on the first experience. The participants will be 10-14 students who were in 7th or 8th grade in the 2007/2008 academic year. There will be a total of 30 contact hours, and some of the changes we plan include providing more scaffolding to the groups. The first project will involve building a pre-designed machine. The engineering design process will be introduced only after students have finished the first project. For the second project, groups will be given input and output specifications for their modules and will have to design and build these and later integrate them in a 'whole-class machine.' The third project will challenge students to complete the whole engineering design process and brainstorm, design, and build each module, and then integrate these.

Another change will be for each group to work on a different module at a time. These modules will, then, be integrated in 'whole-class projects', thus, providing students with short-term goals and also allowing them to work as a class toward a common goal.

Conclusion

This work in progress seeks to further illuminate the question of how to teach an engineering design process to kids through the design of Rube Goldberg machines. Preliminary results indicate that kids have trouble working in teams, applying a design

process, and demonstrating sufficient maturity to focus and manage their own schedule toward an abstract goal.

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ACADEMIC PERFORMANCE AS A PREDICTOR OF STUDENT GROWTH IN ACHIEVEMENT AND MENTAL MOTIVATION DURING AN ENGINEERING DESIGN CHALLENGE IN ENGINEERING AND TECHNOLOGY EDUCATION

Nathan Mentzer
Utah State University

The purpose of this correlational research study was to determine if a student's academic success is correlated with: 1) the student's change in achievement during an engineering design challenge; 2) the student's change in mental motivation toward solving problems and critical thinking during an engineering design challenge. Multiple experimental studies have shown engineering design challenges increase student achievement and attitude toward learning, but conflicting evidence surrounds the impact on higher and lower academically achieving students.

A classroom was chosen in which elements of engineering design were purposefully taught. Student participants represented a diverse set of academic backgrounds (measured by GPA). Participants were measured in terms of achievement and mental motivation at three time points.

Multilevel modeling techniques were employed to identify significant predictors in achievement growth and mental motivation growth during the school year. While initial analysis is in progress at this publication date, interesting factors have evolved. Achievement change is not significantly related to GPA. Mental motivation change is generally not related to GPA.

The Standards for Technological Literacy (STL), include engineering in general, and engineering design, specifically. This paradigm shift to include engineering content in technology education curricula demands the field identify successful approaches to teaching engineering at the high school level. "Design appropriate for technology education is characterized by open-ended problems where the designer bridges the gap between past experiences and the current problem to be solved; one method of achieving this transition is through engineering design challenges" (Lewis, 2005, p. 49).

In the past 15 years, 13 studies have been published which focus on the efficacy of engineering design challenges. Student achievement was unanimously improved at the conclusion of each engineering design challenge. However, upon closer inspection of the disaggregated results, a troubling conflict surfaces. Cantrell, Pekca and Ahmad (2006) concluded that engineering activities reduced achievement gaps of most ethnic minority groups. In contrast, Weir (2004) considered an academic upper and lower half in a university engineering course. Weir's conclusion that engineering challenges actually extend the achievement gap by improving the academically successful students disproportionately to lower achieving students must be further investigated due to its potentially damaging educational impact.

Nine of the 13 studies considered attitudinal measures, and each showed improvement. However, validity and reliability of these instruments was questionable. For this study, the validated California Measure of Mental Motivation (CM3) was used.

Technology Education has typically been a curricular area where a broad range of students can be successful, from the academically gifted students to the academically challenged students. Engineering, traditionally reserved for the academically elite students, will be intersecting a broad cross section of the general education populace. This interface necessarily includes a subset of students who are challenged by traditionally "academic" material. Therefore, the purpose of this study was to investigate a correlation of a student's general academic history with achievement and mental motivation during an engineering design challenge.

A classroom was identified in which a physics teacher partnered with a technology education teacher to infuse and apply engineering concepts. This junior level, high school course includes an academically diverse array of students and provides a semester long engineering design challenge.

In order to address this research question, a repeated measures correlation study was conducted in which data were gathered on student achievement and mental motivation. Trends and changes during the year were compared to a general indicator of each student's academic history.

Data analysis was conducted using multilevel modeling techniques. Achievement scores did not significantly change over time. Statistically significant predictors in this model are special education status, GPA in previous science courses, and the CM3 subscale of creative problem solving. Special education students tended to perform under their peers. Students who maintained a higher science GPA and students scoring higher on creative problem solving tended to demonstrate an increase in achievement scores.

As published with the CM3, a student scoring high in mental focus is diligent, focused, systematic, task-oriented, organized and clear-headed. Mental focus scores increased significantly over time. Statistically significant and positively correlated main effects are GPA in math and science and time. A significant negative interaction was discovered between time and science GPA.

A student scoring high in creative problem solving has a tendency to approach problem solving with innovative or original ideas and solutions according to the CM3. Creative problem solving scores increased significantly over time. Statistically significant and positively correlated main effects are GPA in science and time.

As published with the CM3, a student scoring high in learning orientation is motivated by the desire to increase knowledge and skill base. A high score in cognitive integrity represents motivation to use thinking skills in a fair-minded fashion, seek the truth and be

open-minded. Neither learning orientation nor cognitive integrity scores changed significantly over time or had any statistically significant main effects.

A student scoring high in scholarly rigor was inclined to work hard to interpret and achieve a deeper understanding of complex or abstract material according to the CM3. Scholarly rigor scores did not change significantly over time. The statistically significant and positively correlated main effect was GPA in science.

Student achievement is significantly correlated with science GPA, but not math or communication GPA. Changes in achievement score over time are not significantly correlated with science, math or communication. Mental Motivation was measured by five subscales. Mental focus was correlated with both math and science GPA. Mental focus increases over time were negatively correlated with science GPA indicating that the initial score differential (between higher and lower science GPA students) was decreased over time. Learning orientation and cognitive integrity were not correlated with GPA. Creative problem solving was correlated with science GPA, but gains over time were not correlated with GPA. Scholarly rigor was correlated with science GPA, but change over time was not correlated with GPA.

Knowledge of a student's status as an underrepresented population in engineering and technology education improved model fit statistically for each outcome considered. While this predictor significantly improved the model, it was not a statistically significant predictor. Chance alone may be responsible for the necessity of this predictor in the model, or a large variance may be masking discovery of an important correlation.

The field of technology education embraces the importance of technological literacy and caters to a diverse audience of student learners. Engineering design is an important aspect of technological literacy. An understanding of science (measured by GPA) is positively correlated with student achievement in this course. Most importantly, a change across repeated measures shows no significant correlation to math, science or communication GPA. This indicates that students will not be proportionately advantaged or disadvantaged over time by their previous academic successes.

Mental motivation subscales demonstrate that GPA in science correlates with the scores in mental focus, creative problem solving and scholarly rigor, while math correlates only with mental focus. Each of the five subscales demonstrated a mean increase from pre- to post-testing with mental focus and creative problem solving being statistically significant. This increase over time was generally not correlated to GPA in math, science or communications. This indicates that students who are struggling academically and their higher achieving peers have an equal tendency to increase their mental motivation scores. In the case of mental focus, the impact of GPA in science was negatively correlated with time which means that the gap between low and high achievers is reduced over time.

Secondary technology education teachers should infuse engineering into their curriculum understanding the concepts surrounding the application of engineering design. This study indicates students of varying academic backgrounds will each experience a level of

success which may vary, but change over time will not serve to increase the achievement or motivation gap.

Further research should be conducted to better assess student achievement change over time. This study showed no significant gains in achievement and, therefore, conclusions and implications on achievement change should be conservatively considered.

Additional research should investigate potential correlations of general academic success with achievement and mental motivation for underrepresented populations. In each outcome, it was important to control for this status, but differences were not significant. This recurrent theme necessitates further investigation.

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A STUDY OF FACTORS AFFECTING CAREER DECISION-MAKING SELF-EFFICACY AND ENGINEERING RELATED GOAL INTENTIONS AMONG AFRICAN AMERICAN HIGH SCHOOL STUDENTS

Chandra Austin
University of Minnesota

Introduction

The idea of disproportionate education is not recent. It has been around for decades, stemming from what some call the involuntary citizenship as a result of slavery. "In the past, black Americans, for example were given inferior education by formal statues in the South and by informal practices in the North" (Ogbu, 1987). Parents were taught by oppressors to say to their children that there were certain spheres which they should not enter because they would have no chance for development (Woodson, 1990). However, during an era of segregation came a well-known case entitled Brown vs. Board of Education, which gave hope that racial integration would correct the inequalities and underachievement of minority students (Freeman, Brookhart, & Loadman, 1999). But in this new century, while schools have become integrated as bodies, the content students are offered is still in a segregated state, as are expectations about student destinations. In this research study this will be done by looking at factors currently influencing educational aspects, but I must first start with the historical roots.

History of African American Education

The idea of institutional racism that stems from slavery is believed currently to affect the educational system. Institutional racism can be easily defined as the hierarchical conception of intellectual ability (Denbo & Beaulieu, 2002). Institutional racism has the inherent ability to promote the notion of inferior mental ability and often results in practices such as academic tracking. When tracking is done, it is often as a result of the focus on individual and cultural characteristics of students rather than the ways that the social system structures academic success and failures for varying groups.

Shaffer, Ortman, and Denbo (2002) stated that to understand fully African American student achievement, it is essential to take into consideration the historical context of racial oppression and current conditions in schools. Since there has been, in reality, a divide in ethnic and racial groups, the longing affect that students have suffered must be interpreted. Longstreet (1978) notes that ethnic groups are unique in several different ways: verbal and nonverbal communication, social value patterns, and intellectual modes. With this knowledge, one can conclude that it is virtually impossible to educate different ethnic groups in the same manner (Davenport, 1981). However, even within ethnic groups, there appears to be some disparity with education. Urban students have less access to a variety of educationally important resources, such as small class sizes, highly qualified teachers, computers, advanced level courses, and other curriculum supports (Darling-Hammond, 1997). Middle-class African American students are an example of students who, although they are equipped with more resources, may feel that excelling in

school, while their lower income counterparts are not, is betraying their true identity (Shaffer, Ortman, & Denbo, 2002). Regardless of the disparity, Apple (2004) agrees that schools contribute to the imbalance of power in society by communicating society's economic, political and cultural knowledge to students.

In this study, I hope to explore why more African Americans are not participating in engineering and offer solutions that may attend to the specific barriers these students perceive. This will be done by looking at a broad prospect of educational influences, then narrowing the specific field with the specific population.

Engineering

In the context of engineering education, it is worthwhile to look at the views of Booker T. Washington and William E. B. DuBois. Washington and Du Bois recognized the value of education and recognition of the necessity of black participation in skilled trades (Wharton, 1992). The controversy came in the differences of their approach to leadership and dominance, and philosophies regarding black higher education. Booker T. Washington was born a slave and did not begin his formal education until after the Civil War when he was freed. However, in relation to vocational education, in many instances, Washington foreshadowed the well-known John Dewey by two decades (Gordon, 2008). Washington thought in order for people to gain satisfaction in education, they must give service to other. One way he implemented this belief as president of Tuskegee Institute was to require students to do some form of manual labor as a part of the curricula. Unfortunately, many believed that much of Washington's views forestalled the involvement of African Americans in engineering by almost three decades. This belief was held due to the inferior nature Washington promoted to African American youth. He condemned bright, young minds to vocations beneath their ability, thereby, reinforcing inferiority (Wharton, 1992). Washington's educational philosophy was not designed to produce individuals who would be able to compete with whites for jobs, but to instill in African Americans the glory of being manual laborers (Gordon, 2008; Wharton, 1992).

William Edward Burghardt DuBois was born in Massachusetts to a French mother and Haitian father. Unlike Washington, he was born a free man. Their different backgrounds, their lives and educations, can be said to have been the source of their differences on education for African Americans. Du Bois denounced the work of Washington. He did this by promoting black worth, giving hope and inspiration to those who wanted to pursue engineering as well as other subjects. Du Bois created a notion referred to as the "talented tenth". This was the small percentage of blacks who were endowed with talents and brains to lead the race to self-sufficiency. He insisted that the college trained elite could lift the lower class. He felt success would come from the development of mental faculties.

Contrary to the fact that Booker T. Washington and W. E. B DuBois held different beliefs about vocations and engineering, both can be viewed to have enhanced the African American population in their own way. Engineering is believed to be a vocation which combines the characteristics of science, art, and business. It involves knowledge of the

forces and materials of nature, an understanding of men, and an understanding of economic and social relations (Dowing, 1935). But the history of engineering is slightly different from what is considered the early vocations. The early curriculum in American colleges of engineering was still considered an alternative to what was viewed as the traditional classical discipline. In early America, unlike the fields of medicine and law, engineering education had never been under the exclusive domain of a professional group, the curriculum created strictly by educators (Grayson, 1980). Therefore, those who were not engineers and knew little of the content in which it entailed had enormous input to shaping the field of engineering. As a result, the early engineering curricula contained little technique of engineering practice. Prior to WWI, few opportunities existed for blacks to work in engineering fields. But there were in existing African American schools that educated some. Specifically, the first black engineers to graduate from black schools came from Howard University, North Carolina Agricultural & Technical State University, and Hampton University. More importantly, these schools are still revered for continuing to educate African American students in field such as engineering.

The importance of educating African Americans was stated in the 1930's and is still being restated well into the 21st century. The U.S. has lost some technological ground and will continue to do so if everyone is not provided an equal opportunity to advance in all areas. Some have gone so far as to say that African Americans are not well educated in the field of engineering because the information they are obtaining is not relevant. Woodson (1933) concurs by stating that, "African Americans do not need someone to guide them to what persons of another race have developed, they must be taught to think and develop something for themselves". Or, some may go further back to say that, during slavery, African Americans developed a source of dependency, and now it is their job to grow out of it. Regardless of what the source of this disparity in education, all would agree that it is something that needs to be reconciled. As stated in the previous sections, the idea of curriculum, teacher influence, etc. are not new concepts. These are just concepts that have not been readily adapted as they relate to African American students.

Rationale

 The National Science Foundation (NSF) in 2006 reported that 5.2% of engineering degrees were awarded to African Americans. Although schools today are not deliberately designed to achieve classist or racist ends, through research, most schools and educators are often found to be contradicting (Apple, 2004).Research shows that the current education of African Americans is unequal to that of white students (Norman et al., 2001). However, there is an absence of literature focusing on the field of engineering, specifically. By studying the career decision-making, self-efficacy and engineering goal related intentions these students have as a result of a variety of factors, I hope to gain insight as to why African American students are absent from the field. From this insight, the educational field will be able to gain a better understanding as to how to enhance the educational efforts in assisting with the preparation of African Americans in the field of engineering. In addition, some encouragement factors may be obtained based on what the students view as their perceived needs in order to prepare for such a field. Lastly, if the

factors that influence engineering career decisions are identified, educators will better understand how to foster and develop a culturally responsive environment for African American students. With the birth of a different environment, students may be more inclined to engage in the study of engineering. Knowing how to educate and mediate certain variables that can encourage entrance into engineering will contribute to an increase of minorities, particularly African Americans.

Statement of the Problem

This study intends to fill a gap in knowledge as to why African American students are not entering engineering. Little is known about the engineering career decision-making and related goal intentions among African American students. Specifically, predictors of career decision making self-efficacy and engineering goal intentions are not well researched. Currently, there is a lack of studies of students' perspectives of perceived barriers impacting their choice of a career in engineering. Underutilization of minorities in science and engineering is a problem of national priority (Leslie et al, 1998), and if America is striving to maintain its global competiveness in the world, we must try to educate as many people in different areas as possible.

Theory

There are a number of theories suggesting possible predicting factors of adolescent career decision making. The first theory is the self efficacy theory developed by Albert Bandura. Bandura's (1977) self-efficacy theory makes the assumption that personal self-efficacy is based on four major sources of information: performance accomplishments, vicarious experiments, verbal persuasions, physiological states. Bandura's theory is valuable because a variety of studies have found a link between self-efficacy and the ability of adolescents to make decisions about careers (Lent et al., 1986; Lent & Hackett, 1987; Taylor & Betz, 1983). A second and important theory that will be used and is a by-product of the Social Cognitive Theory (Bandura, 1986) is the Social Cognitive Career Theory (SCCT) developed by Lent, Brown, and Hackett (1987). This theory is essential because its main purpose is to construct connections from other theories which will then identify a better explanation linking those variables that may influence career development (Brown et al, 1996). A third theory that will be used in this study is Super's developmental self-concept theory of vocational behavior. In this theory, Super (1954) asserts that people attempt to apply their self-concept by choosing a career that permits self-expression. He goes on to make the claim that a person's behavior reflects that individual's particular life stage which is not the same in adolescence and adulthood (Osipow, 1983). Super's theory is vital because self-concept and vocational development have proven to be important factors and could influence the creation of more compatible curriculum for African American students. A fourth and last theory that will be referenced is Holland's (1959) Career Typology Theory of Vocational Behavior. In this theory, Holland holds that career choices represent an extension of an individual's personality (Osipow, 1983; Sauermann, 2005). He states that people identify their views of themselves by an occupational title. Holland's theory is influential to this study particularly because of the suggestion that he makes in how people choose careers. If, in

fact, people choose careers where they believe they will be surrounded by people like themselves, the education field needs to develop a strategy to attract African American students. The conclusion could be easily drawn that African American students do not enter engineering because they do not feel that sense of likeness. Although these theories are regarded as important, few of them have been applied to minority populations, specifically, those focused on African American youth. Since African American students are the population which seem invisible in the field, the relationship between theory and reality needs to be established in the field of engineering.

Important Studies

Some of the important literature that will be used to develop variables are laid out in this section. However, the variable development is not strictly limited to these existing studies. Navarro (2007) used a modified version of the Social Cognitive Career Theory to examine whether sociocognitive variables explained math/science goal in Mexican American middle school students. Although this study was done at the middle school level, it is still beneficial to the current study in that it observes an underrepresented minority group. Also, Navarro et al. more specifically found that within this population, math/science interest and goals could be predicted by math/science self-efficacy and outcome expectations. Fouad and Smith (1996) also conducted a study using middle school students and found interest had a relationship with self-efficacy, outcome expectations and intentions. At the end of their study, they noted that more research is needed to test the influence of race and ethnicity as a variable affecting these same variables . Gushue (2006) evaluates the relationship of ethnic identity to career interest and outcome expectations among Latino students. This was identified as a key study again because it involved minority students but also because it studies career decision-making self-efficacy as a key variable. He found that ethnic identity had a direct and positive relationship with career decision-making self-efficacy. A connection between race/ethnicity and career aspirations and decision making was also found by Flores et. al, (2006) and Kenny et al.(2007).

 Hargrove et al. (2002) explored the relationship between family interaction patterns and vocational identity and career decision-making self-efficacy. The researchers found that family interaction patterns play a significant role in the promotion of self-confidence as it relates to career planning. The study also found that family interaction patterns play a role in the formulation of career goals. Lent (1991) and Betz and Hackett (1983) are long time researchers of sociocognitive variables. But, they specifically did a study that examined the relationship between math self-efficacy and science-based college majors. From the results, they were able to conclude that math self-efficacy was significantly related to choosing a science based major. They went on to postulate that this selection of major directly resulted in the career choice within the same field.

Research Questions

There are three dominating research questions that guide this study. The questions will be evaluated using quantitative methods.

1. To what extent are exogenous (family relations, demographic factors, school factors) influential on the dependent variables?

2. To what extent are endogenous (interest, ability, ethnic identity, and math/science self-efficacy) variables influential on the dependent variables?

3. To what extent are exogenous and endogenous variables influential on each other?

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IMPACT OF MENTORSHIP PROGRAMS ON AFRICAN-AMERICAN HIGH SCHOOL STUDENTS' PERCEPTIONS OF ENGINEERING

Cameron D. Denson
University of Georgia

Abstract

The following study seeks to measure the effectiveness of mentorship programs to influence African-American male high school students' perceptions toward engineering after participating in a college-based mentorship program with mentors who are active members in the National Society of Black Engineers (NSBE). In this study, indicators of students' perceptions included students' career awareness of engineering and self-efficacy in the area of math and science. This study used a two-group, posttest only, quasi-experimental design. Following participation in NSBE's mentoring program, the treatment for this study, a survey was used to collect data to answer the following research questions:

Research Questions

1. Is there a significant difference in career awareness of engineering disciplines for students who participated in NSBE's mentorship program when compared with non-mentored students?

2. Is there a significant difference in self-efficacy in the area of math for students who participated in NSBE's mentorship when compared with non-mentored students?

3. Is there a significant difference in self-efficacy in the area of science for students who participated in NSBE's mentorship when compared with non-mentored students?

Introduction

The proposed study sought to measure the effectiveness of the mentorship program currently utilized by the members of the National Society for Black Engineers (NSBE) when matched with African-American male students from the Middle College at North Carolina Agricultural and Technical State University. The researcher chose to focus on the social interactions of mentorship programs and their potential to influence participants' perceptions. Although previous studies have documented the effectiveness of mentorship programs, a recent literature review suggested that there is a lack of literature on mentoring that is based on experimental designs (Underhill, 2005). Using a posttest-only control group design, this research provided a comparative study on the effectiveness of mentorship programs for underrepresented populations.

Research Design

This quasi-experiment utilized a two-group, posttest only design, which framed the research (Campbell & Stanley, 1997). This research design is useful in studies where the administration of a pretest may influence the participants' behavior during the experiment or on the posttest (Gall, Gall, & Borg, 1996). The effects of the treatment administered can be measured by comparing the posttest scores of two populations. This research design is appropriate when trying to influence a stable characteristic such as students' perceptions towards engineering.

The dependent variables were identified as students' perceptions, which included students' career awareness of engineering disciplines and self-efficacy in the area of math and science. The mentorship program in which the students participated represented the treatment for this study. Mentorship in this study has been defined as "a structured mentoring relationship…with the primary purpose of systematically developing the skills and leadership abilities of less-experienced members of an organization" (Murray & Owen, 1991, p. 5). This research study has been carefully designed and should yield useful information that can be generalized within margins to the target population of male high school students attending the Middle College at North Carolina Agricultural and Technical State University (North Carolina A&T, hereafter).

Random assignment was used in this study to select participants, thus, allowing all African-American male students attending the Middle College at North Carolina A&T an equal opportunity to be selected for the study. Participants completed an evaluation of mentorship program at the conclusion of the study in an effort to monitor and better facilitate the mentorship program. Data analysis consisted of performing analysis of variance (ANOVA) tests on the acquired means through independent sample t-tests. Analysis of variance is highly effective when a researcher is interested in comparing and contrasting the mean of two or more samples without increasing the chances of having a Type I error. ANOVA allows the researcher to see if differences in the variable of interest between groups are due to chance, or if there is a significant group effect. It reports very little else about the nature of that relationship, however, it does reveal whether a significant difference exists between groups.

The survey consisted of 31 closed-ended questions using a 4-point Likert-type scale response whose range consisted of: Strongly disagree=1, Disagree=2, Agree=3, Strongly agree= 4. The survey was designed in an effort to gain information about students' perception toward the technical field of engineering. Perceptions included students' career awareness of engineering disciplines and self-efficacy in the area of math and science. Participants were not asked to put their name on the survey, thus, protecting their anonymity. At the time of the test, participants were notified of their rights of anonymity. Demographic information of the participants was collected at the end of the survey during the evaluation phase, only identifying the participant's age (at last birthday), grade level and respective mentor. This descriptive data will help aid in forming group categories for data analysis.

Results - Demographics

Approximately 24 male students (N=24) out of the 83 Middle College students were randomly selected to participate in the study. The treatment group (n=12) consisted of students who participated in the NCETE/NSBE mentorship program, and the control group (n=12) consisted of students attending the Middle College who did not participate in the mentorship program. The sample consisted of predominately Black/African-American (95.8%) and male (100%) students. The grade level break down is as follows: 8 students, or roughly one-third of the participants were freshman (33.3%), 6 participants were sophomores (25%), 4 participants were juniors (16%), and another 6 participants were seniors (25%).

Of the 24 students who participated in the study, 21 surveys yielded useable data. One student was considered an outlier due to the fact that his ethnicity was determined to be White or Caucasian. Another student did not complete the survey, bringing the total number to 22. Upon further analysis, one participant's responses were deemed invalid and unreliable. The markings on the paper and pencil test clearly demonstrated that the participant did not complete the survey to the best of his knowledge, which posed a problem for validity of the results. With 21 valid entries to compare, the researcher randomly eliminated one participant to ensure an even number of participants for the control and experiment groups. The total number of useable data resulted in N=20.

1. Is there a significant difference in career awareness of engineering disciplines for students who participated in NSBE's mentorship program when compared with non-mentored students?

An independent sample t-test was used to compare the means for each construct and determine differences that were statistically significant. For awareness of engineering principles, the mean score for the experimental group was 40.30 and 38.40 for the control group. Standard deviations were 5.72 for the control group and 3.95 for the experimental group. Although the experimental group produced a higher mean score than the control group, these results were not statistically significant at an alpha level of .05 (p=.236).

2. Is there a significant difference in self-efficacy in the area of math for students who participated in NSBE's mentorship when compared with non-mentored students?

Using the same analysis techniques as described above, results are provided for participants' self-efficacy in the area of math as it relates to engineering. For self-efficacy in math, the control group yielded a mean score of 23.3 and 22.6 for the experimental group. The standard deviation for the self-efficacy in math was 3.75 and 3.62, respectively. Though there is a slight difference in the mean scores of the control and experimental group, these results failed to reach significance (p=.931).

3. Is there a significant difference in self-efficacy in the area of science for students who participated in NSBE's mentorship when compared with non-mentored students?

In a comparison of mean scores for students' self-efficacy in science as it relates to engineering, an independent sample t-test yielded the following results. The experimental group produced a mean score of 28.10, and the control group produced a mean score of 25.80. The standard deviation for each group was 4.12 and 3.96, respectively. The experimental group produced a mean score more than two points higher than the control group, however, further analysis determined that this research question did not produce a difference that was determined to be statistically significant (p=.924).

Conclusions and Implications

Past studies have failed in their evaluation of formal mentorship programs, which is evident by the lack of comparative studies that look at mentorship programs. The following study was instrumental in providing a blueprint for evaluating the impact of formal mentorship programs to influence the self-efficacy of students. By providing quantitative and qualitative data analysis, this study has the potential to provide valuable data for researchers looking to increase the retention and recruitment of underrepresented populations in engineering fields through mentorship programs. Although the survey failed to reveal a difference in mean score that was statistically significant, no researcher of note has attempted to compare the self-efficacy of students participating in a formal mentorship program against those not participating. Further analysis of the quantitative and qualitative data should provide answers to the lack of statistical significance. These results will be forthcoming.

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Perception and Self-efficacy Survey

Directions: Please write the requested information in the space provided or **circle** the number that best reflects your answer to the question. There are no right or wrong answers to these questions. We appreciate your assistance.

I. BACKGROUND INFORMATION

1. Home Room Teacher: _____
2. High School: _____
3. Grade Level: _____
4. Gender: 0 = Female 1 = Male
5. Race/Ethnicity with which you most closely identify:

   1 = Black/African American   4 = American Indian/Alaskan Native

   2 = Hispanic/Latino American 5 = White/Caucasian

   3 = Asian/Pacific Islander   6 = Other: _____

6. What is the **highest level** of formal education **completed** by your parents?

	Mother	Father		Mother	Father
Grammar school or less	1	1	College Degree	1	1
Some high school	2	2	Some graduate school	2	2
High school graduate	3	3	Master's degree	3	3
Some college/assoc. degree	4	4	Doctorate/professional degree	4	4

7. Highest degree expected in your lifetime:
   1 = Associate/technical (2 year degree) 2 = Bachelors (4 year degree)   3 = Masters   3 = Doctorate
8. Approximately **how many hours per week** are you employed:
   (a) Off-campus: _____hours/week
   GPA:

   In high school: __.___
   No. of courses **successfully completed** to date in:

    Engineering _____   Math _____   Science _____

9. Did you:

   1 = enter the school year at the Middle College

   2 = transfer from another high school

II. Note: If you participated in the NCETE/NSBE mentorship program please fill out section. All others please *SKIP* section. This section asks about the characteristics of the mentorship program and the kinds of activities that go on in it. Using the scale below, please circle the number that best reflects how often you have experienced the following in the mentorship program

1 = Never **2** = Occasionally **3** = Often **4** = Very Often/Almost Always
n/a = Not Applicable

In this course:

a. Assignments, presentations, and learning activities are clearly related to one another.	1	2	3	4	n/a
b. I work cooperatively with other students on design challenges	1	2	3	4	n/a
c. The team teaches, and learns from each other.	1	2	3	4	n/a
d. There are opportunities to work in groups.	1	2	3	4	n/a
e. I am encouraged to show how particular knowledge can be applied to "real-world" problem.	1	2	3	4	n/a
f. I have opportunities to practice the skills I am learning in the mentorship program.	1	2	3	4	n/a
g. I discuss ideas with my classmates (either individuals or in a group).	1	2	3	4	n/a
h. I get feedback on my work or ideas from my mentor.	1	2	3	4	n/a
i. We do things that require us to be active participants in the mentoring process.	1	2	3	4	n/a
j. The mentor makes clear what is expected of students regarding activities and effort.	1	2	3	4	n/a
k. The mentor gives me **frequent** feedback on my work.	1	2	3	4	n/a
l. The mentor gives me **detailed** feedback on my work.	1	2	3	4	n/a

III. Perceptions of Engineering

This section asks about conceptual knowledge of engineering as a field and career. Using the scale below, please circle the number that best reflects your extent of knowledge 1= Disagree **2** = Slightly Agree **3** = Agree **4** = Strongly Agree

I feel confident in my:

a. Understanding of what engineers do in industry as professionals	1	2	3	4
b. Understanding of engineering as a field which often calls for non-technical considerations (e.g., economic, political, ethical, and/or social issues).	1	2	3	4
c. Knowledge and understanding of the **engineering graphics** in engineering.	1	2	3	4
d. Knowledge and understanding of the **process** of design in engineering.	1	2	3	4

I feel confident in my ability to:

e. Do design.	1	2	3	4
f. Solve an **ill-defined** problem (that is, one that is not clearly defined).	1	2	3	4
g. Identify the knowledge, resources, and people needed to solve an ill-defined problem.	1	2	3	4
h. Evaluate arguments and evidence so that the strengths and weaknesses of competing alternatives can be judged.	1	2	3	4
i. Apply an abstract concept or idea to a real problem or situation.	1	2	3	4
j. Divide ill-defined problems into manageable components.	1	2	3	4
k. Clearly describe a problem orally.	1	2	3	4
l. Clearly describe a problem in writing.	1	2	3	4
m. Develop several methods that might be used to solve an ill-defined problem.	1	2	3	4
n. Identify the tasks needed to solve an ill-defined	1	2	3	4
o. Visualize what the product of a project would look like.	1	2	3	4
p. Weigh the pros and cons of possible solutions to a problem.	1	2	3	4
q. Figure out what changes are needed in prototypes so that the final engineering project meets design specifications.	1	2	3	4

IV. Self Efficacy in Math

This section asks about student's confidence and self belief to use math to solve technological and engineering problems. Using the scale below, please circle the number that best reflects your perceived ability 1= Disagree **2** = Slightly Agree **3** = Agree **4** = Strongly Agree

I feel confident in my:

a ability to accurately calculate numerical
problems mentally.   1 2 3   4   n/a

b. ability to accurately calculate numerical   n/a
problems on paper.   1 2 3   4

c. ability to estimate and make approximations.   1 2 3   4   n/a

d. ability to interpret the accuracy of results and   n/a
measurements.   1 2 3   4

e. ability to calculate the effects of change in   n/a
variables using mathematical models.   1 2 3   4

f. ability to predict the rate of change of variables   n/a
using mathematical models.   1 2 3   4

g. ability to use the knowledge and skills in
mathematics to interpret presentations of
mathematics   1 2 3   4   n/a

h. ability to learn the material taught in your math
courses.   1 2 3   4   n/a

IV. Self Efficacy in Science

This section asks about student's confidence and self belief to use their understanding of science to solve technological and engineering problems. Using the scale below, please circle the number that best reflects your perceived ability 1= None **2** = Slight **3** = Moderate **4** = A Great Deal

I feel confident in my:

a ability to understand the laws of science and
nature to solve problems.   1   2   3   4   n/a

b. ability to understand natural systems.   1   2   3   4   n/a

c. ability to understand basic concepts of science   n/a
and technology.   1   2   3   4

d. ability to use logical and systematic thinking in
scientific contexts.   1   2   3   4   n/a

e. ability to use science to solve technological
problems.   1   2   3   4   n/a

f. ability to predict the rate of change of variables
using scientific equations.   1   2   3   4   n/a

g. ability to use science to solve ill-defined
problems?   1   2   3   4   n/a

h.ability to be part of a problem solving team,
expressing your ideas, listening and responding
to others.   1   2   3   4   n/a

j. ability to learn the material taught in your
science courses.   1   2   3   4   n/a

THANKS VERY MUCH FOR YOUR HELP!
Please return completed questionnaires to whomever distributed them to the class.

STUDENT INTEREST IN STEM CAREERS:
DEVELOPMENT OF INSTRUMENT FOR
HIGH SCHOOL STEM-BASED PROGRAMS

Mark Patrick Mahoney
Ohio State University

Introduction

In 1983, *A Nation at Risk* (National Commission on Excellence in Education [NCEE], 1983) established the resurgence for the science, technology, engineering, and mathematics (STEM) movement in education.   In the 1980s, a gradual change in economic strength was occurring, transferring power from domestic industries to foreign markets. Though this trend's history can be traced back 20 years, it was the *A Nation at Risk* (NCEE) report that brought the reality to the public's attention.

> The time is long past when American's destiny was assured simply by an abundance of natural resources and inexhaustible human enthusiasm, and by our relative isolation from the malignant problems of older civilizations. The world is indeed one global village. We live among determined, well-educated, and strongly motivated competitors. We compete with them for international standing and markets, not only with products but also with the ideas of our laboratories and neighborhood workshops. America's position in the world may once have been reasonably secure with only a few exceptionally well-trained men and women. It is no longer. (p. 10)

The influence of this report and its recommendations are echoed in the feverish development of national standards produced by academic organizations such as the National Council of Teachers of Mathematics (NCTM), the American Association for the Advancement of Science (AAAS), and the International Technology Education Association (ITEA).

Each educational organization was in the process of producing preliminary documents by the close of the 1980s. It is within this process that we may witness the first inclinations of STEM. NCTM (2000), AAAS (1989), and ITEA (2000) documents all suggest the combination or integration of their respective subjects in an attempt to enhance student learning and STEM preparation. In the NCTM's *Principals and Standards for School Mathematics* (2000), students are encouraged to "pursue an educational path that will prepare them for lifelong work as mathematicians, statisticians, engineers, and scientists" (p. 4). The AAAS document, *Science for All Americans*, defines a (scientifically) literate person as "one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations" (p. 4).

ITEA rounds out this example in the following excerpt from the *Standards for Technological Literacy*; "Technology is not simply one more field of study seeking

admission to an already crowded curriculum … it reinforces and complements the material that students learn in other classes" (p. 6).

This proposed subject integration has taken many forms since the overall arrival of standards. Programs, modules, packaged curriculums, and even charter schools have aligned themselves with proposed models of what a STEM educational program should represent. A recent report by the Academic Competitiveness Council (ACC) indicates that there are up to 105 government-funded STEM education programs in the United States, ranging from kindergarten to post-graduate education. Included in this estimate are outreach programs, such as weekend, after school, and summer programs. The report by the ACC also collected information regarding the cost associated with STEM education programs. Overall estimates indicate total government expenditure to exceed $3.12 billion over the 2006 fiscal year. These monies are supplied through a variety of government foundations -- predominately by the National Science Foundation (NSF) at 29%, the Department of Health and Human Services (HHS) at 27%, and the Department of Education (DoE) at 23%.

Evaluations of these programs were collected and examined (ACC, 2007). The evaluations were referenced to review the proposed effectiveness of the STEM programs and the quality of the evaluations themselves. Unfortunately, it was found that a great deal of the evaluations were below the expectations of the council. In fact, those that did display potential still required revisions to add greater validity to the information provided. This is not a new occurrence. NSF has been revising its own grant procedures to account for this lack of efficient evaluation. Educational research grants such as Innovative Technology Experience for Students and Teachers (ITEST), Research and Evaluation on Education in Science and Engineering (REESE), Discovery Research, K – 12, (DR-K12), and Informal Science Education (ISE) are now under review in the attempt to develop a more in-depth evaluation format than previous documentation (NSF, 2008). Programs funded by NSF and other organizations have carried on for years with government money without providing enough sufficient information or measurable influence upon the educational community (ACC, 2007).

Add to this condition the limitless number of private industries that have produced and sold STEM educational products and curricula over the last 20 years. These varied items align themselves with national standards and suggest educational advancement in the form of problem solving, cooperative learning, and subject integration. Some of the more popular examples associated with implementing principles of STEM are Project Lead the Way (PLTW), DesignQuest (PTC), and Engineering byDesign (EbD). However, very little research has been conducted regarding the degree of influence upon education or even student learning (Bottoms, G., & Anthony, K., 2005, PTC, 2006, ITEA, 2008). This is not to suggest that any of the programs or institutions engaged in STEM endeavors are faulty   simply that they require more reinforcement and refinement through proper research and evaluation. A more recent development is the creation of entire educational institutions devoted to STEM development. These schools are not vocational or career and technical schools, but rather college preparatory programs designed to develop student abilities and interest in STEM and STEM careers.

The Problem

STEM-based educational programs and institutions have been developed to address the national need for engineers, technicians, and scientists. Several national organizations have displayed great interest in such development. In 2004, the Education Commission of the States (ECS) issued the report *No Time to Waste: The Vital Role of College and University Leaders in Improving Science and Mathematics Education.* According to the report, the American STEM workforce has quadrupled over the last 20 years. Conversely, the number of students preparing for careers in STEM has been either stagnant or declining. An interesting correlation is noted in the ECS report to address this condition:

> [C]lassroom access to computers and the internet had expanded significantly, as has the availability of Advanced Placement science and mathematics courses. Nearly all states have established academic standards in both science and mathematics, and the annual testing of students in core subjects mandated by the No Child Left Behind Act will be extended, in the 2007 – 08 school year, to include science. Still, on a number of key indicators, America's systems of science and mathematics education continues to perform below par (p. 3)

The recommendations from this report consisted primarily of increased science and mathematics abilities for future teachers as well as greater exposure and collaboration with industry (ECS, 2004).

In 2005 the report, *Tapping America's Potential,* produced a summary of the concerns from a variety of local professional organizations: American Electronics Association, Business-Higher Education Forum, Business Roundtable, National Defense Industrial Association, TechNet, and several more. The report cited warnings in the form of a declining STEM equipped population: increased foreign competition, low student interest toward engineering, low student achievement, and declining research funding (Business Roundtable, 2005). This collection of warnings from the Business Roundtable reinforces the growing amount of concern within American industry. The American Electronics Association (AeA) also shared their concern in the following statement in 2005: "America needs to recognize that future innovation is not predetermined to occur in the United States. Even if we were doing everything right, we still face unprecedented competition from abroad" (p. 3).

Many of the same organizations have invested in educational programs and institutions based upon principles of STEM in hopes of reversing these common concerns.

It is, therefore, imperative to know if STEM-based schools are actually developing student interest in STEM and STEM careers. Currently, no instrument is available to measure accurately student interest in STEM. Data provided by such an instrument could inform STEM-based programs as to the value of their programs regarding the projected influence upon improving the STEM workforce at large.

Additionally, the supporting agencies of such educational programs, like STEM-based schools, would be clued in to the worth and necessity of their current investments, thereby, better determining educational investments based upon research and not hopeful outcomes. Large amounts of money and time have already been provided in the hope that these institutions will provide student interest and abilities related to STEM. However, these donations have yielded little results as demonstrated by the continued reports being constructed each year demanding greater STEM investment and results.

The development of an instrument that can accurately measure student interest in STEM careers is crucial to STEM-based programs, their intended outcomes, and the companies that aid in their function as well as hope to reap from their products.

Objectives of the Proposed Study

The principal objectives of this study are as follows:

1. To review and revise current instruments dedicated or related to assessing student interest, career interest, and/or STEM education.

2. To construct a new instrument created from a selection of existing items and modeled from the Concerns Based Adoption Model in an attempt to measure student interest in STEM careers.

3. To validate the instrument through the advisement of a panel of experts in or related to STEM.

4. To pilot test the instrument for reliability through a random selection of available students currently enrolled within STEM-based schools.

Intended Method

In order to create a student career interest instrument specific to STEM-based high school environments, an item pool from existing scales will be collected. Permission will be sought from organizations representing such instruments. The purpose of the item pool is to provide the researcher with a collection of statements that may represent operational definitions of the chosen affective characteristics. Domain sampling will provide the collection of statements that align with the content domains of the instrument. The intended content domains are as follows:

1. Student interest in science
2. Student interest in technology
3. Student interest in engineering
4. Student interest in mathematics
5. Student interest in STEM

The selected and composed items will be submitted to a panel of experts to aid in the establishment of content-validity. A panel of ten experts in or related to the field of STEM will be collected to review the items intended for use upon this instrument. After appropriate revisions, pilot testing will commence. An initial pilot test will be conducted using a local STEM-based program. The purpose of this initial review is to establish the reliability of the selected items in accurately measuring student interest. A second pilot test will be conducted using a larger selection of available STEM-based programs. Reliability analyses will be produced for both tests.

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CHILDREN'S MULTIPLE REPRESENTATIONS OF IDEAS IN SCIENCE

Brian Gravel
Tufts University

Abstract

The natural language of science is one of multiple representations – scientists "talk" with words, numbers, graphs, schematics, simulations, movies, and so on. These systems of representation evolved over time to serve a need for effective communication of science ideas. Students engaged in science learning activities interact with these conventional systems of representation, and these expressive modes can impact how they think about science. This research aims to uncover more about how students go about representing ideas in science and how their ideas and understanding evolve throughout the process of representing across multiple systems. Specifically, we introduce a new tool which allows students to make stop-action movies about science content in order to see how these representations compare with those constructed in other systems. This paper will present a pilot research study on children's multiple representations of ideas in science.

Introduction

Representation is a somewhat ubiquitous term in many fields of social science research, with a variety of definitions and usages. Kaput (1985) suggests that representation is an "undefined primitive whose meaning unfolds gradually through usage within a particular domain of inquiry" (p. 38). The literature suggests a diversity of definitions for *representation*: Enyedy (2005) offers that representation is "the act of highlighting aspects of our experience and communicating them to others and ourselves" (p. 427); Goldin and Shteingold (2001) suggest that a representation is "typically a sign or a configuration of signs, characters, or objects...the important thing is that it can stand for (symbolize, depict, encode, or represent) something other than itself" (p. 3); and Lee and Karmiloff-Smith (1996) affirm the notion that representation "establishes a 'stand for' relationship between referent and sign" (p. 127; see also Kaput, 1991, 1998). These definitions highlight important aspects of representation which serve as focal points for education research in this area. Symbolization and symbol-use (Nemirovsky, 1994), referential-communicative aspects of representation (Tolchinsky, Landsmann & Karmiloff-Smith, 1992), and cultural and social aspects of developing conventional systems of representation (Confrey, 1991) are all concepts being explored.

Representations are often considered from two perspectives, internal and external (Goldin, 1998; Zhang & Norman, 1994). While some researchers argue that this distinction may be spurious (i.e., "The Phantom of Dualism", see Nemirovsky, in press), external representations of knowledge are the only primary sources of student understanding that researchers are able to collect. Since scientists seamlessly navigate across systems of external representation (such as oral language, written language, mathematical notation, graphing, and gesture) in the practice of researching and

communicating results, research into how students represent scientific knowledge has the potential to further this field of study. Students learning science must find meaning in particular systems of representation while also learning how to appropriately employ them. Additionally, students likely represent their knowledge differently in different systems of representation (Brizuela & Earnest, 2007; Goldin, 1998). A great deal of knowledge about how students learn can be gained through studying how they represent their understanding in science.

The act of representing knowledge helps to strengthen and refine one's understanding of a particular concept (Kaput, 1991; Olson, 1994). This work aims to investigate how iteratively representing understanding across multiple systems impacts knowledge. Enyedy (2005) coined the term "progressive symbolization" as a construct for describing that as children are asked to externalize their ideas, the artifacts they produce and their understanding evolve over time and approach conventional forms. While conventionality is not of immediate concern herein, the notion of representing in different systems holds great potential for unveiling how students make sense of scientific practices. It is reasonable to assume that some systems of representation may be better for representing certain aspects of science (e.g., static vs. dynamic scenarios). Thus, this work will focus on students' representing their ideas in a number of ways, and it is driven by three essential research questions

Research Questions

1. How do students represent their ideas about air as a substance through generating animated explanations of observed demonstrations?

2. How are representations produced through animations both similar and different from representations produced in other systems such as oral language, writing, and drawing?

3. What differences, if any, exist in the kinds of conceptual aspects about air as a substance that children are able to represent through different media?

This work introduces a new system of representation (assuming that drawing, building, writing, and speaking can be agreed upon as existing systems), stop-action movie making, also known as animation[1]. Research concerning animation in instructional settings has largely focused on using animations as demonstration tools (Hagerty, 1992; Kaiser, Proffitt, Whelan, & Hecht, 1992; Mayer & Anderson, 1991, 1992; Mayer & Moreno, 2002). While some report gains in content recall and problem-solving transfer for students who view animations on certain concepts (Hagerty, 1992; Kaiser et al., 1992; Mayer & Anderson, 1991, 1992; Morrison, Tversky, & Betrancourt, 2000), the research does not present a consensus for how animations should be utilized as a learning aide. The literature presented does not appear to be in agreement on how animation can be effective for use in learning situations. However, the research has focused largely on

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[1] An *animation* is defined as a short movie (typically less than thirty seconds) comprised of individual still images that are played in rapid succession (set by a frame rate), similar to a flip book.

animations as demonstrations, rarely as artifacts constructed by students. Air and air pressure are chosen as the content focus because they are generative concepts (Basca & Grotzer, 2001), in that they can cause visible actions while remaining "unseen", making them rich contexts for investigating how students represent their ideas.

Methodology

To investigate the differential impact of using animations versus other forms of representations, the proposed pilot study intends to elicit multiple representations from students across multiple systems. These representations will be produced after students interact with science demonstrations[2] that are designed to highlight conceptual aspects of air and air pressure. Morrison and Tversky (2001) "Conceptual Congruence Hypothesis" suggests that since animations depict changes over time, the situations about which students are asked to generate animations should also include elements of motion and change over time. Thus, students will interact with demonstrations that show a change over time, and they will be asked to represent their understanding of these situations in multiple ways. The specific exploration involves two plastic syringes connected at the nozzles by a short piece of rubber tubing. In this demonstration, as the plunger of one syringe is depressed, the plunger of the other syringe extends (Figure 1). This demonstration has been used by other researchers in investigations of children's notions of air pressure (deBerg, 1995; Séré, 1982; Tytler, 1998) and will be referred to as the "Sealed-Syringe" demonstration. Previous research has shown students begin to develop ideas about air as a substance as early as age five (Driver et al., 1994). However, for the study proposed here, the subjects will be middle school-aged children (ages 12-14 years), as they have been found to have semi-normative ideas about air and pressure (Séré, 1982). The total number of participants for this study will be 8 students, 4 female and 4 male, chosen at random from the pool of participants having given informed consent. Student-generated animations are the mode of representation under investigation; however, these representations will need to be compared with other systems. In addition to asking the students to animate their explanations for the observed phenomena (as seen through the demonstrations), students will also (A) represent their ideas verbally through a semi-structured interview; (B) draw pictures to facilitate an explanation, and (C) use physical elements as aids in verbally describing the scenario (such as balloons, fans, clay, etc.). All representations will be elicited in the context of a clinical interview, a well documented methodology in education research (Brizuela, 1997; Duckworth, 1987, 1996; Piaget, 1965). The novel system, animation, will be employed using the Tufts University Center for Engineering Educational Outreach *SAM Animation* software. SAM is an environment that allows children to make animations with the aid of computer imaging and processing. In *SAM Animation*, a web-camera is connected to the computer which displays a live video image in one window of the software (see Appendix A for a detailed description of the software). This allows the user to make the animation out of whatever materials they desire (e.g., drawings, manipulatives, paper cut-outs, LEGO bricks, etc.).

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[2] [2] While the term "demonstration" is used here, these activities could be considered "explorations", because the student will have the opportunity to interact with the materials in order to gather first hand experience with the phenomena.

The user "snaps" the image they want, and a still picture is recorded and placed in a timeline. The user then adjusts the scene captured by the camera and "snaps" another image. The animation is, therefore, a collection of still images taken from the camera which is focused on some scene external to the computer. The user can "play" the animation at a specific frame rate (measured in frames per second) which they prescribe. The result is a computerized movie, which can be exported as a Quicktime™ file and shared with other students, teachers, and researchers. Church, Gravel, and Rogers (2007) have previously reported success using this software with students in high school physics courses. In the proposed research, students will be taught how to use the animation software (in a minimum of two sessions) prior to the introduction of the air demonstrations. Each participant will take part in three research sessions: (1) a session focused on the exploration, a verbal interview, and drawing representations; (2) a session where each student is offered a range of materials from which to make animated representations of their ideas; and (3) a session where the participant builds a physical artifact to aide verbal explanations. All artifacts will be collected and analyzed alongside the transcripts of each clinical interview.

Implications

This work has the potential to uncover patterns and trends in how students spontaneously represent their understanding of scientific ideas across multiple systems. While it is important to note that definite lines between each of the proposed systems cannot be drawn without generating theoretical concerns (i.e., considering speech as completely independent from written notation can be argued against), perhaps, each of these environments allow students to represent aspects of their understanding in different ways. The introduction of animation as a new representational environment alongside more traditional systems highlights the aspects of representation in science that need further exploration in a dissertation study.

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Figure 1. The "Sealed-Syringe" demonstration device. A fixed amount of air is enclosed in the system such that depressing one plunger results in opposite plunger extending. Students will also be asked to press both plungers down simultaneously, compressing the air inside the system which is another conceptual aspect of the interviews.

SAM Animation is a free-of-charge computer software program written at the Tufts University Center for Engineering Educational Outreach. Figure 1 shows the main screen of SAM Animation and a description of relevant features follows.
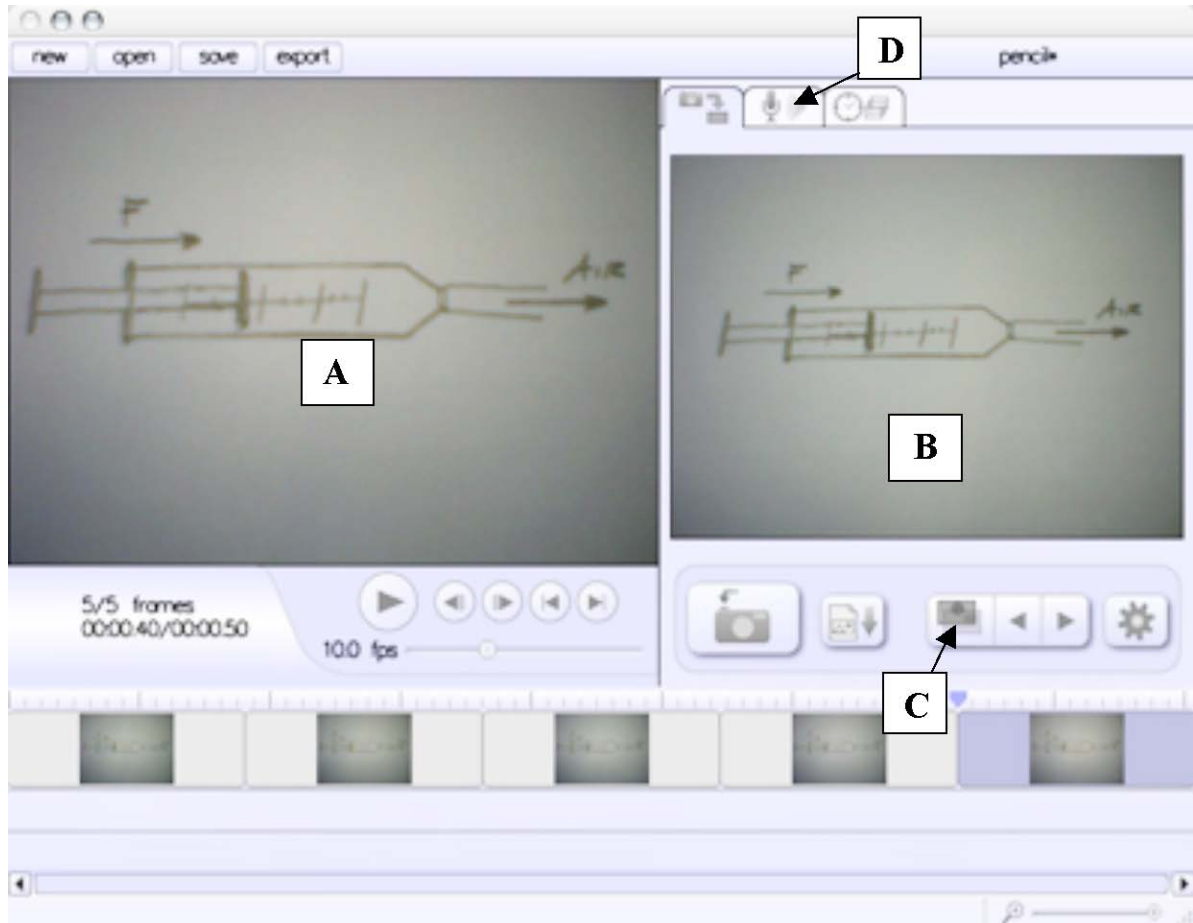

Figure 1. SAM Animation software.

The features of the software are labeled and are described below:

A. *Main animation screen* -in this window, the most recent still image taken from the camera is displayed. Pressing the "play" button beneath the window will play the animation at the prescribed frame rate (set by the slider beneath the window and "play" button)

B. *Camera view* -this window shows the image being fed in from the webcam connected to the computer. Beneath this image is a button with the image of a camera on it. Clicking here captures a still image from the video feed and adds that image to the timeline at the bottom of the screen.

C. *Onion-skinning* -this button allows the user to see a faded image of the last still image captured. This helps the user in aligning scenes created for the animation.

D. *Audio function* -by clicking this tab, the audio screen is accessed. Here the user can add one audio track to the animation.

THE COGNITIVE PROCESSES AND STRATEGIES OF AN EXPERT AND NOVICE IN THE DESIGN OF A WIRELESS RADIO FREQUENCY NETWORK

Matthew D. Lammi
Utah State University

Abstract

This study sought to understand the cognitive processes and procedures employed by an expert and a novice engineer in a realistic radio frequency systems engineering design challenge by using verbal protocol analysis. The engineering design challenge encompassed engineering, political, and social constraints. The audio data was then transcribed, segmented, and coded for analysis.

The processes and strategies of the expert and novice were juxtaposed for analysis. The expert and novice shared some similarities in their cognitive processes and strategies. However, the expert's domain knowledge and experience was vastly distinct from that of the novice. Finally, a few ideas on improving engineering and technology education are presented.

The demand for engineers continues to grow while the supply of domestic engineers entering the work force continues to decline (NAE, 2004). Undoubtedly, an improvement in engineering education curriculum and pedagogy would mitigate this decline. Yet, research in engineering education and cognition is minimal in the United States. Therefore, more research is needed to further understand engineering education and its role in the complete engineering enterprise. This study aims to enhance the engineering cognition knowledge base by analyzing and comparing the cognitive processes and strategies of an expert and novice in systems engineering design.

Research Questions

1. What cognitive processes and strategies are used by expert and novice engineers in systems design?
2. How do the expert and novice cognitive processes and strategies compare?

Background

This study is based on the foundation of cognitive science as it pertains to engineering and technology education (Brown, 2001). The novice is limited by experience and knowledge resulting in a partial and simple schema. The expert has a vast depth of experience and focused practice within a domain resulting in deep and rich schemata (Cross, 2004). Experience and knowledge do not ensure expertise. The manner in which the experience and knowledge is ordered and interrelated has a great impact on expertise. An expert is able to recognize large amounts of information, or chunks (Egan & Schwartz, 1979). From these chunks, an expert can recognize what information is relevant to the issue at hand. This enables the expert to wade quickly and efficiently

through data and facts with fast retrieval from his/her memory or schemata. This deliberate and focused effort was explained by Ericsson (2001) as the primary difference between experts and those who are only proficient in their domains.

Design is a nebulous process that may be perceived from either a scientific or an artistic viewpoint (Cross, 2001). Design is also dynamic and iterative, therefore, it is not easily represented by simplistic linear models (Mawson, 2003). Design, typically, commences with defining the problem space (Cross, 2004). As a result of their lack of design skills, novices spend a large proportion of their time in the problem space (Cross, Christiaans & Dorst, 1994).

With a vast schema based on multiple experiences and focused practice, an expert is able to identify quickly pertinent data in the problem space. As experts move quickly through the problem space, they place a majority of their efforts in the solution space generating one or multiple design artifacts (Lawson & Dorst, 2005). However, as the solution space evolves and elucidates further constraints, the expert returns to and references, or redefines, the problem space iteratively until the design is implemented, tested, and concluded. Additionally, experts design from a solid groundwork of "first principles", or scientific theory on which to base their design concepts (Cross, 2002). These attributes combined give "know how" that is often demonstrated by an expert. Furthermore, Ericsson (2001) states that affective attributes, such as focus and commitment, are a factor in expertise.

Methods

The sample for this study included two participants drawn from opposing ends of the expertise continuum in the domain of radio frequency (RF) engineering system design. As such, they were selected on their skill set within RF engineering system design. Expertise in RF engineering is generally obtained through extensive practice in industry due to the frequent complex human interactions that must be balanced with sound engineering design.

The expert for this study has over thirteen years of RF systems engineering design working for T-mobile in various positions ranging from manager to internal consultant. The expert received formal training with a bachelors degree in electrical engineering. The other participant is on the other end of the spectrum of RF systems engineering, somewhere between novice and an advanced beginner. He is a professor in electronic engineering technology and has been teaching electronics at the post secondary level for more than 35 years. Although he is a novice in RF systems engineering design, he has a breadth of skills in pedagogy and undergraduate electronics.

The participants were asked to design a new wireless cellular network in an isolated college town as though they were engineering design consultants. Constraints were placed in the design challenge to create a realistic, ill-defined scenario. The constraints were to limit capital expenditures and abide by the zoning not to exceed 60 foot towers, and design cell sites to be hidden or stealth. Additionally, the participants were made

aware of high cellular traffic venues, such as the university with 18,000 students and a fictitious annual wakeboarding event that would draw 10,000 individuals. A three dimensional aerial map overlaid with major and minor transportation thoroughfares was given to the engineers to aid in their design as seen in Appendix A.

The audio data was broken into units or segments. The segments were then coded into distinct mental processes used in engineering design. Although there are various methods utilized in coding verbal protocols (Atman & Bursic, 1998; Kruger & Cross, 2001), the Halfin (1973) coding method was used in this study as it specifically addressed engineering design. These mental processes are presented in Appendix B.

Results

As both participants had multiple years of experience at the systems level in electronics, each initially utilized a top-down approach in their design. Both participants also used an iterative process evaluating and visualizing their design against the various constraints. However, the expert was able to analyze more thoroughly and balance the constraints, such as zoning and leasing. The expert and the novice each frequently returned to first principles for predictions and site locations. However, the novice was fully aware of his limitations and stated repeatedly that he did not have the experience and knowledge to make an accurate design. Conversely, the expert was able to make mental predictions or visualizations of the design and relied heavily on experiential and episodic memory. As seen in Appendix C, the percentage of time on task in design was nearly the same at 37%.

The expert's design strategy revealed differences from that of the novice. The expert approached the design from a personal viewpoint, drawing heavily from previous experiences and precedents. One of the most striking contrasts between the participants was the attention the expert gave to the optimization of capital expenditures. This same theme pervaded the expert's entire design process. While the expert made sixteen references to costs, the novice only mentioned costs in three instances. Additionally, the expert's design proposed only seven sites, the novice fifteen, substantially reducing the cost of the proposed design. The differences may be partially attributable to the novice's career in academia while the expert has exclusively been in industry with responsibilities as a manager and principal engineer with cost as a consistent constraint.

Another striking difference between the expert and novice was the amount of domain knowledge. Appendix E is a pair of concept maps that reveal the disparity in knowledge. The novice clearly did not have the breadth and depth of knowledge as did the expert. However, the concept maps reveal that the novice did have a working knowledge of radio frequency electromagnetic wave propagation. The novice made mention of zoning, leasing, and capacity, but this could partially be accounted for by the design brief.

The expert made use of techniques unique to his trade, or gambits, to help overcome the stealth requirements. The expert employed water towers, rooftops, and stadium lights as economical alternatives to other costly stealth solutions. When the novice was prompted for further analysis and design he replied, "Experience would probably tell a person more

information whether [the system design] is enough or…not." Clearly, the novice had a lack of relevant experience and domain specific knowledge to elaborate on his design.

Discussion

Engineering and technology education would do well to educate the students broadly to become global thinkers (National Academy of Engineering, 2005). This global approach to teaching should include costs, organizational behavior, political and societal impacts. The design method may be taught, but an emphasis should be placed on the fact that there is no universal problem solving model. Finally, systems level engineering could be infused into a curriculum similar to that employed by Frank (2005) with a top-down approach. Presenting the overall concept and then delving into components is an alternative method to accommodate a variety of student learning styles (Felder & Silverman, 1988). This paper has presented a few ideas that should be infused into engineering and technology education practice and research to increase technological literacy.

Acknowledgement

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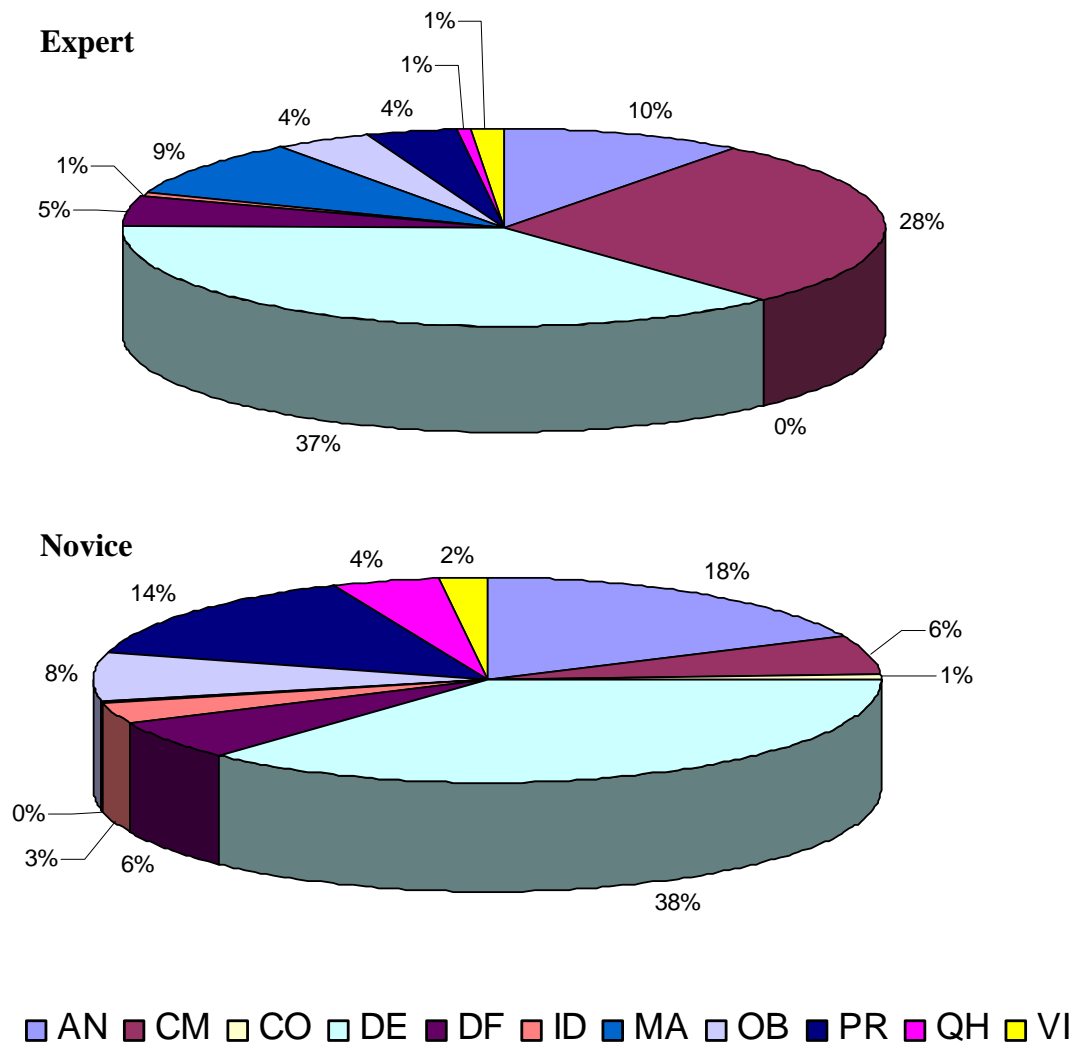
Appendix A
3 Dimensional Aerial Map

Halfin's Mental Processes and Definitions

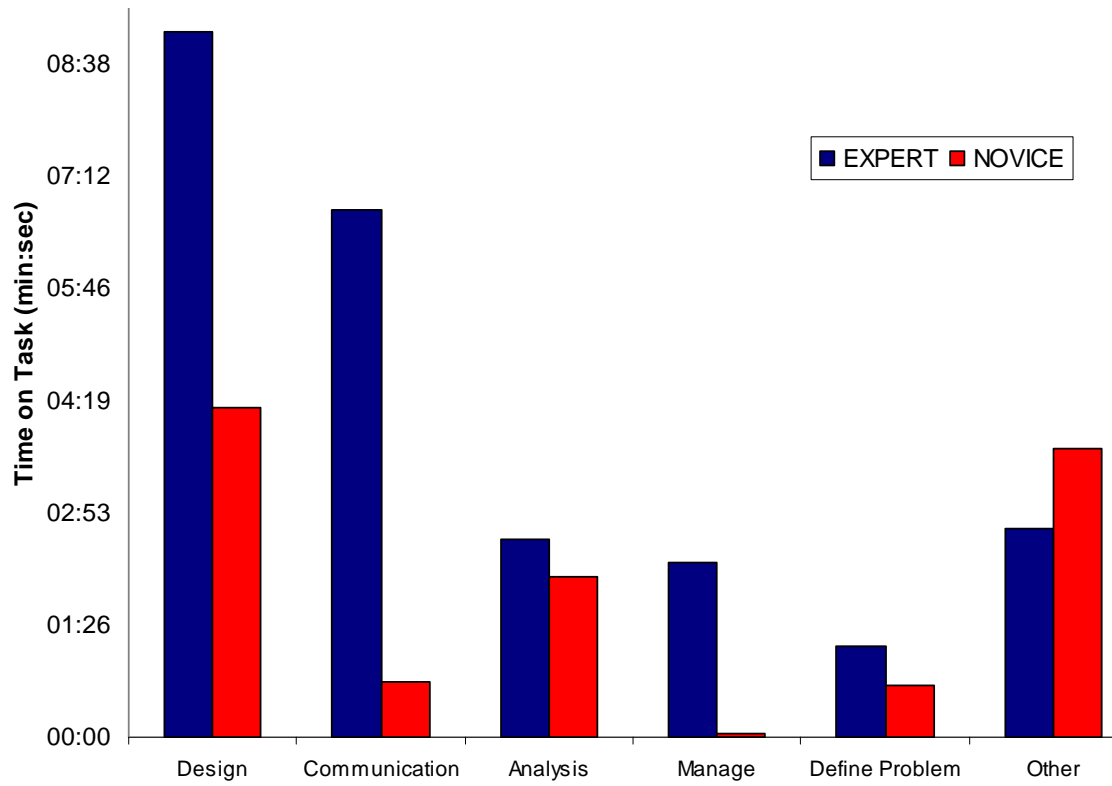| Code	Mental Process and Definition
(DF)	*Defining the Problem or Opportunity Operationally*. The process of stating or defining a problem that will enhance investigation leading to an optimal solution. It is transforming one state of affairs to another desired state.
(OB)	*Observing*. The process of interacting with the environment through one or more of the senses. (Seeing, hearing, touching, smelling, and tasting.) The senses are utilized to determine the characteristics of a phenomenon, problem, opportunity, element, object, event, system, or point of view. The observer's experiences, values, and associations may influence the results.
(AN)	*Analyzing*. The process of identifying, isolating, taking apart, breaking down, or performing similar actions for the purpose of setting forth or clarifying the basic components of a phenomenon, problem, opportunity, object, system, or point of view.
(VI)	*Visualizing*. The process of perceiving a phenomenon, problem, opportunity, element, object, event, or system in the form of a mental image based on the experience of the perceiver. It includes an exercise of all the senses in establishing a valid mental analogy for the phenomena involved in a problem or opportunity.
(CO)	*Computing*. The process of selecting and applying mathematical symbols, operations, and processes to describe, estimate, calculate, quantify, relate, and/or evaluate in the real or abstract numerical sense.
(CM)	*Communicating*. The process of conveying information (or ideas) from one source (sender) to another (receiver) through a media using various modes. (The modes may be oral, written, picture, symbols, or any combination of these.)
(ME)	*Measuring*. The process of describing characteristics (by the use of numbers) of a phenomenon, opportunity, element, object, event, system, or point of view in terms which are transferable. Measurements are made by direct or indirect means, are on relative or absolute scales, and are continuous or discontinuous.
(PR)	*Predicting*. The process of prophesying or foretelling something in advance, anticipating the future on the basis of special knowledge.
(QH)	*Questioning and Hypothesizing*. Questioning is the process of asking, interrogating, challenging, or seeking answers related to a phenomenon, problem, opportunity, element, object, event, system, or point of view. Hypothesizing is a process of stating a theory of tentative relationship between two or more variables to be tested which are aspects of a phenomenon, problem, opportunity, element, object, event, system, or point of view.
(ID)	*Interpreting Data*. The process of clarifying, evaluating, explaining, and translating to provide (or communicate) the meaning of particular data.

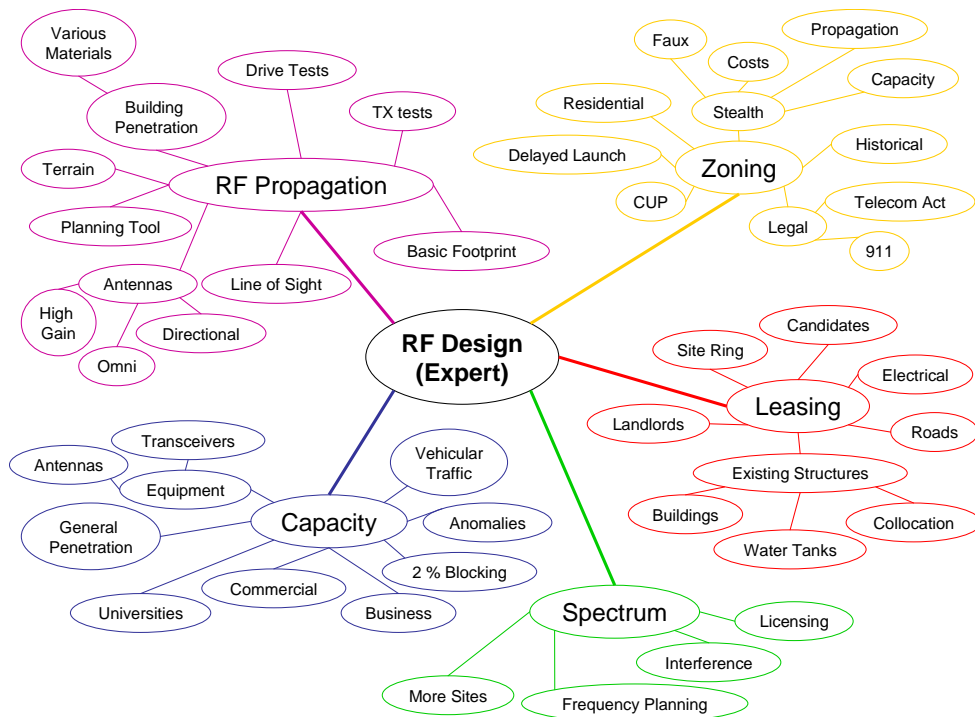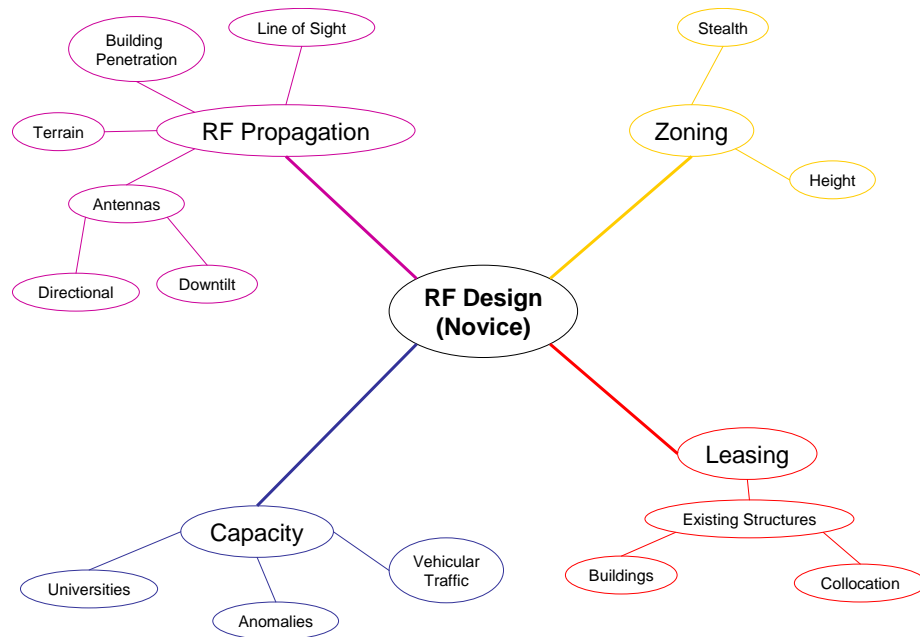| Code	Mental Process and Definition
(MP)	*Constructing Models and Prototypes*. The process of forming, making, building, fabricating, creating, or combining parts to produce a scale model or prototype.
(EX)	*Experimenting*. The process of determining the effects of something previously untried in order to test the validity of a hypothesis, to demonstrate a known (or unknown) truth or try out various factors relating to a particular phenomenon, problem, opportunity, element, object, event, system, or point of view.
(TE)	*Testing*. The process of determining the workability of a model, component, system, product, or point of view in a real or simulated environment to obtain information for clarifying or modifying design specifications.
(DE)	*Designing*. The process of conceiving, creating, inventing, contriving, sketching, or planning by which some practical end may be effected, or proposing a goal to meet the societal needs, desires, problems, or opportunities to do things better. Design a cyclic or iterative process of continuous refinement or improvement.
(MO)	*Modeling*. The process of producing or reducing an act, art, or condition to a generalized construct which may be presented graphically in the form of a sketch, diagram, or equation; presented physically in the form of a scale model or prototype; or described in the form of a written generalization.
(CR)	*Creating*. The process of combining the basic components or ideas of phenomena, objects, events, systems, or points of view in a unique manner which will better satisfy a need, either for the individual of for the outside world.
(MA)	*Managing*. The process of planning, organizing, directing, coordinating, and controlling the inputs and outputs of the system.

Appendix C
Percentage of Time on Task

Expert

- 1%
- 1%
- 4%
- 4%
- 10%
- 9%
- 1%
- 5%
- 28%
- 0%
- 37%

Novice

- 4%
- 2%
- 18%
- 14%
- 8%
- 6%
- 1%
- 0%
- 3%
- 6%
- 38%

□ AN ■ CM □ CO □ DE ■ DF ■ ID ■ MA □ OB ■ PR ■ QH □ VI

PERCEPTIONS OF CREATIVITY IN ART, MUSIC, AND TECHNOLOGY EDUCATION

David Stricker
University of Minnesota

Abstract

This study was conducted to examine the perceptions of art, music, and technology education teachers with regard to creativity in their respective fields. Participants were drawn from the membership databases of the Minnesota Technology Education Association (MTEA), Art Educators of Minnesota (AEM), and Minnesota Music Educators Association (MMEA). The survey used in this study was designed around the themes borne out of creative literature, generally, and creativity specific to the fields of art, music, and technology and engineering education. As a result, the themes of creative process, products, personal traits, and environment shaped the items contained in the survey. Significant differences were found between the subject areas in all themes mentioned above. Specifically, technology educators were less interested in the creative process, perceived creative products differently, valued creative personality traits to a lesser extent, and viewed the creative environment differently when compared with their peers in art and music. Finally, when compared with other demographic variables, the *subject* (art, music, or technology education) the participants taught was the only significant determinant of creativity perceptions in the study.

Introduction

Business and engineering communities emphasize the importance of 'outside the box' thinking and the need for creative solutions as a result of competitive market pressures that characterize the true global economy that exists today (Mahboub, Portillo, Liu, & Chandraratna, 2004). As a result, a question arises: Where in the curriculum are students allowed to exercise their innate creative urges? More specifically, since it is such a valued skill, how is creativity fostered in students? Art, music, and technology education may be the answer (Lewis, 2008). For technology education, specifically, a subject that has set a historical precedence for fostering creative work (see Cohen, 1998; Dewey, 1916; Woodward, 1882, 1883), its current curricular efforts of infusing engineering concepts that demand creative thinking is of particular interest to educators at all levels within the field. Basic to contemporary art education, whose foci are on visual culture that emphasizes creative experiences, are these same issues of creative and critical thinking skills, as well as problem solving (Freedman, 2003). The curricular goals of general creative and critical thinking along with problem solving, and creating products within a certain social construct are demonstrated in music education, as well (Webster, 1987a, 1987b, 1989). Technology education is not the only discipline, therefore, to declare that their curriculum champions creativity. Art and music lay claim to many of the same types of intellectual rigor in creativity to which the engineering-focused technology education curriculum seems to assert a monopoly. In light of this, since creativity is a cornerstone of engineering education currently embraced by technology

education, it must be determined if the engineering-focused technology education curriculum pushes students to explore creativity unique to technology education, but in a way that is not attainable in art or music education.

Purpose of the Study

Identification of creative aspects inherent to the design and problem solving activities being suggested by the new engineering-focused technology education curriculum is a fledgling area. The primary purposes of this study, therefore, were to identify specific aspects of creativity shared by the subjects of art, music, and technology education and to determine if there are creativity aspects unique to technology education. In essence, does the technology education curriculum, with its emphasis of engineering and design principles, offer students an avenue to explore their creative potential in a way that art and music education cannot? As a result, the study sought to answer the following questions shaped by literature pertaining to creativity, generally, and within the three fields previously mentioned:

1. Do technology, art and music teachers differ in their perception of the creative process?

2. Do technology, art and music teachers differ in their perception of the creative product?

3. Do technology, art and music teachers differ in their perception of creative personal traits?

4. Do technology, art and music teachers differ in their perception of the creative environment?

5. Are there predictors of the creativity perceptions among art, music, and technology education teachers?

Methodology

Identification of attributes inherent in creative work in art, music, and technology education is a significant vein that runs through the questions above. Plucker and Runco (1998) stated that creativity has lately been considered to be content specific and both theoretical and empirical evidence has been provided to make this claim. In addition, Baer (1994) said the assessment of creativity should not only be content specific, but task-specific within content areas. Therefore, identifying whether a general agreed upon group of attributes believed to be common to all creative endeavors was fundamental in establishing a starting point for this inquiry. Using these concepts, the development of a seventy-nine item survey instrument was developed to collect data from the association members mentioned previously.

Descriptive statistics including means and standard deviations were used on the data gathered from all items, including demographics. Mean comparison and rankings were conducted to determine if one subject area perceived certain creative items as more important when compared to another subject. In an effort to identify any predictors associated with the educators' creativity perceptions, demographic information was collected. MANOVA was used to test these dependent variables as a combined set of attributes concerned with each respondent's total score added across all the items used to indicate the level of importance and whether the demographic data interacted differently with them. Separate ANOVAs were conducted if significant relationships were found.

Instrumentation

The items contained in the survey were sectioned into five categories: one addressing demographic information and four dealing with the nature of creativity consistent with the literature: creative process; creative product; creative personal traits; and the creative environment. The categories and the number of items contained in each of them, seminal authors, and common indicating terminology embedded in the literature and, therefore, used to compose the items in the survey, are found in Appendix A. Participants rated via a seven point Likert-type scale, with 7 indicating "extremely important" and one indicating "not important", the importance of each item relative to their particular field. The participants were, also, asked five demographic questions related to the subject and grade level they taught, how long they had been teaching their subject, current level of education, and gender. The survey instrument is included in full in Appendix B.

Results

Although participants from all three subjects perceived the creative process as important to creative work, generally, technology education teachers were less interested in the importance of the creative process than the teachers of art and music (Appendix C). In addition, technology education teachers perceived a product's ease of use, practical implications, value to the community, craftsmanship, ability to respond to a need, and general adherence to technical standards as being important features of a creative product in their field when compared to art and music teachers (Appendix D). Art teachers valued creative personality traits significantly more than their peers in technology education (Appendix E). The perception of the importance group work and competition was significantly higher for technology teachers than for art teachers (Appendix F).

Finally, of the variables of subject (art, music, or technology education) taught, grade levels taught, years of teaching experience, level of education, and gender, the *subject* the participants taught was the only significant determinant of creativity perceptions in the study (Appendix E).

Conclusion

Evidence regarding the implementation engineering curriculum has been encouraging. For example, Yaşar, Baker, Robinson-Kurpius, Krause, and Roberts (2006) found

teachers were supportive of the idea of infusing design and technology into the curriculum. However, Yasar's et al. research, also, revealed that these teachers had negative perceptions of engineers, generally. As demonstrated in the engineering and engineering education literature, creative thinking is the foundation to successful design within a contemporary technology curriculum. Since the perceptions of technology education teachers found in this study were significantly different with regard to items focused on a variety of creativity characteristics, this may foreshadow difficulty in the full acceptance of the engineering-focused technology education curriculum in the field of technology education. The results of this study should be used to initiate a dialog regarding the capability of the field of technology education to embrace the types of creativity valued by the art and music fields.

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Appendix A
Components of the Survey

Categories	Seminal Author(s)	Example Indicators
Process (16 items)	Lubart (1999, 2000-2001), Torrance (1966), Sternberg (1985)	ability to transform things, observation, risk taking, flexibility, flow, synthesis, inventive use of an idea, act in a systematic manner
Product (14 items)	Getzels & Csikszenthmihalyi, (1976), Eisner (1962)	originality, completeness, novelty, technical quality, expressive power, aesthetic quality
Personal Traits (29 items)	Torrance (1963), Guilford (1950, 1976), Millar (2002)	humor, playfulness, ability to fantasize, ability to delay closure, tenacity, sensitivity to beauty, awareness of feelings/senses
Environment (15 items)	Amabile, T.M. (1983, 1990).	time management, sensory input, individual work, teamwork, knowledge, aptitude, technology

Perceptions of Creativity in Art, Music and Technology Education

Consent Form

You may decline to answer any questions, and you are free to withdraw from the survey at any time.

This research survey is part of a dissertation project and subsequent publications intended to gain insight into how you feel creativity is approached in your field. Your response will be compiled for data analysis with the goal of assessing how Art, Technology, and Music teachers view the creative process, creative products, creative environment, and personality traits of creative people relative to their subject. All responses of the 682 participants in this study will be kept confidential and no individual participant will be identified in the research process.

There are no foreseeable risks and no direct benefits for your participation in this survey. All of the responses will be kept confidential and each potential participant has been assigned a unique code only for the purposes of data analysis and eliminating your name from future contacts to complete the survey. The data from the survey will be kept by research staff at the University of Minnesota for only research related to the objectives of this project.

Again, we want to stress that your identity will be kept confidential and only results of collective data analysis may be used for publication. Your participation is voluntary and no loss of benefits or rights will be endured if you choose not to participate.

If you have any questions about this research project, please contact David Stricker at 612-624-6204 or via email stri0026@umn.edu or you may contact Dr. Theodore Lewis at 612-624-6204 or via email lewis007@umn.edu. If you have questions regarding your rights as a participant, please contact the University of Minnesota Institutional Review Board (IRB) office at 612-626-5654 or irb@umn.edu for assistance.

<u>Directions</u>: Under each of the four sections found below, you will find specific directions that guide you in how to complete the survey. Art, Technology, and Music teachers will be responding to this survey and particular items may be more familiar or relevant to each field.

Demographics

This section of the questionnaire deals with background information relating to you and your school (Mark only one response for each item).

1. What subject do you currently teach?
   ○ Art
   ○ Music
   ○ Technology Education

2. What grade level do you currently teach?
   ○ Middle/Junior High
   ○ High School
   ○ Other

3. How many years have you been teaching your subject?
   ○ 1-10
   ○ 11-20
   ○ 21-30
   ○ 31 or more

4. What is your current level of education?
   ○ Bachelors degree
   ○ Masters Degree
   ○ Doctorate

5. Gender:
   ○ Male
   ○ Female

Process

This section of the questionnaire asks you to evaluate the extent to which each of 16 statements relating to processes involved with creative work are consistent with the way teachers in your field think about creativity. Please fill in the number (*1 = not important, 7 = extremely important*) you feel best reflects how essential these statements are to the creative process in your subject area.

Not Important   Extremely Important

1. Having relevant knowledge of prior products or solutions is an important aspect of creative work. ①②③④⑤⑥⑦
2. To produce creative work a person must be familiar with standards for acceptable solutions. ①②③④⑤⑥⑦
3. The creative process requires the ability to generate a number of exploratory ideas or solutions. ①②③④⑤⑥⑦
4. Finding or identifying challenging problems is a critical dimension of the creative process. ①②③④⑤⑥⑦
5. Creativity includes the ability to find gaps, inconsistencies or flaws in existing solutions. ①②③④⑤⑥⑦
6. Generating a representation of the problem or challenge is part of the creative process. ①②③④⑤⑥⑦
7. Seeking out reactions to possible solutions is an important dimension of the creative process. ①②③④⑤⑥⑦
8. The creative process sometimes requires taking a break from the problem or challenge at hand to allow ideas to incubate. ①②③④⑤⑥⑦
9. Creative solutions sometimes come to mind as a "flash" or sudden awareness. ①②③④⑤⑥⑦
10. Metaphors and analogies are useful aids in creative thinking. ①②③④⑤⑥⑦
11. The act of creating sometimes involves reformulation of the initial problem or challenge as one becomes engaged in the work. ①②③④⑤⑥⑦
12. The creative process may begin even though the final product may not be formed in the "mind's eye". ①②③④⑤⑥⑦
13. The creative process often includes gathering and drawing upon all resources that can be helpful in completing a task. ①②③④⑤⑥⑦
14. The possession of relevant knowledge is an important aid to the creative process. ①②③④⑤⑥⑦
15. Creativity is improved if a person that is familiar with technical rules. ①②③④⑤⑥⑦
16. Creativity is improved if a person is familiar with relevant principles or theories. ①②③④⑤⑥⑦

Product

This section of the questionnaire asks that you to evaluate the extent to which each of 14 statements relating to the nature of creative products are important in your field. Please fill in the number (*1 = not important, 7 = extremely important*) you feel best reflects how essential statement is to the creative products in your subject area.

Not Important   Extremely Important

1. In my field, a creative product must posses a high degree of novelty. ①②③④⑤⑥⑦
2. A creative product is likely to influence or suggest additional future creative products. ①②③④⑤⑥⑦
3. A product is considered creative if it is unusual or seen infrequently in the category to which it belongs. ①②③④⑤⑥⑦
4. The degree to which a product responds to a need or problem determines its level of creativity. ①②③④⑤⑥⑦
5. A creative product follows the accepted and understood rules of the discipline. ①②③④⑤⑥⑦
6. A creative product has clear and practical implications ①②③④⑤⑥⑦
7. To be considered creative, a product in my field must be of value to the community at large. ①②③④⑤⑥⑦
8. A creative product breaks with the tradition from which it emerges. ①②③④⑤⑥⑦
9. Products are creative if they combine elements in unusual ways. ①②③④⑤⑥⑦
10. A product is creative if it commands the attention of a person using, listening to, or viewing it. ①②③④⑤⑥⑦

Product (continued)

11. A creative product in my field is easy to understand, interpret, or use. ① ② ③ ④ ⑤ ⑥ ⑦
12. The craft component of completed works is critical in determining how creative they are. ① ② ③ ④ ⑤ ⑥ ⑦
13. To be deemed creative, a product in my field must be revolutionary in some way. ① ② ③ ④ ⑤ ⑥ ⑦
14. A creative product in my field must conform to acceptable technical requirements. ① ② ③ ④ ⑤ ⑥ ⑦

Personal Traits

This section of the questionnaire asks you to evaluate the extent to which each of 29 statements relate to personal traits creative people in your field posses. Please fill in the number (*1 = not important, 7 = extremely important*) you feel best reflects how essential these statements are to personal traits of creative people in your subject area.

1. A creative person in my field can generate a large number of ideas that are relevant to the problem at hand. ① ② ③ ④ ⑤ ⑥ ⑦
2. Creative people in my subject area have an ability to produce uncommon or unique responses. ① ② ③ ④ ⑤ ⑥ ⑦
3. The ability to develop and elaborate upon ideas is a trait that creative people in my field possess. ① ② ③ ④ ⑤ ⑥ ⑦
4. A creative person considers a variety of types of information when thinking about a problem. ① ② ③ ④ ⑤ ⑥ ⑦
5. Being open minded is an important trait one must possess to be considered creative in my field. ① ② ③ ④ ⑤ ⑥ ⑦
6. When faced with a problem or challenge a creative person is able to distinguish clearly between relevant and irrelevant information. ① ② ③ ④ ⑤ ⑥ ⑦
7. The ability to resist the impulse to accept the first solution that comes to mind and to explore all possible ideas would be a trait of a creative person in my field. ① ② ③ ④ ⑤ ⑥ ⑦
8. Creative people in my subject area tap into their emotions in order to generate ideas or solutions to a problem or challenge. ① ② ③ ④ ⑤ ⑥ ⑦
9. A creative person has the ability to put together ideas into novel and pleasing combinations. ① ② ③ ④ ⑤ ⑥ ⑦
10. A creative person has the ability to fantasize and go beyond concrete reality. ① ② ③ ④ ⑤ ⑥ ⑦
11. A creative person seeks out ways to stimulate more than one of their senses to increase their flow of ideas. ① ② ③ ④ ⑤ ⑥ ⑦
12. A creative individual may look at everyday objects and see something novel and exciting. ① ② ③ ④ ⑤ ⑥ ⑦
13. A creative person in my field is interested in looking beyond exteriors; exploring the inner workings of an object, problem or idea. ① ② ③ ④ ⑤ ⑥ ⑦
14. The degree to which a person is able to look past the task at hand and visualize the systems it functions in is a characteristic of a creative person. ① ② ③ ④ ⑤ ⑥ ⑦
15. Creative people in my field have the ability to see peculiarity and have the ability to combine ideas or images in unusual ways that evoke surprise. ① ② ③ ④ ⑤ ⑥ ⑦
16. In my field the ability to be humorous or playful is an indicator of a creative person. ① ② ③ ④ ⑤ ⑥ ⑦
17. A key component of a creative person in my field is a concern for the future, and a desire to be a part of its shaping. ① ② ③ ④ ⑤ ⑥ ⑦
18. Creative people in my field usually show unusual interest in their particular pursuit. ① ② ③ ④ ⑤ ⑥ ⑦
19. Creative people in my field have great tolerance for vagueness. ① ② ③ ④ ⑤ ⑥ ⑦
20. Creative people in my field possess great knowledge of the principles and theories relating to their area of interest. ① ② ③ ④ ⑤ ⑥ ⑦
21. Creative people in my field are known for the persistence that they bring to their work. ① ② ③ ④ ⑤ ⑥ ⑦
22. Creative people in my field have the ability to improvise. ① ② ③ ④ ⑤ ⑥ ⑦

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Personal Traits (continued)

		Not Important						Extremely Important
23.	Creativity in my field is really a gift that cannot be taught.	1 2 3 4 5 6 7
24.	Creative people are seldom satisfied with their work and would rather not bring quick closure to a task.	1 2 3 4 5 6 7
25.	Creative people display flexibility of mind; they are capable of changing their mental set easily.	1 2 3 4 5 6 7
26.	Creative people can manipulate many related ideas at the same time.	1 2 3 4 5 6 7
27.	Creative people possess high intrinsic motivation for their work.	1 2 3 4 5 6 7
28.	Creative people tend to have novel ideas relating to their subject.	1 2 3 4 5 6 7
29.	Creative people have high sensitivity to problems: they can see challenges in situations where others are oblivious to them.	1 2 3 4 5 6 7

Environment

This section of the questionnaire asks you to evaluate the extent to which each of 15 statements relate to the role environment plays in promoting creativity in your field. Please circle the number (1 = *not important*, 7 = *extremely important*) you feel best reflects the degree in which environment contributes to creativity in your subject area.

		Not Important						Extremely Important
1.	Creativity is enhanced when people work in groups.	1 2 3 4 5 6 7
2.	Creativity is enhanced in environments that allow risk taking.	1 2 3 4 5 6 7
3.	Creative people in my field tend to be more productive when they work by themselves.	1 2 3 4 5 6 7
4.	In my field work environments that are open and offer flexibility are aids to creative work.	1 2 3 4 5 6 7
5.	Classrooms that offer structure can be beneficial to the development of creativity.	
6.	An atmosphere of competition tends to have a positive effect on creative work.	1 2 3 4 5 6 7
7.	Creativity is aided in environments that offer rewards for such work.	1 2 3 4 5 6 7
8.	Creativity is aided in environments that offer feedback about a person's work.	1 2 3 4 5 6 7
9.	Being able to work within constraints is a measure of creativity.	1 2 3 4 5 6 7
10.	Creativity is fostered when people are encouraged to pursue activities that are of interest to them.	1 2 3 4 5 6 7
11.	Creativity is more likely to be achieved when one's activities are aimed towards a goal.	1 2 3 4 5 6 7
12.	Creative environments are usually messy or chaotic.	1 2 3 4 5 6 7
13.	In the classroom creativity is aided if the teacher provides guidelines for how the work should proceed.	1 2 3 4 5 6 7
14.	In the classroom students are more likely to be creative when the teacher allows them freedom to work in their own way.	1 2 3 4 5 6 7
15.	Students are more likely to produce creative work if they receive sound instruction in the knowledge and principles relating to their work.	1 2 3 4 5 6 7

Appendix C Mean Comparison of the Creative Process Items

	Items/Statements	Art		Music		Technology		
		Mean	SD	Mean	SD	Mean	SD	P
Q6	Having relevant knowledge of prior products or solutions is an important aspect of creative work.	5.39	1.29	5.38	1.16	5.26	1.45	.856
Q7	To produce creative work a person must be familiar with standards for acceptable solutions.	4.57	1.60	5.00	1.49	4.95	1.43	.143
Q8	The creative process requires the ability to generate a number of exploratory ideas or solutions.	6.32	.83	6.02	.93	6.10	1.10	.082
Q9	Finding or identifying challenging problems is a critical dimension of the creative process	5.61	1.26	5.37	1.34	5.19	1.25	.206
Q10	Creativity includes the ability to find gaps, inconsistencies or flaws in existing solutions.	5.57	1.14	5.13	1.38	5.26	1.33	.070
Q11	Generating a representation of the problem or challenge is part of the creative process.	5.33	1.10	4.88	1.32	5.26	1.08	.024
Q12	Seeking out reactions to possible solutions is an important dimension of the creative process.	5.16	1.34	4.94	1.52	5.14	1.20	.487
Q13	The creative process sometimes requires taking a break from the problem or challenge at hand to allow ideas to incubate.	6.29	.90	5.99	1.18	5.38	1.41	.000*

N Art = 75, n Music = 127, n Technology =42, *sig. p

		Art		Music		Technology		
	Items/Statements	Mean	SD	Mean	SD	Mean	SD	P
Q14	Creative solutions sometimes come to mind as a "flash" or sudden awareness	6.23	.97	6.08	1.08	5.79	1.07	.093
Q15	Metaphors and analogies are useful aids in creative thinking.	5.93	1.26	5.86	1.08	5.33	1.05	.015*
Q16	The act of creating sometimes involves reformulation of the initial problem or challenge as one becomes engaged in the work.	6.08	.88	5.57	1.04	5.62	.96	.001*
Q17	The creative process may begin even though the final product may not be formed in the "mind's eye".	6.32	.83	6.06	.98	5.76	.91	.007*
Q18	The creative process often includes gathering and drawing upon all resources that can be helpful in completing a task.	6.08	1.00	5.81	1.03	6.02	1.00	.151
Q19	The possession of relevant knowledge is an important aid to the creative process.	5.76	1.05	5.82	1.11	5.52	1.09	.319
Q20	Creativity is improved if a person that is familiar with technical rules.	4.93	1.48	4.79	1.57	4.83	1.64	.823
Q21	Creativity is improved if a person is familiar with relevant principles or theories.	5.04	1.34	5.08	1.40	5.31	1.12	.548

N Art = 75, n Music = 127, n Technology =42,
*sig. p

Appendix D Mean Comparison of the Creative Product Items

Items/Statements	Art		Music		Technology		P
	Mean	SD	Mean	SD	Mean	SD	
Q22 In my field, a creative product must posses a high degree of novelty.	4.64	1.49	3.95	1.51	4.10	1.69	.009*
Q23 A creative product is likely to influence or suggest additional future creative products.	5.67	1.16	5.06	1.28	5.07	1.35	.003*
Q24 A product is considered creative if it is unusual or seen infrequently in the category to which it belongs.	4.88	1.65	4.13	1.44	4.24	1.46	.003*
Q25 The degree to which a product responds to a need or problem determines its level of creativity.	4.05	1.58	3.57	1.59	4.74	1.29	.000*
Q26 A creative product follows the accepted and understood rules of the discipline.	3.48	1.48	3.55	1.63	4.00	1.25	.183
Q27 A creative product has clear and practical implications.	2.95	1.43	3.63	1.69	5.00	1.23	.000*
Q28 To be considered creative, a product in my field must be of value to the community at large.	2.72	1.43	3.31	1.73	4.60	1.27	.000*
Q29 A creative product breaks with the tradition from which it emerges.	4.55	1.79	3.92	1.50	4.93	1.35	.000*

N Art = 75, n Music = 127, n Technology =42
*sig. p

Items/Statements	Art		Music		Technology		
	Mean	SD	Mean	SD	Mean	SD	P
Q30 Products are creative if they combine elements in unusual ways.	5.57	1.25	5.01	1.17	4.98	1.24	.003*
Q31 A product is creative if it commands the attention of a person using, listening to, or viewing it.	5.25	1.41	5.18	1.41	4.86	1.35	.316
Q32 A creative product in my field is easy to understand, interpret, or use.	3.19	1.52	4.07	1.47	4.93	1.22	.000*
Q33 The craft component of completed works is critical in determining how creative they are.	3.49	1.56	4.11	1.38	4.45	1.19	.001*
Q34 To be deemed creative, a product in my field must be revolutionary in some way.	4.00	1.69	3.53	1.47	4.24	1.30	.014*
Q35 A creative product in my field must conform to acceptable technical requirements.	3.24	1.45	3.54	1.67	4.88	1.35	.000*

N Art = 75, n Music = 127, n Technology =42
*sig. p

Appendix E Mean Comparison of the Personal Trait Items

Items/Statements	Art		Music		Technology		P
	Mean	SD	Mean	SD	Mean	SD	
Q36 A creative person in my field can generate a large number of ideas that are relevant to the problem at hand.	5.71	1.28	5.21	1.28	5.57	1.15	.020
Q37 Creative people in my subject area have an ability to produce uncommon or unique responses.	6.15	.82	5.70	.93	5.57	1.17	.001*
Q38 The ability to develop and elaborate upon ideas is a trait that creative people in my field possess.	6.21	.91	5.94	.98	5.90	1.10	.112
Q39 A creative person considers a variety of types of information when thinking about a problem.	6.25	.90	5.74	1.11	6.05	.94	.002*
Q40 Being open minded is an important trait one must possess to be considered creative in my field.	6.33	1.06	5.87	1.36	6.29	.74	.013*
Q41 When faced with a problem or challenge a creative person is able to distinguish clearly between relevant and irrelevant information.	4.99	1.34	5.16	1.30	5.45	.97	.163
Q42 The ability to resist the impulse to accept the first solution that comes to mind and to explore all possible ideas would be a trait of a creative person in my field.	5.71	1.39	5.14	1.43	5.67	1.28	.010*
Q43 Creative people in my subject area tap into their emotions in order to generate ideas or solutions to a problem or challenge.	5.81	1.01	6.05	.995	3.86	1.59	.000*
Q44 A creative person has the ability to put together ideas into novel and pleasing combinations.	6.00	.97	5.85	1.10	5.00	1.36	.000*

N Art = 75, n Music = 127, n Technology =42
*sig. p

Items/Statements	Art		Music		Technology		
	Mean	SD	Mean	SD	Mean	SD	P
Q45 A creative person has the ability to fantasize and go beyond concrete reality.	6.21	.87	5.99	1.18	5.64	.96	.021
Q46 A creative person seeks out ways to stimulate more than one of their senses to increase their flow of ideas.	5.88	1.12	5.75	1.27	5.05	1.38	.002*
Q47 A creative individual may look at everyday objects and see something novel and exciting.	6.45	.70	5.85	1.22	5.79	1.03	.000*
Q48 A creative person in my field is interested in looking beyond exteriors; exploring the inner workings of an object, problem or idea.	6.07	.95	5.70	1.25	5.81	1.09	.093
Q49 The degree to which a person is able to look past the task at hand and visualize the systems it functions in is a characteristic of a creative person.	5.68	.99	5.28	1.32	5.62	1.08	.045
Q50 Creative people in my field have the ability to see peculiarity and have the ability to combine ideas or images in unusual ways that evoke surprise.	6.16	.87	5.58	1.19	5.31	1.07	.000*
Q51 In my field the ability to be humorous or playful is an indicator of a creative person.	5.03	1.57	5.34	1.46	4.29	1.66	.001*
Q52 A key component of a creative person in my field is a concern for the future, and a desire to be a part of its shaping.	4.69	1.48	4.82	1.61	5.40	1.23	.042
Q53 Creative people in my field usually show unusual interest in their particular pursuit.	5.49	1.29	5.94	1.11	5.52	1.13	.014*

N Art = 75, n Music = 127, n Technology =42
*sig. p

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Items/Statements	Art		Music		Technology		
	Mean	SD	Mean	SD	Mean	SD	P
Q54 Creative people in my field have great tolerance for vagueness.	4.48	1.66	3.84	1.56	4.10	1.78	.028
Q55 Creative people in my field possess great knowledge of the principles and theories relating to their area of interest.	5.37	1.30	5.38	1.29	5.55	1.06	.733
Q56 Creative people in my field are known for the persistence that they bring to their work.	5.79	1.20	5.92	1.21	5.81	.80	.692
Q57 Creative people in my field have the ability to improvise.	6.43	.81	6.48	.87	6.36	.73	.675
Q58 Creativity in my field is really a gift that cannot be taught.	3.73	1.70	4.38	1.70	3.71	1.73	.013*
Q59 Creative people are seldom satisfied with their work and would rather not bring quick closure to a task.	4.61	1.43	4.87	1.42	4.55	1.42	.315
Q60 Creative people display flexibility of mind; they are capable of changing their mental set easily.	5.45	1.15	5.06	1.17	4.86	1.34	.018*
Q61 Creative people can manipulate many related ideas at the same time.	5.71	1.04	5.48	1.19	5.19	1.33	.072
Q62 Creative people possess high intrinsic motivation for their work.	5.95	1.10	6.00	1.31	5.55	.99	.066
Q63 Creative people tend to have novel ideas relating to their subject.	5.81	1.15	5.78	1.13	5.38	.854	.087
Q64 Creative people have high sensitivity to problems: they can see challenges in situations where others are oblivious to them.	5.64	1.07	5.56	1.13	5.64	.96	.856

N Art = 75, n Music = 127, n Technology =42
*sig. p

Appendix F Mean Comparison of the Creative Environment Items

Items/Statements	Art		Music		Technology		
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**p**
Q65 Creativity is enhanced when people work in groups.	4.03	1.66	4.45	1.71	5.14	1.42	.002*
Q66 Creativity is enhanced in environments that allow risk taking.	6.41	.89	6.16	1.14	6.07	.95	.144
Q67 Creative people in my field tend to be more productive when they work by themselves.	4.63	1.45	4.39	1.51	4.10	1.61	.186
Q68 In my field work environments that are open and offer flexibility are aids to creative work.	6.05	1.13	5.74	1.26	5.60	1.28	.105
Q69 Classrooms that offer structure can be beneficial to the development of creativity.	5.12	1.40	4.97	1.39	4.93	1.26	.688
Q70 An atmosphere of competition tends to have a positive effect on creative work.	3.97	1.55	3.75	1.63	5.14	1.34	.000*
Q71 Creativity is aided in environments that offer rewards for such work.	4.17	1.54	4.37	1.52	5.55	.92	.000*
Q72 Creativity is aided in environments that offer feedback about a person's work.	5.83	1.19	5.48	1.24	5.64	1.01	.137
Q73 Being able to work within constraints is a measure of creativity.	4.69	1.78	4.53	1.72	4.83	1.36	.559
Q74 Creativity is fostered when people are encouraged to pursue activities that are of interest to them.	6.09	1.04	6.25	.89	5.95	.85	.172

N Art = 75, n Music = 127, n Technology =42
*sig. p

Items/Statements	Art		Music		Technology		
	Mean	SD	Mean	SD	Mean	SD	p
Q75 Creativity is more likely to be achieved when one's activities are aimed towards a goal.	5.24	1.21	5.64	1.14	5.69	1.07	.034
Q76 Creative environments are usually messy or chaotic.	3.63	1.60	3.90	1.61	4.00	1.56	.377
Q77 In the classroom creativity is aided if the teacher provides guidelines for how the work should proceed.	5.01	1.36	5.09	1.30	4.64	1.27	.163
Q78 In the classroom students are more likely to be creative when the teacher allows them freedom to work in their own way.	5.12	1.30	5.14	1.26	5.26	1.23	.832
Q79 Students are more likely to produce creative work if they receive sound instruction in the knowledge and principles relating to their work.	5.65	1.16	5.78	1.18	5.43	1.25	.250

N Art = 75, n Music = 127, n Technology =42
*sig p