J-STEM

Journal of Research in STEM Education

Vol 3, No 1/2, December 2017

j-stem.net

EDITORIAL BOARD

Editor-in-Chief

Mehmet Aydeniz, The University of Tennessee, USA

Associate Editors

Lynn Liao Hodge, The University of Tennessee, USA
Gokhan Kaya, Kastamonu University, Turkey

Editorial Board

Mandy Biggers, Pennsylvania State University, USA
Margaret Blanchard, North Carolina State University, USA
Gultekin Cakmakci, Hacettepe University, Turkey
Csaba Csíkos, University of Szeged, Hungary
Patrick Enderle, University of Texas at Austin, USA
Gunnar Friege, Universität Hannover, Germany
Christine Harrison, King's College London, U.K.
Teruni Lamberg, University of Nevada, Reno, USA
Erin Peters-Burton, George Washington University, USA
Ji-Won Son, University at Buffalo, USA
Jana Visnovska, University of Queensland, Australia
Susan Yoon, University of Pennsylvania, USA

Contact

All queries related to manuscript submissions can be directed to Dr. Aydeniz, the Editor-in-Chief, jstemeditor@gmail.com

Mehmet Aydeniz, PhD.
Associate Professor of Science Education.
Program Coordinator, Science Education.
Department of Theory and Practice in Teacher Education
The University of Tennessee, Knoxville
A 408 Jane & David Bailey Education Complex
Knoxville, TN 37996-3442
USA
Phone: +1-865-974-0885

Publisher / Founder : i-STEM / Gultekin Cakmakci

ISSN:2149-8504

Contents

Papers	Page Number(s)
Real STEM: An Interdisciplinary STEM Program *Robert Mayes, Kent Rittschof, Bryon Gallant, Charlie Martin*	1-16
Persistence in STEM Majors: Investigating Whether and When High-Performing Students Leave STEM during Undergraduate Studies *Christopher W. Kohler*	17-33
Discourses that Inform the Chilly Climate in Math and Physics *Laura Parson, C. Casey Ozaki*	34-47
Elementary Teachers' Perceptions of Engineering and Engineering Design *Rebekah Hammack, Toni Ivey*	48-68

ISSN:2149-8504 (online)

Journal of Research in STEM Education

Vol 3, No 1/2, December 2017, 1-16

RESEARCH REPORT

Real STEM: An Interdisciplinary STEM Program

Robert Mayes[a1], Kent Rittschof [a], Bryon Gallant[a], Charlie Martin[b]

[a]*Georgia Southern University, USA;* [b]*Georgia College and State University, USA*

Abstract: *The integration of STEM programs within the educational framework through the establishment of STEM-designated schools and academic/career pathways is a national trend in the United States. The goal of implementing STEM in grade 6 to 12 schools is to prepare students for the demands of the 21st century, while addressing future workforce needs. Often, however, the STEM disciplines are taught within silos independent of each other. Students miss the opportunity to participate in the interrelationship between the STEM disciplines, resulting in missed opportunities to build critical reasoning skills. The Real STEM project focused on the development of interdisciplinary STEM experiences for students. The project was characterized by sustained professional development which was job-embedded and competency-based, and focused on the development of five STEM reasoning abilities within real-world contexts. To accomplish this we promoted inclusion of tasks that drew on multiple STEM disciplines, embraced the use of authentic teaching strategies, and supported development of collaboration through interdisciplinary STEM professional learning communities within the school and STEM experts from the community. The four tenets of the Real STEM project are presented, research on impact on teacher practice is provided, and school and teacher takeaways are discussed.*

Keywords: Interdisciplinary STEM, authentic teaching, collaboration, reasoning

Real STEM: An Interdisciplinary STEM Program

The integration of STEM into schools is a national trend in the United states, apparent in the call to establish STEM designated middle and high schools (President's Council of Advisors on Science and Technology, 2010; Tanenbaum, 2016), as well as in the creation of STEM academic/career pathways for future workforce development (National Research Council, 2013). The Next Generation Science Standards (2013) and the Common Core State Standards for Mathematical Practice (National Governors Association, 2010) provide science and engineering practices and mathematical practices that support the inclusion of STEM in schools. These practices include modeling, integrating mathematics and computational thinking into science, planning and carrying out investigations of real world problems, analyzing and interpreting data, and designing solutions. An important question that emerged from our project around implementation of these interdisciplinary practices was, how do educators trained in one of the STEM domains incorporate the less familiar practices into their schools and classrooms?

The Real STEM project addressed what we believe is one essential component in integrating STEM into middle schools (students ages 11 to 13) and high schools (students ages 14-18): sustained professional development in interdisciplinary STEM. Sustained professional development is job-embedded (Croft, Coggshall,

---

[1] Corresponding Author: Department of Teaching and Learning, Georgia Southern University, Statesboro, GA 30460. Contact: rmayes@georgiasouthern.edu

Mayes, R., Rittschof, K., Gallant, B., & Martin, C. (2017). Real STEM: An Interdisciplinary STEM Program. *Journal of Research in STEM Education*, *3*(1/2), 1-16.

ISSN:2149-8504 (online)

Dolan, and Powers, 2010; Huffman, Hipp, Pankake, and Moller, 2014) and competency-based (Burke, 2005), with the aims of building interdisciplinary professional learning communities (PLCs) consisting of school administrators and teachers of science, mathematics, technology, and engineering (Fulton and Britton, 2011). We conjectured that an interdisciplinary STEM program should provide support and mentoring for teachers in the following four key tenets supporting STEM teaching and learning:

- Interdisciplinary STEM: ensuring STEM is taught as an interdisciplinary approach (Stohlmann, Moore, and Roehrig, 2012)
- Authentic Teaching Strategies: incorporating project-based teaching, problem-based teaching, and place-based education strategies to actively engage students (Bell, 2010; Thomas, J. W., 2000; Boud and Feletti, 2013; Smith and Sobel, 2010)
- Collaboration: creating STEM PLCs within the school supported by community, business, research institute and school partnerships (Blankenship and Ruona, 2006; Council for Corporate and School Partnerships, 2001)
- STEM Reasoning: setting outcomes that go beyond student engagement to development of five 21st century STEM reasoning abilities (Holland, 2014; Schwarz, 2009; Wing, 2006; Householder and Hailey, 2012; Mayes, Forrester, Christus, Peterson, & Walker, 2014)

Within this report, we first discuss the Real STEM project which was designed to actively engage schools in these tenets. Second, we present some results of the project impact on teacher practice. Third, we share some of what we saw as critical takeaways for successful implementation of interdisciplinary STEM programs in schools.

Real Stem Project

The Real STEM project was funded by the Georgia Department of Education Innovation Fund to provide professional development supporting implementation of interdisciplinary STEM experiences through course modules in existing courses, as well as through new interdisciplinary STEM courses at the middle school and high school grade levels. The project supported development of interdisciplinary STEM professional learning communities of teachers in 12 schools in Georgia, six paired high schools and feeder middle schools.

The primary student outcomes of the project were to 1) increase student engagement and persistence in STEM and 2) improve students' STEM reasoning. The intended long term outcomes of Real STEM were to meet future STEM workforce needs by increasing student retention in the STEM pipeline and to develop STEM literate citizens who can make informed decisions about grand challenges impacting their future. Teachers participated in summer workshops with professional development field experiences that prepared them to guide students in authentic interdisciplinary STEM research, modeling, and design experiences. As a part of these authentic experiences, teachers were mentored on collaborating with regional STEM experts and interdisciplinary STEM faculty to identify authentic place-based STEM challenges. The STEM research design experience was to be student centric, with students formulating research questions within the frame of challenges identified by STEM experts. The STEM experts were to mentor the teachers and support students as they explored their problem, collected data, and analyzed the data. These experts also served on panels to which students reported findings. Students were required to view the problem through interdisciplinary STEM lenses, bringing chemistry, biology, physics, earth sciences, computational science, engineering, and mathematics to bear on the problem where appropriate. The Real STEM leadership team led the summer workshop and conducted monthly classroom observations in the 12 partner schools over the five years of the project. The leadership team also studied the impact of the Real STEM program on 1) teacher practice, 2) student affect, and 3) student learning. The four tenets of the Real STEM program are described in the following sections.

Tenet 1: Interdisciplinary STEM Inclusion

We take the perspective that a meaningful STEM task must incorporate at least two of the four STEM fields (Fig. 1). In our work with schools, we saw teacher's challenged to reach beyond their area of expertise to implement interdisciplinary tasks. We observed a lot of science and mathematics (S&M) tasks "done to students" without meaningful interdisciplinary integration, as well as a lack of technology or engineering (T&E) integration into tasks. We ask teachers to start by having students view problems through all four STEM lenses, before eliminating those that do not apply. We stress use of real-world problems, which are often interdisciplinary and occur in complex systems. This requires moving beyond teaching STEM in traditional content silos to taking an interdisciplinary STEM perspective. We also need to move beyond the traditional science paradigms of experimental science and theoretical science, to include the newer paradigms of computational science and data-intensive science (the T in STEM).

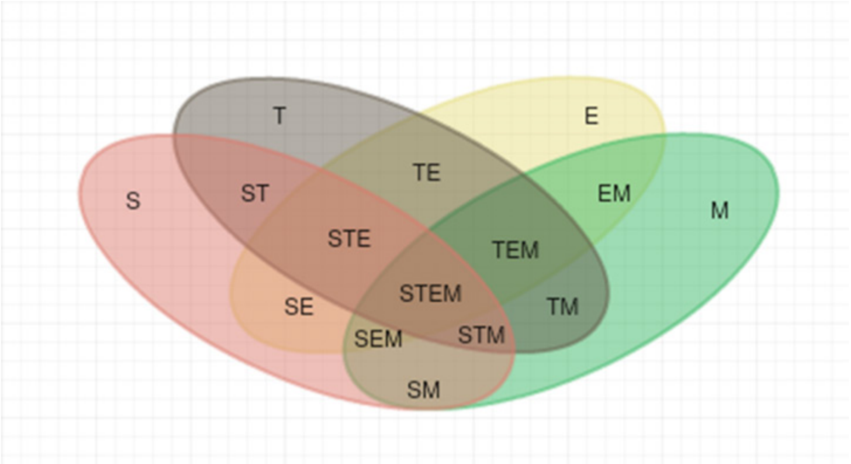


Figure 1. STEM is interdisciplinary, occurring at the intersection of at least two STEM fields

Tenet 2: Authentic Teaching Strategies

A primary project goal of integrating STEM into a school is to provide students with the opportunity to engage in real-world problem solving through hands-on experimentation, research, modeling, and design challenges. Broadening participation in STEM is best accomplished by moving towards more student-centric practices and moving away from the traditional teacher-directed classroom (Jones, 2007). We mentor teachers in implementing authentic teaching strategies including project-based learning (Buck Institute for Education, 2017), problem-based learning (Savery, 2006; Strobel and Barheveld, 2009), and place-based education (Smith and Sobel, 2010). A review of the literature provided a number of desirable authentic teaching characteristics (Edelson and Reiser, 2006) which are listed in Table 1.

Table 1.

Authentic Teaching and Learning Design Elements

1.Real-world relevance	Learning rises to the level of authenticity when it asks students to work actively with abstract concepts, facts, and formulae inside a realistic—and highly social—context mimicking the real world.
2. Ill-defined problem	Challenges cannot be solved easily by the application of an existing algorithm; instead, activities are relatively undefined and open to multiple interpretations, requiring students to identify the tasks and subtasks needed to complete the major task.
3. Sustained investigation	Authentic activities comprise complex tasks to be investigated by students over a sustained period of time.
4. Multiple sources and perspectives	Authentic activities provide the opportunity for students to examine the task from a variety of theoretical and practical perspectives, using a variety of resources, which requires students to distinguish relevant information in the process.
5. Collaboration	Authentic activities make collaboration integral to the task, both within the course and in the real world.
6. Reflection (metacognition)	Authentic activities enable learners to make choices and reflect on their learning, both individually and as a team.
7. Interdisciplinary perspective	Authentic activities have consequences that extend beyond a particular discipline, encouraging students to adopt diverse roles and think in interdisciplinary terms.
8. Integrated assessment	Assessment is not merely summative in authentic activities but is woven seamlessly into the major task in a manner that reflects real-world evaluation processes.
9. Polished products	Authentic activities culminate in the creation of a whole product, valuable in its own right.
10. Multiple interpretations and outcomes	Rather than yielding a single correct answer obtained by the application of rules and procedures, authentic activities allow for diverse interpretations and competing solutions.

We found project-based learning to be a good initial step in implementing authentic teaching strategies. Project-based learning allows the teacher to remain in control of assigning the task, such as this Real STEM teacher engaging students in engineering water bottle rockets (Fig. 2). Project-based learning allows for inclusion of several but not all of the authentic learning characteristics including: 3) sustained investigation; 5) student collaboration through small group design teams; 6) reflection on learning; 7) interdisciplinary approaches; 8) integrated assessment through a performance task demonstrating understanding; and 9) polished final products.

Figure 2. Project-based learning: Engineering water bottle rockets

Teacher-assigned projects allow the teacher to target specific STEM concepts, however this potentially restricts addressing other desirable authentic learning characteristics, including 1) real-world relevance for the student; 2) ill-defined, more open-ended problems; 4) requiring research into multiple sources and perspectives; and 10) diverse interpretations and outcomes.

Problem-based learning can potentially incorporate all ten authentic learning characteristics, but this requires that teachers allow student input on selection of the problem. We found 1) real-world relevance for the student often was lacking if the teacher selected the problem. The more student-centric the problem selection was, the greater the potential engagement of the student. For example, a Real STEM teacher had students brainstorm potential STEM projects. The students chose the problem of building a full-scale electric car powered by a solar panel (Fig. 3).

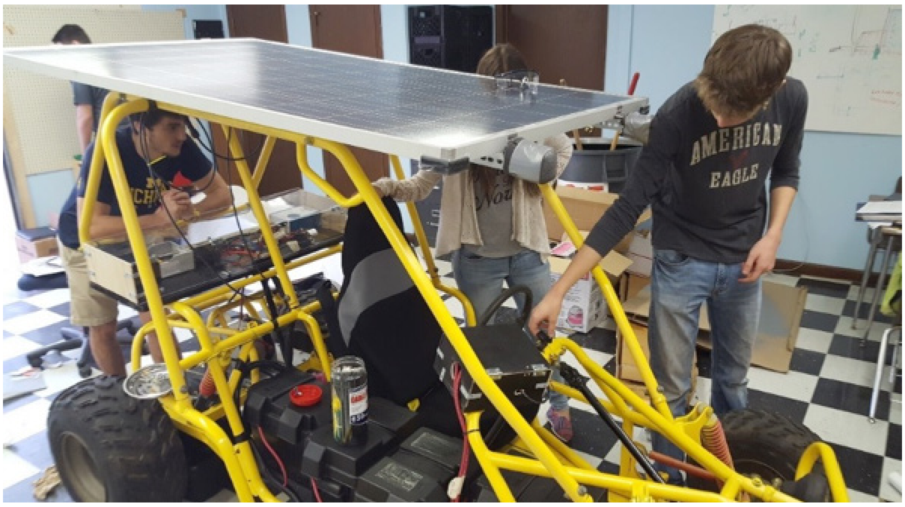


Figure 3. Problem-based learning: Designing an electric car

The students formed teams to work on different components of the car. The car is currently underway using battery power, though they were still working on incorporating the solar panel. Student selected problems can potentially come at the cost of targeting specific STEM concepts, since the problem drives what is studied. In response, learning outcomes need to shift from pre-determined content understanding to process abilities, such as reasoning and problem solving.

Place-based education incorporates authentic teaching elements 2 through 10, embraces a student-centric focus, and motivates the final element: 1) real world relevance tied to student's locale. Students work within a realistic, social context related to their local place, providing the opportunity for a maximum student-centric experience. We explore with teachers grand challenges within STEM fields identified by national/international experts, such as the eight grand challenges of environmental science (National Research Council, 2001). Students connect the challenges to their locale and identify problems they would be interested in studying, following the environmental science call to "think globally, act locally". The problems are vetted through student peer mentors, the teacher professional learning communities, and community STEM experts. One of our Real STEM schools chose the grand challenge of hydrological forecasting. They revitalized a pond on the school property, studying parking lot drainage issues and the pond ecosystem (Fig. 4). The teacher professional learning communities in our partner schools have incorporated grand challenge problems into existing classes through STEM Fridays (dedicating a day to STEM) or by developing new STEM courses.

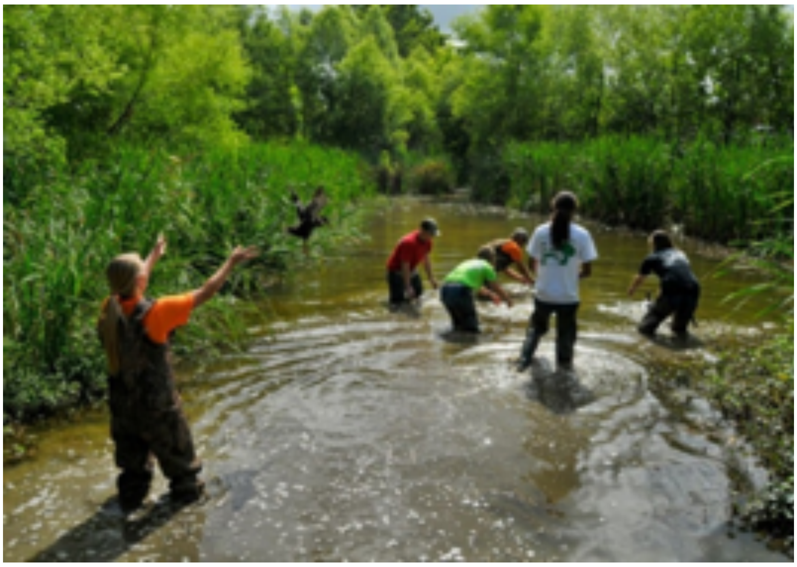


Figure 4. Place-based Education: Revitalizing a pond near the school

Tenet 3: Community Collaboration

Interdisciplinary STEM requires a team approach to teaching in order to support authentic real-world ill-structured problems (Blankenship and Ruona, 2006). Few teachers have the expertise to address different STEM aspects of such problems. First, teachers have to be comfortable with not knowing all the answers, and to be confident in saying, "I do not know, but let's work together to find out." Second, a strong teacher professional learning community is essential in providing expertise from multiple STEM areas. Real STEM schools established interdisciplinary STEM learning communities that included, at-minimum, teachers of science and mathematics, and when available engineering and technology teachers, as well as an administrator. The professional learning communities were to meet regularly to consult on implementing STEM tasks. Third, development of collaborations with STEM community experts is essential, including establishing STEM Advisory Boards consisting of business, industry, research institute, and government representatives (Council for Corporate and School Partnerships, 2001). We explore a continuum of STEM expert support levels with our participating partners: low intensity (guest expert, field trip), moderate intensity (mentor, STEM problem/challenge, funding STEM materials/supplies), and high intensity (teacher externship, student internship, funding STEM professional development). Further, the Real STEM project hosted field trips for teachers to interact with STEM experts from areas as diverse as agriculture, energy, and ocean science (Fig. 5).

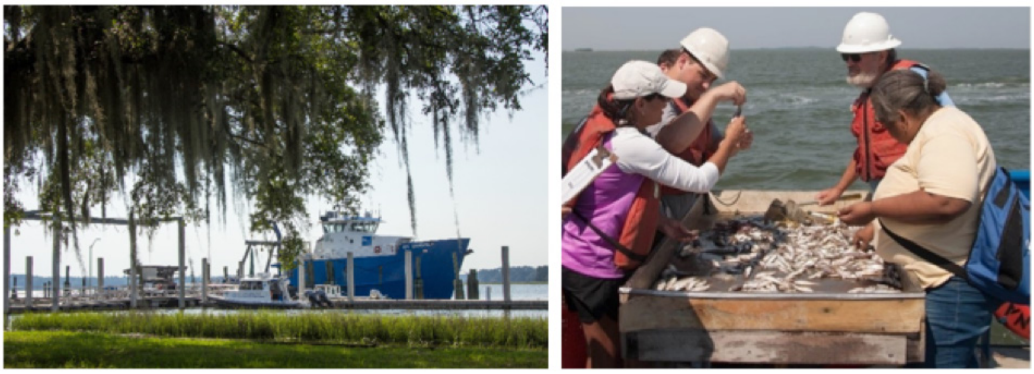


Figure 5. Teacher field trip on the UGA SKIO research vessel R/V Savannah, sailing out of Skidaway Institute for Oceanography: Teachers assist scientists with count from a trawling run. We thank the University of Georgia, Skidaway Institute of Oceanography for providing opportunities to REAL STEM members to participate in Oceanographic Research Expeditions aboard the Research Vessel Savannah. Ship time was

ISSN:2149-8504 (online)

supported by the US National Science Foundation in association with award OCE 1459293 to Marc E Frischer.

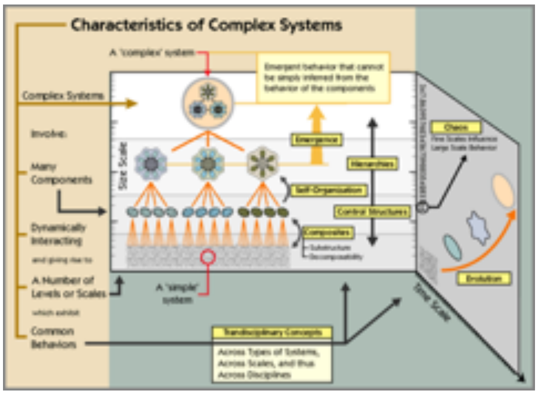
Tenet 4: Reasoning Outcomes

For interdisciplinary STEM programs to grow and be sustained they must do more than increase student engagement. STEM programs need to have established learning outcomes. What are the standards addressed by a STEM experience? What does STEM do for school science and mathematics test scores? We believe that the more student-centric and ill-structured a problem is, the more difficult it is to connect with predetermined STEM content standards. In fact, attempting to do so may inversely impact the open-ended nature of STEM tasks. To help address this dilemma we collaborate with teachers on linking their STEM tasks to process standards. The learning outcomes we highlight are the development of student ability to think like a scientist, think like a computer scientist, think like an engineer, and think like a mathematician. STEM experts have different problem solving processes, which while they overlap are not the same. Our review of the literature resulted in the identification of five STEM reasoning modalities which are 21st century abilities STEM experts call for students to develop: complex systems reasoning, scientific model-based reasoning, technological computational reasoning, engineering design-based reasoning, and mathematical quantitative reasoning. Figure 6 provides a short summary of the five reasoning abilities along with citations of some of the leading STEM experts promoting the reasoning abilities.

<table>
<tr><th>STEM Reasoning Ability</th><th>Visual Representation</th></tr>
<tr><td>

Complex system reasoning is the ability to analyze problems by recognizing complexity, patterns, and interrelationships within a system featuring a large number of interacting components (agents, processes, etc.) whose aggregate activity is nonlinear (not determined from the summations of the activity of individual components) and typically exhibits hierarchical self-organization under selective pressures (Holland, 2014)

</td><td>


Characteristics of Complex Systems
A 'complex' system
Emergent behavior that cannot be simply inferred from the behavior of the components
Complex Systems
Involve:
Many Components
Dynamically Interacting
and giving rise to
A Number of Levels or Scales
which exhibit
Common Behaviors
Size Scale
Emergence
Hierarchies
Self-Organization
Control Structures
Composites
Substructure
Decomposability
Chaos
Fine Scales Influence Large Scale Behavior
Evolution
A 'simple' system
Time Scale
Transdisciplinary Concepts
Across Types of Systems, Across Scales, and thus Across Disciplines

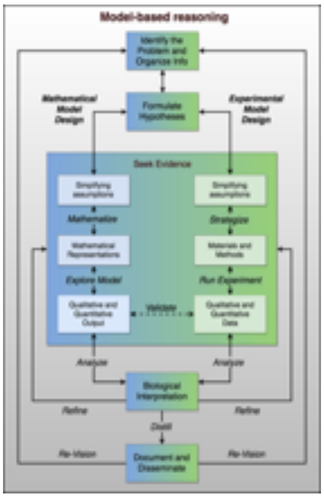
(New England Complex Systems Institute Website: http://www.necsi.edu/visual/systems.html)

</td></tr>
<tr><td>

Scientific Model-based Reasoning is the ability for students to construct scientific models in order to explain observed phenomena (Schwarz, 2009).

Engaging students with models and modeling is an epistemic approach which can provide opportunities to use widely shared scientific practices to make and evaluate knowledge claims. Modeling can support effective pedagogy because it provides students opportunities to ask questions, seek evidence, perform analyses, and construct arguments that can increase students' understanding of the scientific process and biological content. Modeling also affords opportunities for anchoring course content in real-world problems and facilitating metacognition (Dahlquist et al., 2018).

</td><td>


Model-based reasoning
Identify the Problem and Organize Info
Formulate Hypotheses
Mathematical Model Design
Experimental Model Design
Seek Evidence
Simplifying assumptions
Simplifying assumptions
Mathematize
Strategize
Mathematical Representations
Materials and Methods
Explore Model
Run Experiment
Qualitative and Quantitative Output
Validate
Qualitative and Quantitative Data
Analyze
Analyze
Biological Interpretation
Refine
Refine
Distill
Re-Vision
Re-Vision
Document and Disseminate

(Dahlquist et al., 2018)

</td></tr>
</table>

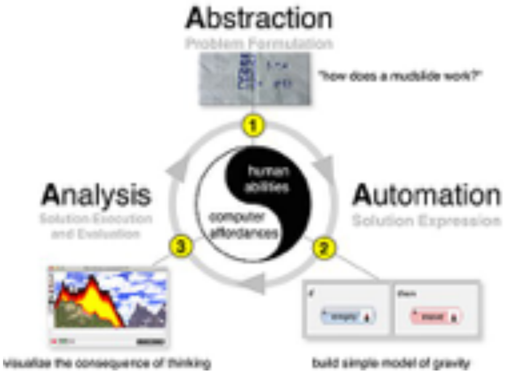
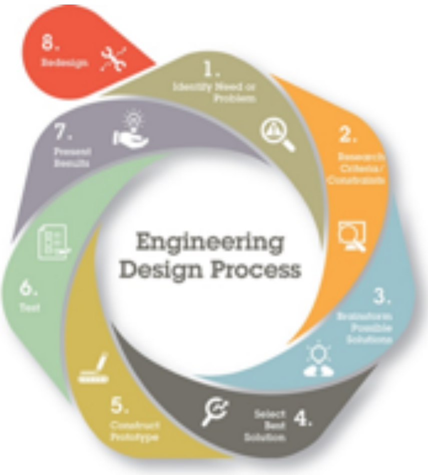
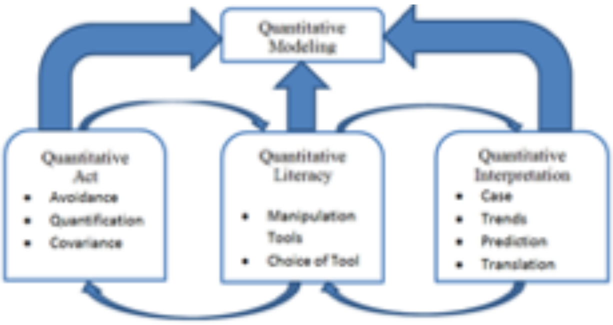
Technological Computational Reasoning is an analytical approach grounded in the computer sciences that includes a range of concepts, applications, tools, and skill sets that allow us to strategically solve problems, design systems, and understand human behavior by following a precise process that engages computers to assist in auto-mating a wide range of intellectual processes (Wing, 2006; Wilensky and Resnick, 1999)	 Abstraction Problem Formulation "how does a mudslide work?" 1 human abilities computer affordances Analysis Solution Execution and Evaluation Automation Solution Expression 2 3 visualize the consequence of thinking build simple model of gravity (Repenning, A. Basawapatna, and N. Escherle, 2016.)
Engineering Design-based Reasoning is the ability to engage in the engineering design process through implementation of a series of process steps to come up with a solution to a problem. Many times the solution involves designing a product (like a machine or computer code) that meets certain criteria and/or accomplishes a certain task (Householder and Hailey, 2012).	 8. Redesign 1. Identify Need or Problem 2. Research Criteria/ Constraints 3. Brainstorm Possible Solutions 4. Select Best Solution 5. Construct Prototype 6. Test 7. Present Results Engineering Design Process (Jenkins, 2015: Teaching Channel Website https://www.teachingchannel.org/blog/2015/09/29/rube-goldberg-machines-and-the-engineering-design-process/)
Mathematical Quantitative Reasoning is mathematics and statistics applied in real-life, authentic situations that impact an individual's life as a constructive, concerned, and reflective citizen. QR problems are context dependent, interdisciplinary, open-ended tasks that require critical thinking and the capacity to communicate a course of action (Mayes et al., 2014)	 Quantitative Modeling Quantitative Act Avoidance Quantification Covariance Quantitative Literacy Manipulation Tools Choice of Tool Quantitative Interpretation Case Trends Prediction Translation (Mayes et al., 2014)

Figure 6. STEM reasoning modalities and visual representations

Real Stem Evaluation

The Real STEM project gathered data on impact of the project on teacher practice, student affect, and student reasoning. The tools used to analyze impact are described in this section.

Teacher practice was assessed through teacher interviews with focus groups, a Teacher Practice Survey, and Reform Teaching Observation Protocol (RTOP; Piburn and Sawada, 2000) class observations. The external evaluator conducted interviews with focus groups of teachers at the close of the summer professional development. The interviews focused on teachers understanding of project expectations, potential challenges, development of business/research institute partnerships, and what support would be helpful in the future. The focus groups consisted of PLC teachers from each of the participating schools. The Teacher Practice Survey was based on the Concerns-Based Adoption Model (CBAM; Loucks-Horsely, 1996), providing data on teachers concerns, confidence, and commitment in implementing interdisciplinary STEM experiences in schools. The CBAM was administered online through the Qualtrics survey tool and analyzed by the external evaluator for the Real STEM project. The RTOP was conducted monthly by the Real STEM team during observations of classrooms implementing interdisciplinary STEM experiences. RTOP (Piburn and Sawada, 2000) is an observational instrument for reformed teaching. The RTOP was modified to include categories for authentic teaching and interdisciplinary STEM.

Student affect was assessed through a Real STEM Student Survey administered online through the Qualtric survey tool and analyzed by the external evaluator for the project. The student survey link was provided to lead teachers of the STEM courses in participating schools. The teachers were requested to have all students participating in Real STEM courses complete the survey. The Student STEM Reasoning Assessment was developed by the Real STEM project team to assess student STEM reasoning across all five reasoning areas identified for the project. The assessment is multiple choice and administered online using the Qualtric survey tool. The lead teachers of the STEM courses were asked to administer the assessment as a pre-post, but due to the variety in implementation of the STEM courses across schools some teachers selected only to give the reasoning assessment as a post-test and others did not give the assessment.

Results of impact on students will be reported in a future paper under development by the research team. Here we focus on the Real STEM projects impact on teacher practice. The Real STEM program evaluation indicated several successful outcomes and documented areas needing improvement.

Real STEM Focus Groups

In the two focus groups reported on here, seven middle grades teachers, one high school teacher, and one high school administrator participated. Three teachers had participated in Real STEM for one year, one teacher for three years, and one teacher had three-months experience. Three other teachers and the administrator were new to Real STEM.

Understanding of Real STEM expectations. Teachers appeared to have a clear understanding of expectations for the research class they were developing. They mentioned that the courses were to engage students in real-world problem-based activities and that they were to incorporate a variety of reasoning skills. One teacher emphasized that the course was to enable students to think like people in STEM disciplines. Teachers also mentioned that they were expected to meet as a professional learning community to work on the course. All expressed concerns about their ability to do this effectively given lack of common planning time and challenges for scheduling meetings out of school time.

Partnering with businesses, scientists, and research institutions. Participants mentioned a variety of partners who were working with their classes. Responses included descriptions of partners more actively engaged working with students and not simply providing materials or field trips for the classes. Examples included: Lowes manager working with financial aspects of building projects; high tech industry partners (Flight Safety International, Gulf Stream Aviation using 3D CAD software); partner donating 24 laptops to the program; Fish and Wildlife; Georgia Department of Natural Resources; former air force fighter pilot that taught students how to fly space shuttle simulator at school; Mitsubishi Systems; Plant Vogel waste management; businesses sharing jobs of the future; solar farm electrical; local lumber company and auto company providing supplies.

Teaching Reasoning Skills. Responses were limited regarding the teaching of reasoning skills. Teachers talked about projects for which students had to use reasoning skills, but little on how they were teaching reasoning skills. One group talked about modeling reasoning skills in their course or unit. Another described how they get students to understand the fundamentals of what they are doing and get them to extrapolate how to work their way around problems.

Challenges to implementation. Focus group participants mention a number of challenges to implementation. Areas mentioned included getting students to think for themselves and to be self-motivated to find and use data, not enough time to address focus of project and to teach reasoning skills, having to come up with your own problems, scaling from the number of students they are currently serving to meet increasing demand for the class, difficulty accomplishing all the goals (research, reasoning skills, develop partners) in a one-semester course, and not having sufficient working computers to meet needs of students. Finally, several teachers said that they had difficulty getting together for PLC meetings because they did not have common planning time.

Administrative support. There was variety in the level of administrative support among the participants. Several teachers said their principals were very supportive or flexible. Others said their principals were also supportive so long as it did not cost anything, they did not need anything, or it would not get them in trouble. However others commented that they had very little support from their administrators and that they did not know about the project or how to support it.

Support from Real STEM. Participants were consistent in their praise for the support they received from Real STEM. One teacher described her relationship with project leaders as "mature" in which information passed in two ways. They explained that it was very easy to call if they had questions or needed help. Teachers said that project personnel checked in with their project at least once a month and that they were in the schools for events like STEM nights. Real STEM also provided teachers with ideas for resources as well as bringing books and other materials. Teachers expressed need for the project to provide more support in how to select place-based problems and assistance in building STEM Advisory Boards.

Summary comments. The teacher focus group demonstrates the interest and activity in developing STEM partnerships with businesses and research institutes as called for by the Real STEM project. While the teachers showed a good understanding of the goals of Real STEM, the areas of concern with reasoning outcomes, PLC organization, and varied levels of administrative support are reflected in the other assessments of the program as well. The middle schools have found it easier to have PLCs collaborating on STEM research and design courses, due to the cross disciplinary team structures that exist in many middle schools and the availability of connections courses as a natural place to implement STEM courses. Connections courses are 8th grade classes that provide for exploration of topics that promote interest in high school pathways such as connected STEM courses. The more subject area silo structure of high schools and the development and staffing of new courses in STEM make it more challenging for high schools to implement STEM courses. In order to overcome the PLC and structure issues of implementing interdisciplinary STEM programs, it was essential to have administrative support and participation. The Real STEM project called for interdisciplinary STEM PLCs that included an administrator to serve as champion for the program. In schools where the administration has taken on this role the STEM programs have done well. When administrative support has been laissez-faire the program has been dropped or relied on the efforts of a teacher champion and continued in only one course.

Teacher Practice Survey

All teachers assigned to Interdisciplinary STEM Professional Learning Communities (PLC) in partner schools were invited to complete the Real STEM Teacher Survey. The total number of teachers engaged in PLCs across all partner schools was n = 65, of which 39 completed the survey (60% return rate). The return rate is indicative of the varying level of collaboration within the PLCs at different schools. PLCs varied in size from 2 to 17, with 8 of 12 PLCs of size 3 to 4. Some PLCs were very active, with the PLC team meeting regularly to plan tasks for the STEM courses, while other STEM courses were planned primarily by the lead teacher. Of those completing surveys, 7 (17.9%) were in their first semester as Real STEM participants, 22 (56.4%) were in their second semester, and 11 (28.2%) had participated in more than three semesters. When asked what best described their role in Real STEM, 11 (28.2%) responded that they taught a Real STEM course, 8 (20.5%) taught a module or unit, and 21 (53.8%) were members of learning communities.

The Teacher Survey is based on a Concerns-Based Adoption Model, a well-established model for studying how people develop as they learn about and adopt an innovation. The survey asks teachers to rate their level of concern, confidence and commitment with implementing the Real STEM tenets of 1) collaboration with experts; 2) authentic instruction; 3) teaching for understanding; 4) interdisciplinary STEM; and 5) STEM reasoning. The teachers rate their levels on a scale from 1 to 5 by reflecting back on how they felt at the beginning of participation in Real STEM and how they felt at the end of the school semester. Data from Fall 2016 on this survey indicated a statistically significant decrease in concern, increase in confidence, and increase in commitment to implementation on all five Real STEM tenets. We provide a more detailed analysis of the Spring 2017 implementation.

The results from the Spring 2017 implementation of the Teacher Survey are summarized in Table 2. The results from Fall 2016 were replicated, with statistically significant improvement (with probability level set to $p < .001$ to account for the multiple comparisons) on all three levels on all five tenets. The teachers were less concerned, more confident and had increased commitment to implement the tenets of the Real STEM Project. The average change across all levels was 1.2, moving from an average of 2.5 to 3.7 on a 5 point scale, or an approximately 48% average change from the initial rating toward more STEM supportive views among teachers. The highest final mean values are in the area of commitment to implement the tenets. While there was growth in all areas, there is room for improvement in all areas with no highest mean rating exceeding 4 out of a possible 5.

Table 2.

Teacher Survey Paired Sample T-test
Differences from beginning of participation to end of implementation

Levels	Tenets	Mean Begin	Mean End	Std. Dev.	T-value	p-value Significance
Concern	Collaboration Experts	2.08	3.54	1.144	-7.982	0.001
	Authentic Instruction	2.26	3.67	1.141	-7.721	0.001
	Teaching Understanding	2.79	3.85	1.169	-5.618	0.001
	Interdisciplinary STEM	2.18	3.54	1.328	-6.393	0.001
	STEM Reasoning	2.21	3.38	0.997	-7.391	0.001
Confidence	Collaboration Experts	2.16	3.42	1.267	-6.147	0.001
	Authentic Instruction	2.45	3.55	1.290	-5.281	0.001
	Teaching Understanding	2.84	3.89	1.229	-5.279	0.001
	Interdisciplinary STEM	2.47	3.79	1.297	-6.255	0.001
	STEM Reasoning	2.45	3.55	1.181	-5.771	0.001
Commitment	Collaboration Experts	2.76	3.89	1.095	-6.372	0.001
	Authentic Instruction	2.74	3.92	1.036	-7.046	0.001
	Teaching Understanding	3.18	4.00	1.010	-4.981	0.001
	Interdisciplinary STEM	2.79	3.95	1.175	-6.076	0.001
	STEM Reasoning	2.92	3.97	1.089	-5.957	0.001

RTOP Observation

The modified RTOP observation instrument consists of qualitative and quantitative observations of project implementation in the classroom. The qualitative observations include the learning environment (e.g., student makeup, classroom setting), a program report section of overall project implementation, and summary lesson observation write-up. These qualitative observations were used to frame the state of school implementation.

The quantifiable observations include instructional strategies (authentic instruction, teaching for understanding, interdisciplinary STEM, STEM reasoning, and delivery), which are observed on 10 minute intervals and logged on an observation rating chart. Table 3 provides summary data on the quantitative observations across all participating schools (data represents estimated fractions of time a category was observed, e.g. 0.96 out of 1 or 96% of the time).

Table 3.

RTOP Observation Averages

Categories	Elements of Category	Observation Averages
Instructional Strategies	Authentic Instruction: real world relevance, PBL/PBE, collaboration, student centric	0.96
	Teaching Understanding: enduring understanding, essential question, authentic assessment, performance task	0.77
	Interdisciplinary STEM: multidiscipline, STEM connections	0.68
	Delivery: lecture, discussion, assessment, administrative task	0.14
	Delivery: hands-on, active learning	0.86
Reasoning Modalities	STEM Reasoning CS: complex systems	0.05
	STEM Reasoning MB: science model-based	0.21
	STEM Reasoning CR: technology computational	0.13
	STEM Reasoning DR: engineering design-based	0.38
	STEM Reasoning QR: mathematics quantitative	0.26

The instructional strategies category provides averaged estimates of the percentages of class time spent on each area based on two observations by the project leader, providing a snapshot from two class periods of what is happening in practice. In two class observations we do not expect to see all the elements in a category. So what does this snapshot tell us? Authentic teaching practices were displayed approximately 96% of the time for the two observations per 12 classes observed. Teaching for understanding practices were evident approximately 77% of the time in classes observed. Interdisciplinary STEM was evident approximately 68% of the time, with teachers engaging students in more than one STEM area. Discussion or hands-on activities occurred approximately 86% of the time, with passive delivery of material occurring only approximately 14% of the time. This is evidence that the teachers were implementing the active teaching tenet of the program.

There was a great deal of variation in which reasoning modalities were the focus of the class sessions, which is not surprising. We do not expect that all five reasoning modalities would appear every day. The majority of the Real STEM courses used either science or engineering as a driver for the course, so it is not unexpected that two of the three most occurring reasoning modalities were engineering design-based reasoning (approximately 38%) and science model-based reasoning (approximately 21%). Mathematical quantitative reasoning was also one of the most observed modalities (approximately 26%) due to the integration of mathematics into the engineering and science tasks, primarily through either measurement or statistics. Technological computational reasoning (approximately 13%) was the least evident among the four basic STEM reasoning modalities. We believe this is due to a lack of teacher preparation in computational science, since most teachers do not have a background in computer science. The majority of the teachers viewed the T in STEM as using technology as a tool (i.e. using a computer or calculator), rather than as teaching students to think like a computer scientist. Some teachers had begun incorporating computational reasoning through the use of Arduino (small microcontroller board) based tasks, but targeted professional development in the area of technology appears to be needed. Finally, while STEM tasks were often embedded in complex real-world systems, overall teachers were not explicit about engaging students in understanding the system. Indeed, while the percentages indicate the estimated amount of time spent on STEM reasoning modalities in the observed sessions, the number says nothing about the quality or depth of engagement in the reasoning modality. Overall the exposure to the reasoning modalities individually is positive, but increasing exposure to multiple reasoning modalities in the same class to increase interdisciplinary STEM focus should be a goal of interdisciplinary STEM courses. The variability in the STEM programs at the 12 schools, which we consider a strength, make the validity of this overall average something that needs to be considered when interpreting the value. We provide the average as a quick means of seeing the overall implementation in the observed classes.

Summary

The Real STEM project allowed for each school partner to implement a STEM program that addressed the unique needs of their students and the configuration of their school. The resulting variation in program implementation across schools should be taken into consideration when interpreting the results.

Teacher Practice

The teachers participating in the Real STEM professional development expressed significantly reduced concerns (1.3 gain or a 56% higher average rating), higher confidence in (1.2 gain or 47% higher average rating), and stronger commitment to implementing (1.1 gain or 37% higher average rating) the five tenets of teaching STEM proposed by the project. RTOP classroom observations of the interdisciplinary STEM courses in the 12 participating schools observed a strong implementation of authentic teaching strategies, teaching for understanding, providing interdisciplinary STEM opportunities to students, and focusing on active hands-on learning. The reasoning modalities most often observed were engineering design-based reasoning, mathematics quantitative reasoning, and science model-based reasoning.

We recommend:

1. sustained professional development for all teachers on integrating STEM through interdisciplinary STEM Professional Learning Communities (PLC) (Blankenship and Ruona, 2006; Fulton and Britton, 2011; Huffman, Hipp, Pankake, and Moller, 2001; Croft, Coggshall, Dolan, and Powers, 2010; Loucks-Horsely, 1996)
2. professional development focused in the areas of complex systems reasoning (Bar-Yam, 2005; Holland, 2014) and technology computational reasoning (Bitesize BBC, 2018), if these are desired areas of focus
3. administrative support in developing school-community partnerships that promote collaboration with STEM experts (Burke, 2005; Jones, 2007; Piburn and Sawada, 2000; Smith and Sobel, 2010)

School and Teacher Takeaways

Schools and teachers implementing STEM programs can take the following away from our Real STEM project experience.

- Interdisciplinary STEM professional learning communities are critical to the success of your STEM program. Interdisciplinary STEM teaching requires experts from multiple areas (Tanenbaum, 2016; Fulton and Britton, 2011)
- Administrative level support for STEM is essential if the program is to grow beyond dedicated first-adaptors. Develop a school wide STEM plan and provide time for professional learning

communities to jointly plan curriculum (Huffman, Hipp, Pankake, and Moller, 2001).

- Develop community STEM partnerships that encourage place-based real-world problem solving and provide regional experts to partner with teachers (Smith and Sobel, 2010). Rural communities are more isolated resulting in less opportunities to interact with STEM researchers, but STEM experts exist in most communities, such as the county agricultural extension agent, and technology can provide online interactions with more distant experts (Council for Corporate and School Partnerships, 2001).
- Authentic teaching strategies are paramount to engaging students in authentic STEM problems (Bell, 2010; Boud and Feletti, 2013; Savery, 2006). Interdisciplinary STEM requires a change in teacher practice.
- Set appropriate learning goals for your STEM program which focus on process abilities such as reasoning and problem solving (Mayes, 2014). Move beyond engaging activities to authentic tasks.

Acknowledgement

This material is based on work supported by the U.S. Department of Education and Georgia GOSA. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding agencies.

References

Bar-Yam, Y. (2005). *Making Things Work: Solving complex problems in a complex world.* Cambridge,MA: New England Complex Systems Institute Knowledge Press.

Bell, S. (2010). Project-Based Learning for the 21st Century: Skills for the Future. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, *83*(2), 39-43.

Bitesize BBC. (2018). What is computational thinking? https://bbc.com/education/guides/zp92mp3/revision/1.

Blankenship, S. S. & Ruona, W. E. A. (2006). Professional learning communities and communities of practice: A comparison of models, literature review. *Journal of Educational Change*, 7, 221-258.

Boud, D. & Feletti, G. (2013). *The Challenge of Problem-based Learning (2nd edition)*. London: Kogan Page.

Buck Institute for Education (2017). What is project-based learning? Retrieved from https://www.bie.org/about/what_pbl.

Burke, J. (2005). *Competency based education and training*. London: Taylor & Francis Group.

Council for Corporate and School Partnerships (2001). Guiding principles for business and school partnerships.

Croft, A., Coggshall, J. G., Dolan, M., & Powers, E. (2010). Job-embedded professional development: What it is, who is responsible, and how to get it done well. National Comprehensive Center for Teacher Quality. Retrieved from https://files.eric.ed.gov/fulltext/ED520830.pdf.

Dahlquist K.D., Aikens M.L., Dauer J.T., Donovan S.S., Eaton C.D., Highlander H.C., Jenkins K.P., Jungck J.R., LaMar M.D., Ledder G., Mayes R.L., & Schugart R.C. (2017). *An invitation to modeling: building a community with shared explicit practices*. PeerJ Preprints 5:e3215v1 https://doi.org/10.7287/peerj.preprints.3215v1

Edelson, D. C., & Reiser, B. J. (2006). Making authentic practices accessible to learners: Design challenges and strategies. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences*, (pp. 335-354). Cambridge, UK: Cambridge University Press.

Fulton, K. & Britton, T. (2011). *STEM Teachers in Professional Learning Communities: From good teachers to great teaching.* National Commission on Teaching and America's Future: Washington, D.C. Retrieved from https://nctaf.org/wp-content/uploads/ 2012/01/ NCTAFreportSTEMTeachersinPLCsFromGoodTeacherstoGreatTeaching.pdf

Holland, John H. (2014). *Complexity: A Very Short Introduction*. New York: Oxford Press.

Householder, D. L., & Hailey, C. E. (2012). Incorporating engineering design challenges into STEM courses. National Center for Engineering and Technology Education. Retrieved from http://ncete.org/flash/pdfs/ NCETECaucusReport.pdf.

Huffman, J. B., Hipp, K. A., Pankake, A. M., & Moller, G. (2001). Professional learning communities: Leadership, purposeful decision making, and job-embedded staff development. *Journal of School Leadership*, *11*(5), 448-463.

Jenkins, T. (2015). Rube Goldberg Machines and the Engineering Design Process. Teaching channel. https:// www.teachingchannel.org/blog/2015/09/29/rube-goldberg-machines-and-the-engineering-design-process/

Jones, L. (2007). *The Student-Centered Classroom*. New York: Cambridge University Press.

Justi, R. S. & Gilbert, J. K. (2002). Modelling, teachers' views on the nature of modelling, and implications for the education of modellers. *International Journal of Science Education*, *24*(4), 369-387.

Loucks-Horsely, S. (1996). Professional development for science education: A critical and immediate challenge. In National Standards and the Science Curriculum, Bybee, R. (Ed), Dubuque, IA: Kendall/Hunt Publishing Co.

Mayes, R., Forrester, J., Christus, J. S., Peterson, F., & Walker, R. (2014). Quantitative reasoning learning progression: matrix. *Numeracy*, 7(2).

National Governors Association Center for Best Practices, Council of Chief State School Officers (2010). Common core state standards for mathematics. Washington D.C.: NGAC, CCSSO.

National Research Council (2001). Knowing what students know: The science and design of education assessment. Committee on the Foundations of Assessment. J. W. Pellegrino, N. Chudowsky, & R. Glaser (Eds.) *Board on Testing and Assessment*, Center for Education, Division of Behavioral and Social Sciences and Education. Washington, D.C.: National Academies Press.

National Research Council. (2013). Monitoring progress toward successful K-12 STEM education: A nation advancing?. Committee on the Evaluation Framework for Successful K-12 STEM Education, Board on Science Education and Board on Testing and Assessment, Division of Behavioral and Social Sciences and Education. Washington, D.C.: The National Academies Press.

Next Generation Science Standards. (2013). *Next generation science standards: For states, by states*. Washington, D.C.: The National Academies Press.

Piburn, M., & Sawada, D. (2000). *Reformed teaching observation protocol (RTOP) Reference Manual*, National Science Foundation: Arlington, VA.

President's Council of Advisors on Science and Technology (2010). Prepare and inspire: K-12 education in science, technology, engineering, and math (STEM) for America's future. Retrieved from https://nsf.gov/ attachments/117803/public/2a--Prepare_and_Inspire--PCAST.pdf.

Repenning, A., Basawapatna, A., & Escherle, N. (2016). Computational Thinking Tools. IEEE Symposium on Visual Languages and Human-Centric Computing, Cambridge, UK, 2016.

Savery, J. R. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-based Learning*, *1*(1), 9-20.

Schwarz, C. (2009). A learning progression of elementary teachers' knowledge and practices for model-based scientific inquiry. Paper presented at the annual meeting of the American Educational Research Association, San Diego, CA, 2009.

Smith, G. A., & Sobel, D. (2010). *Place and community based education in schools*. New York, NY: Routledge.

Stohlmann, M., Moore, T. J. & Roehrig, G. H. (2012). Considerations for Teaching Integrated STEM Education. *Journal of Pre-College Engineering Education Research*, *2*(1), https://doi.org/10.5703/1288284314653.

Strobel, J., & Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms. *Interdisciplinary Journal of Problem-based Learning*, *3*(1), 44-58.

Tanenbaum, C. (2016). STEM 2026: A vision for innovation in STEM education. American Institutes for Research. Retrieved from http://www.air.org/system/files/downloads/report/STEM-2026-Vision-for-Innovation-September-2016.pdf.

Thomas, J. W. (2000). *A review of research on project-based learning*. San Rafael, CA: Autodesk Foundation.

Wilensky, U. & Resnick, M. (1999). Thinking in levels: A dynamic systems perspective to making sense of the world. *Journal of Science Education and Technology*, *8*(1), 3-19.

Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*(3), 33-35.

Journal of Research in STEM Education

Vol 3, No 1/2, December 2017, 17-33

RESEARCH REPORT

Persistence in STEM Majors: Investigating Whether and When High-Performing Students Leave STEM during Undergraduate Studies

Christopher W. Kohler

[a]*University of Buffalo, USA*

Abstract: *The focus of this study was to investigate the effects of both pre- and post-matriculation academic achievement on the likelihood and timing of high-achieving student departures from STEM majors at elite universities. While there has been robust research on persistence in STEM as a whole, survival analysis to investigate the timing of events is still a novel tool to investigate departure from STEM majors. Using longitudinal data collected at Harvard, secondary analysis was conducted to examine the research questions using discrete-time survival analysis. The researcher found that demographic characteristics of the students in the sample were not significant in predicting time-to STEM major attrition. However, verbal achievement was found to be the most significant predictor of STEM major attrition, with higher levels of verbal achievement leading to higher levels of attrition from STEM majors to non-STEM majors.*

Keywords: STEM major, STEM attrition, survival analysis, high-achieving students, elite universities

Introduction

One of the unique aspects of higher education in the United States is the ability to switch academic major once admitted and enrolled at a university. Many students enter university with an intended major, only to change pathways at some point during their undergraduate career. For students entering university with intended majors in Science, Technology, Engineering and Mathematics (STEM), this is even more prevalent (Rask, 2010; Griffith, 2010). The United States has seen a steep decline in the number of STEM degrees conferred as a whole. For example, the number of undergraduate students earning a degree in engineering has decreased by 16 percent from 1985 to 2006 (Kokkelenberg & Sinha, 2010). Students intending to major in a STEM field at entry to postsecondary education have a lower probability of receiving a degree in their initial major than students beginning their undergraduate studies in other fields, and the least likely students to persist toward a degree in STEM fields are women and historically disadvantaged minority groups (Price, 2010; Kokkelenberg & Sinha, 2010). In fact, while the population of underrepresented minority groups (African American, Hispanic or Latino/a, and Native American) in the United States in 2010 accounted for 29.3 percent of the total population, only 14.7 percent of the STEM bachelor's degrees awarded in 2010 were attained by members of these groups (Estrada et al., 2016).

As the production of a sufficient number of STEM graduates who are prepared for the workforce in these fields has become a national policy imperative in the United States, the retention of STEM students through graduation is targeted as a means to accomplish this goal (Chen & Soldner, 2013). The research on factors influencing the retention of students, both in general and in STEM majors, is quite robust; however,

---

[1] Corresponding Author. E-mail: wkohler@buffalo.edu

Kohler, C. (2017). Persistence in STEM majors: Investigating whether and when high-performing students leave STEM during undergraduate studies. *Journal of Research in STEM Education*, *3*(1/2), 17-33.

ISSN:2149-8504 (online)

it is mostly descriptive. Additionally, there is a lack of specific inquiry into the persistence of high-achieving students in STEM majors. Chen & Soldner (2013) found that the probability of leaving STEM majors for other non-STEM majors was higher in the cohort of high-achieving students than the cohort of low-achieving students. More research is necessary to understand the underlying push and pull of departing STEM majors, particularly among high-achieving students.

Factors Relating to STEM Persistence and Attrition

When examining STEM persistence, it is important to distinguish the differences between persistence in STEM majors and persistence in higher education as a whole. The current study focuses on the persistence in specific majors, namely STEM majors. Research on student persistence has tended to focus mainly on student dropout instead of investigating students choosing to switch majors without leaving a particular institution (Simon et al., 2015). While the literature on both retention in general and STEM specifically is robust, there is a paucity of studies focusing on students who switch from STEM majors to other majors. A review of the literature focusing on STEM persistence follows.

Vincent Tinto (1993), in his canonical work on student retention, suggests that individual characteristics of students regarding their enrollment in higher education and attendance at a specific institution are important predictors of persistence in a certain field of study, and ultimately towards graduation. Persistence, therefore, is the juxtaposition between both individual factors and institutional factors that are influencing students in their studies. This understanding of persistence was a major shift from previous retention studies focused solely on individual factors, such as student motivation and effort.

The literature related to persistence in STEM majors focuses mainly on three factors: gender, race, and achievement level. The literature on gender differences in postsecondary STEM persistence provides conflicting evidence. While some studies have demonstrated a significant difference in STEM persistence between men and women (Rask, 2010), others have determined that gender differences in persistence are not significant (King, 2016). Still, others have demonstrated both significant and non-significant results based on the type of analysis used (Chen & Soldner, 2013). These disparate findings muddy the waters when trying to understand gender-related issues in STEM persistence.

King (2016) finds that women are as likely as men to persist in university STEM majors, both in STEM majors with a significant minority of females (computer science, engineering, mathematics, and physical science) as well as the life sciences where women are more equally represented. This finding contrasts with Min, Zhang, Long, Anderson & Ohland's (2011) study of the loss rate of undergraduate engineering students, particularly that female students leave engineering earlier and at higher rates than do male students.

The negative environment women may experience while pursuing a STEM major may also have a deleterious effect on progression toward degree completion. Women in STEM and setbacks in their progression towards a STEM degree have been shown to be biased by gender-STEM stereotypes (LaCosse, Sekaquaptewa & Bennett, 2016). When cues in the setting promote this gender stereotype, such as witnessing the negative treatment of other women in a STEM setting, this ultimately lowers women's intentions to remain in STEM fields or pursue STEM careers. Nonverbal stereotype behaviors have shown to be even more detrimental to women's persistence in STEM majors and careers (LaCosse, Sekaquaptewa & Bennett, 2016).

The "weed-out" system can also be a factor that leads to negative experiences during STEM study, as the predominantly male environment. The fact that STEM fields have been predominantly male makes the social system new and uncomfortable for female students when dealing with their male peers (Seymore & Hewitt, 1997). This socialization factor of STEM persistence may be a factor in not only the risk of attrition for women in STEM majors but also the timeframe of attrition. As Min, Zhang, Long, Anderson, and Ohland (2011) found, the semester that women are most at risk of departure in engineering majors was during the second year of study.

The "leaky pipeline" of women in STEM fields continues after graduation, potentially influencing the decision-making of current women pursuing STEM majors. Glass, Sassler, Levitte, and Michelmore (2013) studied female STEM graduates in a nationally representative sample to compare the trajectories of women in STEM versus women in non-STEM professional fields. The results demonstrate that women in STEM fields are dramatically less likely to persist in STEM careers, but not because women are leaving the workforce in general. Women are moving from careers in STEM fields to careers in non-STEM fields at very high rates, and are unlikely to return to the STEM field after attrition. Additionally, the moves tend to take place early on in careers, often within the first five years. This trend is troubling and could be a signal to women in STEM majors to seek out other majors due to the risk of leaving the STEM field even after completing a STEM degree.

Race has been another oft-focused area of study regarding retention, both in general and in STEM fields. Griffith (2010) finds some notable differences in original major and persistence based on race. Of students declaring a STEM major at the point of application, only 47% of minority students remain in a STEM major by sophomore spring, as compared to 58% of non-minority students (Griffith, 2010). By senior year, the differential is greater: only 36% of minority students entering as STEM majors remain by senior year, while 46% of non-minority students persist to senior year in a STEM major.

Role modeling has been shown to be beneficial to student persistence in STEM, particularly regarding race. Studies have shown that when exposed to faculty of their own gender or race in STEM courses they are more likely to persist. Price (2010) finds a relationship between instructor race and gender and student persistence: students taught by an instructor of the same race are more likely to persist in a STEM major, while female students taking courses with female instructors are less likely to persist in STEM majors. Carrel, Page & West (2009) found that, while the gender of STEM instructors had little impact on academic performance of male students, it had a great impact on female students' grades in mathematics and science classes, as well as the likelihood of persistence and STEM degree completion. Additionally, the impact was strongest among students with high ability in mathematics as demonstrated on standardized tests. High achieving students in math and science are, in principle, the students whom should be persisting to STEM degrees and entering the STEM field. Studies, such as Price's (2010) indicate that the mechanism driving the result of this role modeling phenomenon is not identified. Influences during their education should be examined to diminish the likelihood of attrition, including facilitating mentor/mentee relationships at certain high-risk times for attrition from STEM majors.

This study aims to explore the factors that lead to whether and, if so, when high-achieving students entering postsecondary study as intended STEM majors decide to change to majors other than STEM. Survival analysis is particularly well suited to investigate this question.

Method

Sample

For this study's focus on high-achieving students and STEM major persistence, the researcher was particularly interested in examining the highest-achieving students, particularly ones at the most prestigious universities in the United States. Permission was obtained to use a restricted-use data set from a longitudinal study of concentration choice of students at Harvard University. The data set, Factors Influencing Concentration Choice Among Undergraduates, 1979-1983, was a four-year longitudinal study undertaken to explore the reasons why students entering college with intentions to major in science end up abandoning their plans before they declare a major in their second year of study. These data were collected by Susan Bailey, Barbara Burrell, and Norma Ware and are available through the Henry A. Murray Research Archive of the Institute for Quantitative Social Science at Harvard University, Cambridge, Massachusetts [Producer and Distributor]. The researchers were particularly focused on gender and science majors, examining the factors that seem to facilitate a choice of science majors for women.

In the summer before their first year at Harvard, 300 students from the classes of 1982 and 1983 were selected to participate in the study. Questionnaires were sent out and collected in August before they entered undergraduate. The questionnaire included information on their background, previous academic achievement, and major choice. In November of their first year, a second questionnaire was sent to the students, expanding on the first questionnaire by including information on experiences at Harvard, particularly in major departments and general college experiences. Subsequently, questionnaires were sent out in the fall of the participants' sophomore, junior and senior year. These questionnaires included information on majors but also expanded on the previous data by asking questions on immediate and long-term post-college plans.

The study by Bailey, Burrell, and Ware provides an ideal set of data to examine the research questions posed by this study. High achieving students at an ultra-prestigious university are being examined. In principle, the students entering an institution such as Harvard all have the ability to persist in STEM majors. However, the factors that play into this unique set of students' non-persistence remain relatively unexamined. Therefore, using the data collected by Bailey, Burrell and Ware, this study will examine three main potential predictors of student persistence in STEM majors: demographic factors, measured by minority status and gender; pre-university matriculation achievement, as measured by scores on both mathematics and verbal sections of the SAT standardized test; and post-university matriculation achievement, as measured by the average grade point average in both STEM and non-STEM courses during students' first year of study. The longitudinal aspect of the data set also provides an opportunity to examine the issue of STEM major persistence in a new way: by using discrete-time survival analysis to investigate not only the chance of leaving a STEM major, but examining whether certain factors play a role in both if and when a student does not persist in a STEM major.

As outlined by Singer & Willett (2003), survival analysis is appropriate when a study has three methodological features (p. 310): A target event, a beginning of time, and a metric for clocking time. In this study, the target event is a change from a STEM major to a non-STEM major. Again, the purpose of this study is to examine changes in major, not dropout (or stopout) from the university as a whole. The initial starting point, or the beginning of time, is the first wave of data collection in the data set: the data collected about intended major in the summer before matriculation at Harvard. As a metric for clocking time, this study uses the time metric of the year of study. Therefore, the study has four additional waves of STEM major persistence, one at the beginning of the freshman, sophomore, junior and senior year.

The data on major in the data set did not distinguish majors as STEM or non-STEM, instead listing each major individually without categorizing it as such. Therefore, how to define a STEM major for this study was essential to examine our research questions. While some studies find that not all STEM majors are created equal regarding student persistence, particularly females in engineering (e.g., Min et al., 2011), others find no significant differences in persistence between the physical sciences and life sciences (King, 2016). To better understand STEM persistence, we cast a wide net and define STEM majors as biological and physical sciences, mathematics, computer science, engineering, and premedical studies.

As previously mentioned, the first wave of data from Bailey, Burrell and Ware's study was collected pre-matriculation and asked students to indicate three majors they were considering. For this study, students were categorized as intending to major in STEM if they had indicated that at least one of their top two choices of major was a STEM major, as defined by the researcher using the definition above. The data collected in the second wave, in November of the freshman year, also asked students to list the three top choices of major. This question about top major choices is because students do not have to declare their major at this point of study. The same method was used to define an intended STEM major at this wave as well: if a STEM major was listed as one of the top two choices. The major indicated in the final three waves are the declared majors of the students in the sample and therefore are coded into STEM and Non-STEM majors for this study.

The minority variable in the study is defined based on the self-reported race on the questionnaire during the first wave of data collection. While the role of race in STEM persistence has been well examined, the results have varied, depending on the definition of minority versus majority group. Several studies (e.g., Griffith,

2010) define minority status as non-white racial groups, while others (e.g., Min et al., 2011) define minority status as ethnic groups that are significantly underrepresented in high levels of engineering and science, usually excluding Asians from their definition of minority status. In this study, due to our broader definition of STEM majors, we define minority status as white versus other ethnic groups.

The variables defining pre-university matriculation achievement as math and verbal SAT scores are broken down into two groups. This study is particularly interested in seeing differences between the highest-achieving students and other students. Therefore, we define our highest achieving group as students who have scored 700 or greater on the math section of the SAT. Additionally, to determine if there are survival and hazard probability differences between students with high scores on the math versus the verbal SAT, we also examine students with 700 or greater on the verbal section of the SAT. For our measures of post-matriculation achievement, we use a continuous measure of both STEM and non-STEM grade point average during students' first year of study. Since students may still be "undeclared" during their first year of study at Harvard, the grade point average in STEM versus non-STEM classes may have a strong impact in a change in intention to declare a STEM major.

Examining the total sample (N = 300), 95 students in the sample are found not to intend to major in STEM at the point before matriculation. Therefore, the total number of students investigated in this study is 205. For minority status, approximately 48 percent of the sample was white (n = 98) and approximately 22 percent were minorities (n = 44). Another 30 percent did not indicate their race on the questionnaire (n = 63). The sample was approximately 52 percent female (n = 106) and 48 percent male (n = 99). 56 percent of students scored 700 or higher on the math SAT (n = 115), while only 38 percent scored 700 or higher on the verbal SAT (n = 77). Of the sample of 205 students intending to major in a STEM field before matriculation, only 68 students remain in a STEM major at the last wave of data collection, during the fall semester of their senior year. Our event of interest (departure from a STEM major) is experienced by 137 students, or approximately 67 percent of the sample.

Results

Background

Table 1.

Bivariate correlations of variables used in the discrete-time survival analysis

Variable	Mean	SD	Correlations						
			Depart STEM?	Minority[b]	Gender[c]	Math SAT Score[d]	Verbal SAT Score[d]	First-year STEM GPA	First-year Non-STEM GPA
Depart STEM?[a]	.67	.47	1.00	-.03	.02	-.15*	.08	.28**	-.12
Minority[b]	.31	.46		1.00	-.02	-.17	-.29**	-.28*	-.16
Gender[c]	.52	.50			1.00	-.05	.03	-.01	.07
Math SAT Score[d]	.60	.49				1.00	.32**	.38**	.32**
Verbal SAT Score[d]	.40	.49					1.00	.19**	.28**
First-year STEM GPA	2.77	.79						1.00	.54**
First-year Non-STEM GPA	3.08	.54							1.00

a 1 = Yes, 0 = No   * p < .05 ** p < .01
b. 1 = Minority, 0 = White
c. 1 = Female, 0 = Male
d. 1 = ≤ 700, 0 = < 700
e. 1 = Minority, 0 = White

Table 1 shows the Pearson correlation coefficients computed among the six predictors with STEM major departure. The results of these correlational analyses indicated that two of the six predictors were significantly correlated with STEM major departure. Math SAT score was negative and significantly correlated with STEM major departure, $r(203) = -.15$, $p < .05$. First-year STEM GPA was significantly, but positively correlated with STEM major departure, $r(203) = .28$, $p < .01$; and negatively with minority status, $r(203) = -.28$, $p < .01$. To note, STEM major departure was not significantly correlated with either minority status, $r(203) = -.03$, $p > .05$; or with gender, $r(203) = .02$, $p > .05$.

Discrete-time survival analysis was conducted using SPSS statistical software package. Life tables were calculated with the SURVIVAL program using a "person-level" data set (Singer & Willet, 2003), while a "person-period" data set was used with the LOGISTIC REGRESSION program to examine four discrete-time hazard models with six individual covariates: minority status, gender, math SAT achievement level, verbal SAT achievement level, first-year STEM grade point average, and first-year non-STEM grade point average. Four individual models were defined as follows:

Model A: $\text{Logit } h(tj) = [\alpha 1\ D1 + \alpha 2D2 + \alpha 3D3 + \alpha 4\ D4]$

Model B: $\text{Logit } h(tj) = [\alpha 1\ D1 + \alpha 2D2 + \alpha 3D3 + \alpha 4\ D4] + \beta 1 \text{ minority} + \beta 2 \text{ gender}$

Model C: $\text{Logit } h(tj) = [\alpha 1\ D1 + \alpha 2D2 + \alpha 3D3 + \alpha 4\ D4] + \beta 1 \text{ minority} + \beta 2 \text{ gender} +$

$\beta 3 \text{ mathSAT} + \beta 4 \text{ verbalSAT}$

Model D: $\text{Logit } h(tj) = [\alpha 1\ D1 + \alpha 2D2 + \alpha 3D3 + \alpha 4\ D4] + \beta 1 \text{ minority} + \beta 2 \text{ gender} +$

$\beta 3 \text{ mathSAT} + \beta 4 \text{ verbalSAT} + \beta 5 \text{ freshmanSTEMgpa} + \beta 6 \text{ freshmanNON-STEMgpa}$

Where Dj is the time indicator at time period j, and h(tj) is the probability that individual i experiences the event in time period j (Singer & Willett, 2003).

Model A explored only the main effects of the semester time indicators, which serves as the baseline for comparisons. Model B adds the demographic characteristics of minority status and gender to the time-only indicators. Model C includes the pre-matriculation achievement variables of math SAT and verbal SAT to the other variables. Finally, Model D adds the post-matriculation variables of first-year STEM GPA and first-year non-STEM GPA to complete the model. The change statistics, -2LL (Log Likelihood) of the baseline Model A and Models B, C, and D indicate if a significant difference exists between the models.

Discrete-Time Survival Analysis Results

Table 2.

Life table survival and hazard estimates for entire sample of students beginning as intended STEM majors

	Number who…						
Year	Were at risk (still in STEM major) at the beginning of the year	Left STEM major during year	Were censored at the end of the year	Hazard Probability	Survival Probability	Odds	Logit(Hazard)
0	205	0	0	0	1	0	
1	205	24	0	0.117	0.882	0.132	-2.020
2	181	42	0	0.232	0.678	0.302	-1.197
3	139	52	0	0.374	0.480	0.597	-0.514
4	87	19	68	0.218	0.489	0.279	-1.275

Table 2 summarizes the overall life table estimates by interval for the entire sample, including the number of students at risk (still in STEM majors) at the beginning of each interval, number of students experiencing the event of interest (departure from a STEM major) during that interval, hazard probability and survival probability during the interval, odds of event occurrence during the interval, and the logit(hazard) function. The censored students are the individuals that did not experience the event. The only students censored in this study are the students remaining in STEM majors in their senior year of study; hence only censored cases exist in the fourth year (or fifth wave).

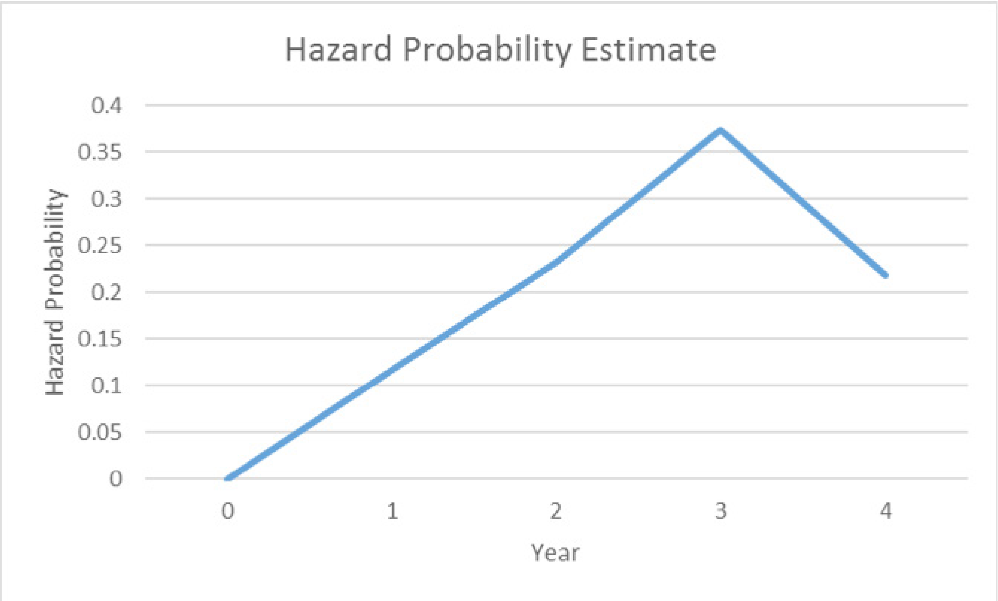


Figure 1. Hazard probability estimate for entire sample of students beginning as intended STEM majors.

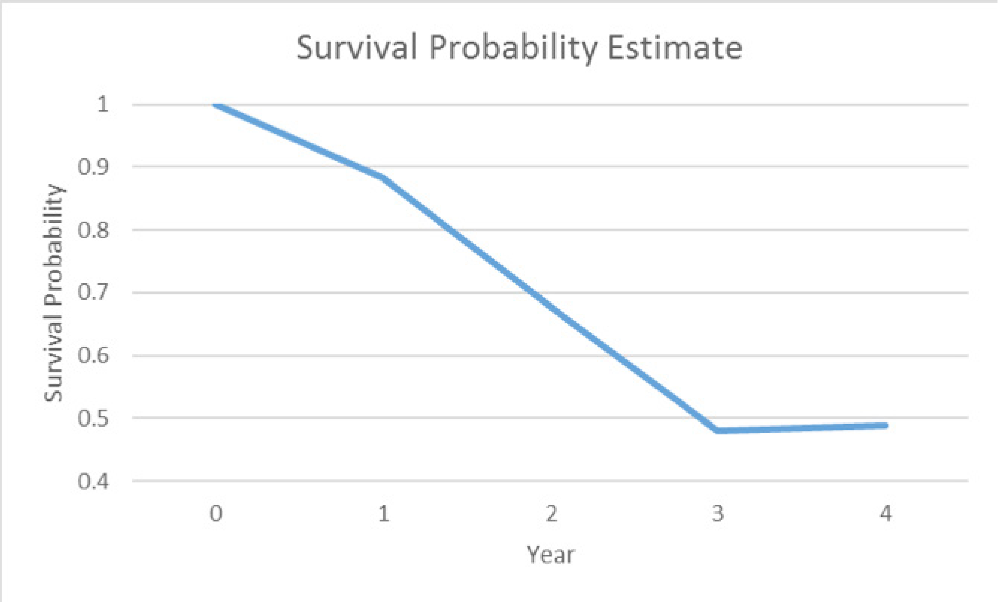


Figure 2. Survival probability estimate for entire sample of students beginning as intended STEM majors.

Figure 1 plots the hazard probability estimate for the entire sample. The hazard of leaving a STEM major increases throughout the undergraduate career until a peak at the beginning of the junior year (j =3), before decreasing at the last time period. The corresponding survival probability estimates are shown in Figure 2. The survival probability demonstrates a decreasing trend up until the junior year, then remains stable through the senior year.

Table 3.

Life table survival and hazard estimates for sample of students beginning as intended STEM majors, by minority status

White

Year	Number who… Were at risk (still in STEM major) at the beginning of the year	Left STEM major during year	Were censored at the end of the year	Hazard Probability	Survival Probability	Odds	Logit(Hazard)
0	98	0	0	0	1	0	
1	98	12	0	0.122	0.877	0.139	-1.969
2	86	27	0	0.314	0.602	0.457	-0.781
3	59	20	0	0.339	0.453	0.512	-0.667
4	39	6	33	0.153	0.559	0.181	-1.704

Minority

Year	Number who… Were at risk (still in STEM major) at the beginning of the year	Left STEM major during year	Were censored at the end of the year	Hazard Probability	Survival Probability	Odds	Logit(Hazard)
0	44	0	0	0	1	0	
1	44	6	0	0.136	0.863	0.157	-1.845
2	38	4	0	0.105	0.772	0.117	-2.140
3	34	12	0	0.352	0.578	0.545	-0.606
4	22	6	16	0.272	0.470	0.375	-0.980

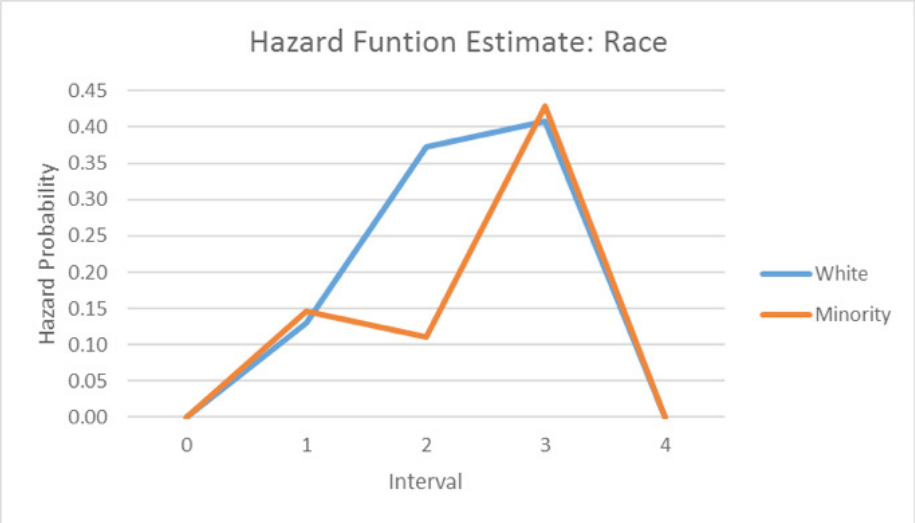


Figure 3. Hazard probability estimate for sample of students beginning as intended STEM majors, by minority status.

ISSN:2149-8504 (online)

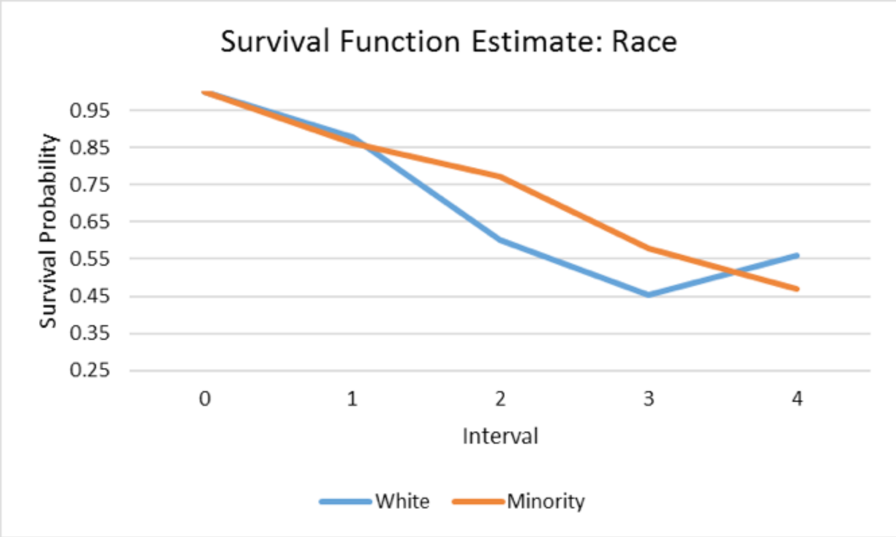


Figure 4. Survival probability estimate for sample of students beginning as intended STEM majors, by minority status.

Table 3 shows the life table for the two minority status groups studied: white students and students of other ethnicities. While the hazard probability increases at similar rates for white and minority students from pre-matriculation STEM major intention to first-semester STEM major departure, we see a large degree of difference in hazard probability at the beginning of the sophomore year. The difference in hazard is highlighted in Figure 3. The hazard probability for minority students at the beginning of the sophomore year is approximately 10.5 percent, while for white students it is 31.4 percent. The hazard rate evens out between minority status groups at the beginning of the junior year, which is also at its highest for both groups. Figure 4 shows the corresponding survival probability, showing the higher survival probability for minority students through year two and three. Interestingly, the probability of persisting in a STEM major for minority students is less in the final year of study, potentially illustrating that minority students may be more likely to persist up until the fourth year, but may experience a bottleneck effect that this point in their studies.

Table 4.

Life table survival and hazard estimates for entire sample of students beginning as intended STEM majors, by gender

Male

	Number who…						
Year	Were at risk (still in STEM major) at the beginning of the year	Left STEM major during year	Were censored at the end of the year	Hazard Probability	Survival Probability	Odds	Logit(Hazard)
0	99	0	0	0	1	0	
1	99	10	0	0.101	0.899	0.112	-2.186
2	89	14	0	0.157	0.757	0.186	-1.678
3	75	26	0	0.346	0.550	0.530	-0.633
4	49	15	34	0.306	0.453	0.441	-0.818

Female

	Number who…						
Year	Were at risk (still in STEM major) at the beginning of the year	Left STEM major during year	Were censored at the end of the year	Hazard Probability	Survival Probability	Odds	Logit(Hazard)
0	106	0	0	0	1	0	
1	106	14	0	0.132	0.867	0.152	-1.882
2	92	28	0	0.304	0.603	0.437	-0.826
3	64	26	0	0.406	0.413	0.684	-0.379
4	38	4	34	0.105	0.531	0.117	-2.140

Table 4 presents the life table survival and hazard estimates for the students in the sample, comparing by gender. As highlighted in Figure 5 and 6 below, the hazard probability for males is lower than for females through the beginning of the junior year, with the beginning of the sophomore year showing a larger hazard for females than for males. The survival probability demonstrates that, at the beginning of the senior year, the survival probability is greater for females than for males. The hazard probability is great for males than for females at the beginning of the senior year. While the hazard appears greater for females throughout their undergraduate career, the females who persist to the senior year appear to have a higher survival probability than their male classmates.

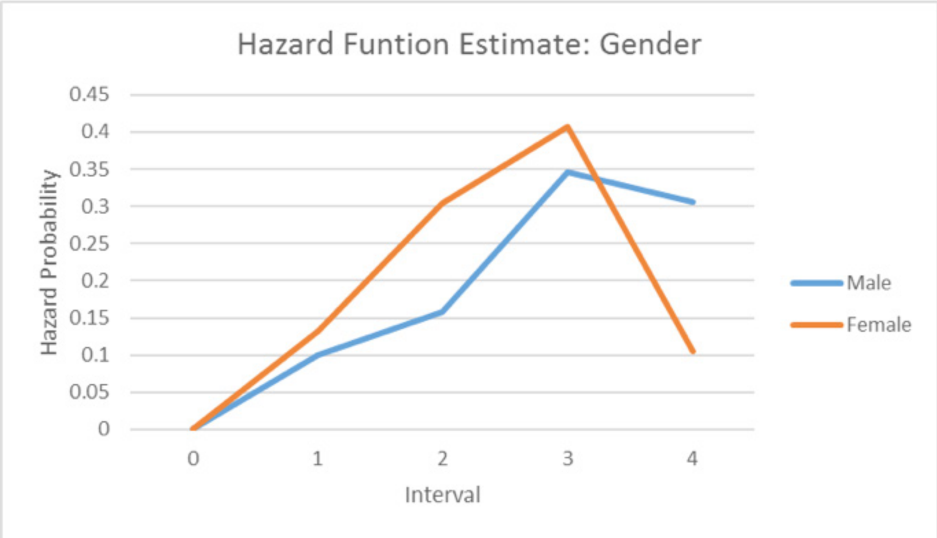


Figure 5. Hazard probability estimate for sample of students beginning as intended STEM majors, by gender.

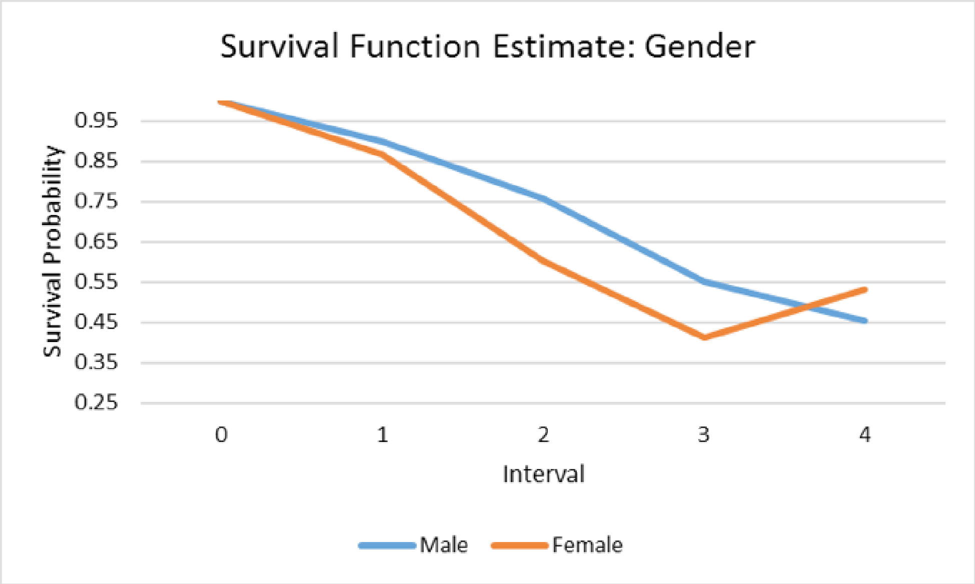


Figure 6. Survival probability estimate for sample of students beginning as intended STEM majors, by gender.

Table 5.

Life table survival and hazard estimates for entire sample of students beginning as intended STEM majors, by level of achievement on the Mathematics SAT test

Low							
	Number who...						
Year	Were at risk (still in STEM major) at the beginning of the year	Left STEM major during year	Were censored at the end of the year	Hazard Probability	Survival Probability	Odds	Logit(Hazard)
0	77	0	0	0	1	0	
1	77	13	0	0.168	0.831	0.203	-1.593
2	64	18	0	0.281	0.597	0.391	-0.938
3	46	21	0	0.456	0.390	0.840	-0.174
4	25	6	19	0.240	0.413	0.315	-1.153
High							
	Number who...						
Year	Were at risk (still in STEM major) at the beginning of the year	Left STEM major during year	Were censored at the end of the year	Hazard Probability	Survival Probability	Odds	Logit(Hazard)
0	115	0	0	0	1	0	
1	115	11	0	0.095	0.904	0.105	-2.24
2	104	23	0	0.221	0.704	0.283	-1.258
3	81	23	0	0.284	0.557	0.396	-0.924
4	58	13	45	0.224	0.555	0.288	-1.241

Table 5 and 6 and the corresponding hazard and survival probability plots show the difference in STEM major persistence for students with SAT scores on the math and verbal sections of the SAT of 700 or higher with those students with lower scores. Here, we see an intriguing trend: students with high achievement on the SAT in math have higher survival probabilities and lower hazard probabilities throughout all periods of undergraduate study, with the highest hazard rate for students with lower SAT scores at the beginning of the junior year. However, the opposite is true for student achievement on the verbal SAT. While the hazard rate is similar at the first time period (beginning of freshman year), subsequent semesters show a greater hazard probability and lower survival probability for students with the highest verbal SAT scores over students with lower verbal SAT scores.

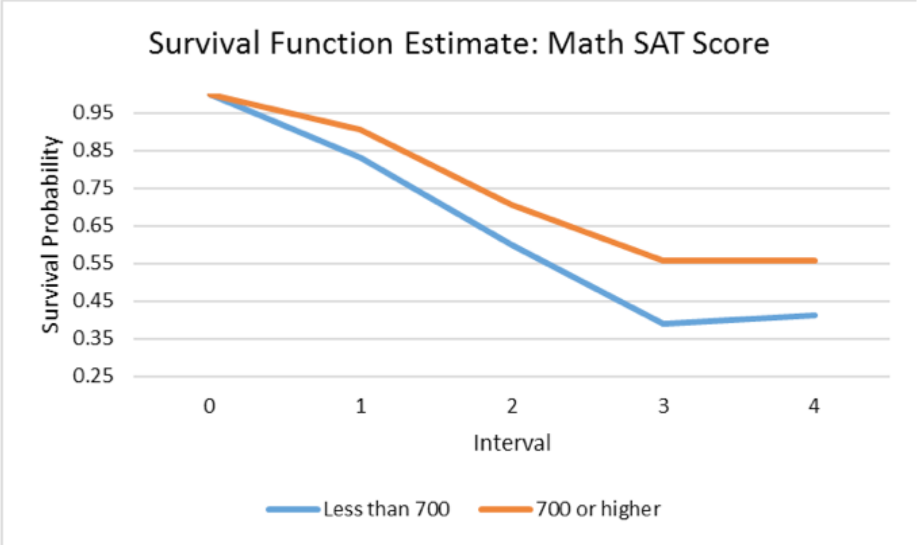


Figure 7. Survival probability estimate for sample of students beginning as intended STEM majors, by level of achievement on the Mathematics SAT test.

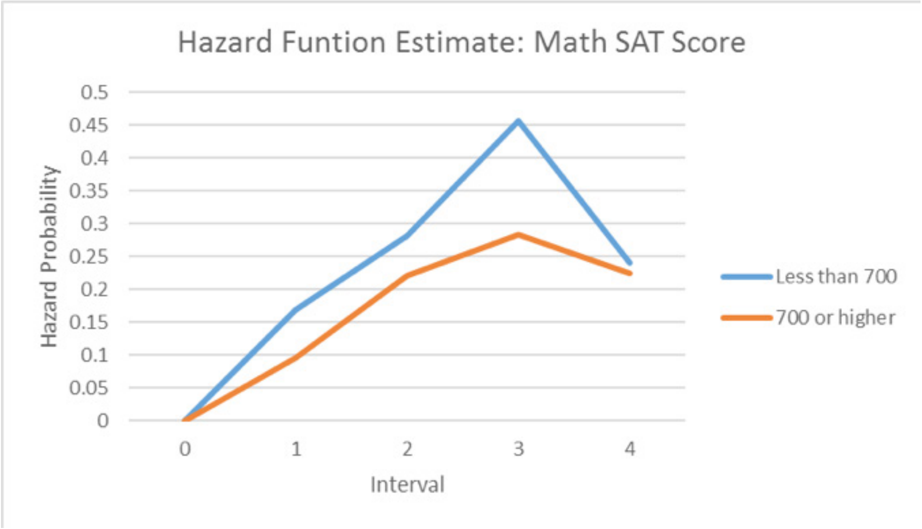


Figure 8. Hazard probability estimate for sample of students beginning as intended STEM majors, by level of achievement on the Mathematics SAT test.

Table 6.

Life table survival and hazard estimates for entire sample of students beginning as intended STEM majors, by level of achievement on the Verbal SAT test

Low							
	Number who...						
Year	Were at risk (still in STEM major) at the beginning of the year	Left STEM major during year	Were censored at the end of the year	Hazard Probability	Survival Probability	Odds	Logit(Hazard)
0	115	0	0	0	1	0	
1	115	16	0	0.139	0.860	0.161	-1.822
2	99	20	0	0.202	0.687	0.253	-1.373
3	79	26	0	0.329	0.535	0.490	-0.712
4	53	11	42	0.207	0.531	0.261	-1.339
High							
	Number who...						
Year	Were at risk (still in STEM major) at the beginning of the year	Left STEM major during year	Were censored at the end of the year	Hazard Probability	Survival Probability	Odds	Logit(Hazard)
0	77	0	0	0	1	0	
1	77	8	0	0.103	0.896	0.115	-2.154
2	69	21	0	0.304	0.623	0.437	-0.826
3	48	18	0	0.375	0.434	0.600	-0.510
4	30	8	22	0.266	0.458	0.363	-1.011

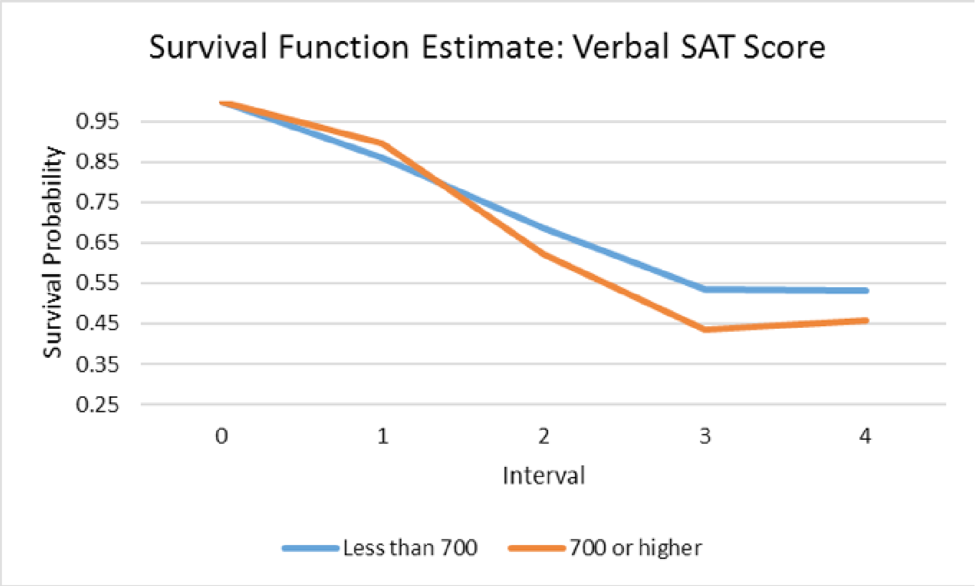


Figure 9. Survival probability estimate for sample of students beginning as intended STEM majors, by level of achievement on the Verbal SAT test.

ISSN:2149-8504 (online)

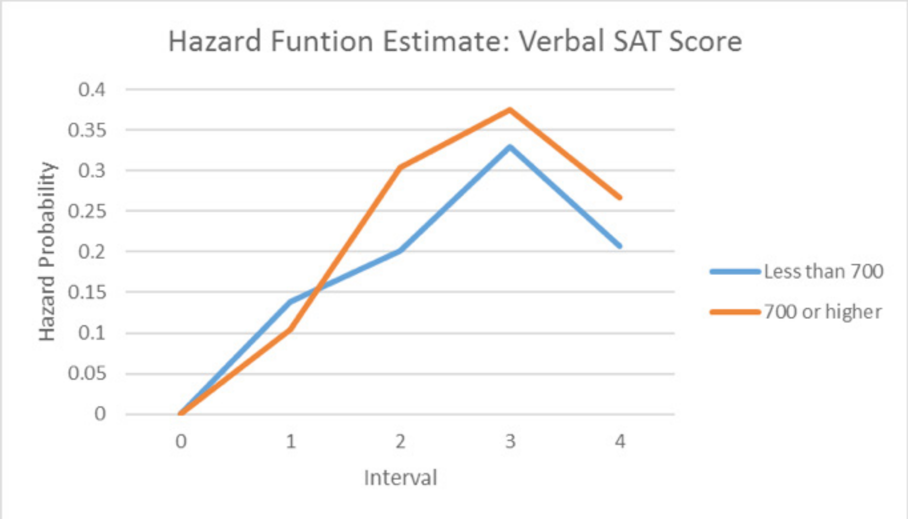


Figure 10. Hazard probability estimate for sample of students beginning as intended STEM majors, by level of achievement on the Verbal SAT test.

Table 7 highlights the results of the parameter estimates obtained from the fitting of the four discrete-time hazard models to the time to departure from STEM major data, as defined earlier. Model A does not include any substantive predictors, so the baseline is the entire sample of students (Singer & Willett, 2003). We see that the parameter estimates for the time period dummy variables increases up until time period 3, or junior year (B = -.676, S.E. .224, Exp (B) = .508 p < .01), then decreases again at time period 4, or senior year (B = -1.494, S.E. .334, Exp (B) = .224 p < .001.

Model B adds the demographic variables of minority status and gender to the time indicators. In model B, we do not see significant effects of either minority status (B = -.166, S.E. .264, Exp (B) = .847 p > .05) or gender (B = .281, S.E. .249, Exp (B) = 1.325 p > .05).

Model C adds the variables of pre-college achievement, specifically high-scoring students on math and verbal SATs. The results suggest that the odds of departure from STEM majors are significantly lower for students scoring 700 or higher on the math SAT, B = -.687, S.E. .288, Exp (B) = .503, p < .01. The odds of switching from a STEM major to a non-STEM major for the highest scoring students on the math SAT are .503 times that of students scoring less than 700. Alternatively, the odds of departure from STEM majors are greater for students who scored 700 or higher on the verbal SAT test; B = .607, S.E. = .293, Exp (B) = 1.836, p < .05. The estimated odds of switching from a STEM major to a non-stem major are about 1.8 times that of students scoring less than 700.

Continuing to the full model (Model D), the post-enrollment achievement measures of first-year GPA in STEM and non-STEM subjects are added to the previous model. The odds of departure from a STEM major are found to be significantly lower for students with higher STEM grades in their first year of study; B = -.467, S.E. = .200, Exp (B) = .627, p < .05. For every one-point increase in freshman STEM GPA, the estimated odds of switching from a STEM major to a non-STEM major are .627 times that of lower achieving students. First-year non-STEM GPA is not found to be significant, B = .016, S.E. = .264, Exp (B) = 1.016, p > .05.

Discussion and Conclusion

Despite the great breadth of research on university persistence and factors related to dropout from institutions of higher education in the United States, there has been relatively little attention devoted toward investigations into factors related to changes in major during a student's undergraduate career. Additionally, while there has been some research on dropout from STEM majors, studies are often related to certain specific disciplines, such as engineering (Min et al., 2011) and often include both changes in major and dropout/stopout. Further, studies lack focus on high-achieving students. While some studies have found significant results based on high-achievement (Ware & Lee, 1988), this study seeks to focus on this under-researched group of students.

Discrete-time survival analysis was used to analyze the rate of students changing majors from STEM fields to non-STEM fields using longitudinal data collected from Harvard University. This dataset provides an opportunity to examine factors related to STEM major persistence specifically in the context of the highest-achieving students at prestigious universities. What factors lead to a high probability of departure from STEM majors, and when are these departures most likely to occur? These are the questions this study seeks to answer.

Examining the data on STEM major persistence, we see a trend across all variables studied. Hazard rates are highest at time period 3, or the beginning of the junior year of study. However, the hazard probability estimates do differ among different groups at other time periods, particularly in the case of minority group status

Table 7.

Results of fitting four models of discrete-time survival analysis to year of departure from STEM majors

	Model A			Model B			Model C			Model D		
Predictor(s)	β	SE	e^{β}	β	SE	e^{β}	β	SE		β	SE	e^{β}
D1^a	-1.929***	.260	.145	-2.027***	.306	.132	-1.894***	.374	.150	-.782	.748	.457
D2^a	-1.110***	.214	.330	-1.202***	.265	.301	-1.038***	.346	.354	.083	.739	1.086
D3^a	-.676**	.224	.508	-.737**	.270	.478	-.535	.348	.586	.636	.755	1.889
D4^a	-1.494***	.334	.224	-1.558***	.365	.211	-1.346***	.432	.260	-.099	.810	.905
Minority^b				-.166	.264	.847	-.117	.282	.890	-.307	.300	.736
Gender^c				.281	.249	1.325	.239	.256	1.271	.207	.260	1.230
Math SAT^d							-.687**	.288	.503	-.479	.305	.619
Verbal SAT^d							.607*	.293	1.836	.680*	.303	1.975
Freshman STEM GPA										-.467*	.200	.627
Freshman Non-STEM GPA									.016	.264	1.016	
-2LL	403.903***			402.198			394.720*			387.904*		
Change in -2LL				1.705			7.478			6.816		

a. Dummy variables representing the main effect of time period
b. 1 = Minority, 0 = White
c. 1 = Female, 0 = Male
d. 1 = ≥ 700, 0 = < 700

* $p < .05$ ** $p < .01$ *** $p < .001$

The hazard probability estimate for white students is higher than for minority students at the beginning of sophomore year, before evening out at the beginning of the junior year. Additionally, when examining the hazard and survival probability estimates for gender differences, we witness a greater hazard probability for women up until the beginning of the senior year, where we see the hazard probability at this time period to be higher for men. This signifies that, while the hazard is greater for women earlier in their studies, the women that persist in STEM majors up until the senior year have a greater survival probability than the men remaining at this point of their undergraduate careers. While King (2016) found that women are as likely as men to persist in university STEM majors, both in STEM majors with a significant minority of females as well as the life sciences, there appear to be differences in the timing of STEM attrition which should be examined further.

Perhaps the most significant finding in the study was the revelation regarding college entrance examination results and STEM major persistence, particularly the effect of the highest-scoring students on the verbal section of the SAT. Perhaps unsurprisingly, the study found a significant difference between the highest-scoring students on the math SAT section and lower scoring students, with the odds of changing from a STEM major to a non-STEM major for the highest-scoring students about .5 times that of lower-scoring students. However, the students with the highest verbal SAT scores were significantly more likely to depart from STEM majors for non-STEM majors, with odds almost two times that of students with verbal SAT score of under 700. Chen & Soldner (2013) also found a significant difference in STEM attrition based on achievement, finding that the probability of students leaving STEM majors was higher in the cohort of high-achieving students than the cohort of low-achieving students. The findings in the current study suggest that the disciplines in which students have high achievement have a role in predicting the odds of STEM attrition. Students with very high achievement on the verbal SAT may choose to switch to majors which demand greater verbal skills after experiencing general education classes during their first few semesters. Beggs, Bentham and Taylor (2008) find that the greatest factor influencing students' major choice is a match with their interests, while financial success is ranked lowest. High achieving students may find that a non-STEM major is of greater interest, and without a factor such as financial success to influence them to remain in a STEM major, they may leave STEM for another discipline. Further research should be conducted to examine this finding, particularly in high-achieving student populations.

This study, of course, has its limitations. While the data set was of particular interest due to the student population in question, the data is quite dated. Future research should examine similar questions to examine whether STEM persistence is still affected differently between math achievement and verbal achievement, as measured on the SAT. Additionally, the size of the dataset prevents the results from being generalizable to the student population as a whole. A greater number of students would allow researchers to draw stronger conclusions about whether and when high-achieving students do not persist in STEM majors. However, the discrete-time survival analysis used in the study gives keen insight to higher education administrators and policymakers to better understand when certain intervention programs for certain student populations may be needed most, and when they may be most effective.

References

Astin, A. W. (1999). Student involvement: A developmental theory for higher education. *Journal of College Student Development, 40*(5), 518-529.

Beggs, J. M., Bantham, J. H., & Taylor, S. (2008). Distinguishing the factors influencing college students' choice of major. *College Student Journal*, *42*(2), 381-394.

Carrell, S. E., Page, M. E., West, J. E., & National Bureau of Economic Research. (2009). Sex and science: How professor gender perpetuates the gender gap. Cambridge, Mass: National Bureau of Economic Research

Chen, X. & Soldner, M. (2013). *STEM attrition: College students' paths into and out of STEM fields*. National Center for Education Statistics, Institute of Education Sciences (NCES 2014-001). Washington, DC: U.S. Department of Education.

Estrada, M., Burnett, M., Campbell, A. G., Campbell, P. B., Denetclaw, W. F., Gutierrez, C. G., . . . Zavala, M. (2016). Improving underrepresented minority student persistence in STEM. *CBE - Life Sciences Education*,*15*(3), 1-10.

Glass, J. L., Sassler, S., Levitte, Y., & Michelmore, K. M. (2013). What's so special about STEM? A comparison of women's retention in STEM and professional occupations. *Social Forces*, *92*(2), 723-756.

Griffith, A. L. (2010). Persistence of women and minorities in STEM field majors: Is it the school that matters? *Economics of Education Review*, *29*(6), 911-922.

Ishitani, T. T. (2008). How to explore timing of intervention for students at risk of departure. *New Directions for Institutional Research*, *2008*(137), 105-122.

King, B. (2016). Does postsecondary persistence in STEM vary by gender? *AERA Open*, *2*(4), 1-10.

Kokkelenberg, E. C., & Sinha, E. (2010). Who succeeds in STEM studies? An analysis of Binghamton University undergraduate students. *Economics of Education Review*, *29*(6), 935-946.

Lacosse, J., Sekaquaptewa, D., & Bennett, J. (2016). STEM stereotypic attribution bias among women in an unwelcoming science setting. *Psychology of Women Quarterly*, *40*(3), 378-397.

Min, Y., Zhang, G., Long, R. A., Anderson, T. J., & Ohland, M. W. (2011). Nonparametric survival analysis of the loss rate of undergraduate engineering students. *Journal of Engineering Education*, *100*(2), 349-373.

Morrison, L., & Silverman, L. (2012). Retention theories, models and concepts. In A. Seidman (Ed.), *College student retention: Formula for student success* (pp.61-80). Lanham, MD: Rowman & Littlefield.

Murtaugh, P., Burns, L., & Schuster, J. (1999). Predicting the retention of university students. *Research in Higher Education*, *40*(3), 355-371.

Price, J. (2010). The effect of instructor race and gender on student persistence in STEM fields. *Economics of Education Review*, *29*(6), 901-910.

Rask, K. (2010). Attrition in STEM fields at a liberal arts college: The importance of grades and pre-collegiate preferences. *Economics of Education Review*, *29*(6), 892-900.

Seidman, A. (2012). *College student retention: formula for student success*. Lanham, MD: Rowman & Littlefield.

Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences*. Boulder, Colo.: Westview Press.

Simon, R., Aulls, M., Dedic, H., Hubbard, K., & Hall, N. (2015). Exploring student persistence in STEM programs: A motivational model. *Canadian Journal of Education*, *38*(1), 1-27.

Singer, J. D., & Willett, J. B. (2003). *Applied longitudinal data analysis: modeling change and event occurrence*. New York: Oxford University Press.

Tinto, V. (1975). Dropout from Higher Education: A Theoretical Synthesis of Recent Research. *Review of Educational Research*, *45*(1), 89-125.

Tinto, V. (1993). *Leaving college: rethinking the causes and cures of student attrition*. Chicago: University of Chicago Press.

Ulriksen, L., Madsen, L. M., & Holmegaard, H. T. (2010). What do we know about explanations for drop out/opt out among young people from STM higher education programmes? *Studies in Science Education, 46*(2), 209-244.

Ware, N. C., & Lee, V. E. (1988). Sex Differences in Choice of College Science Majors. *American Educational Research Journal*, *25*(4), 593.

Journal of Research in STEM Education

Vol 3, No 1/2, December 2017, 34-47

RESEARCH REPORT

Discourses that Inform the Chilly Climate in Math and Physics

Laura Parson[a1], C. Casey Ozaki[b]

[a]*Auburn University, USA;* [b]*University of North Dakota, USA*

Abstract: *The purpose of this study was to uncover and describe the institutional classroom practices of STEM education at a Midwest research university (MRU). Using the framework of feminist standpoint theory, this study explored the everyday experiences of undergraduate women in math and physics to provide a unique perspective on the STEM education teaching and learning environment. In analysis of student interviews, faculty interviews, classroom observations, and instructional documents, we found that the difficult and intimidating aspects of the teaching and learning environment that created challenges for women participants were guided by STEM discourses of individualism, competition, and difficulty. These findings indicate that recent efforts to reduce the "chilly" climate have been unsuccessful because the discourses that motivate the chilly climate have not changed. Recommendations include revising the STEM institution to one that is inclusive for non-man students by identifying and revising the teaching and learning practices motivated by the discourses of competition, individualism, and difficulty.*

Keywords: STEM education, Institutional Ethnography, Higher Education, Qualitative Research, Chilly Climate

Institutional Discourses that Inform the Chilly Climate in Math and Physics

For many undergraduate women in Science, Technology, Engineering and Math (STEM), the classroom environment is a setting that is man-normed, highly impersonal, and individualistic (Morganson, Jones, & Major, 2010; Vogt, Hocevar, & Hagedorn, 2007). Referred to as a "chilly climate," STEM classroom environments are frequently organized as, "competitive, weed-out systems that are hierarchically structured with impersonal professors. These characteristics are traditionally acknowledged as customary, even respectable, teaching practices in traditional research university science, mathematics, and engineering classrooms" (Vogt et al., 2007, p. 339).

While the competitive STEM academic environment is often accepted and even promoted at traditional research universities (Vogt et al., 2007), this chilly climate can lead women to feel that they do not belong in STEM fields. For many women at the undergraduate and graduate level, the competitive STEM environment is discouraging instead of motivating; research suggests that women in STEM feel like they do not have the social and emotional support they need to be successful or they feel that they are not academically strong enough to be successful in the STEM industry (Herzig, 2010; Sartorius, 2010; Shapiro & Sax, 2011). The classroom climate and lack of support creates a disconnect that restricts undergraduate women's enrollment and persistence in STEM fields and may prevent them from feeling that they belong in STEM fields (Sartorius, 2010). This disconnect may have a negative effect on women student's persistence to graduation. For example, Gayles and Ampaw (2014) found that campus climate and environmental factors negatively affected women's persistence in STEM majors.

---

[1] Corresponding author. *Department of Educational Foundations, Leadership, & Technology*, Auburn University, 4036 Haley Center, Auburn, AL 36849
E-mail: ljp@auburn.edu

Parson, L., & Ozaki, C. C. (2017). Discourses that Inform the Chilly Climate in Math and Physics. *Journal of Research in STEM Education*, 3(1/2), 34-47

ISSN:2149-8504 (online)

Guided by the discourses of individualism and competition, STEM teaching and learning practices that contribute to a chilly climate are weed-out courses, courses that grade on a curve, reliance on lecture as a teaching method, and comprehensive exams (Mervis, 2011; Morganson et al., 2010; Shapiro & Sax, 2011). For example, weed out courses are introductory STEM courses designed to be so difficult they push out students perceived to be unprepared for (or identify those perceived to be unable to be successful in) difficult upper division courses (Mervis, 2011). This practice can create a competitive environment that is negative for women and minorities: "women do not find competition a meaningful way to receive feedback and may even find it to be offensive" (Shapiro & Sax, 2011, p. 8). The competitive nature of STEM courses is reinforced in large, lecture-based classroom and instructional practices that promote competition between students to be at the top of the class (Shapiro & Sax, 2011). Finally, competition in STEM classes is often reinforced through grading policies and a focus on individual achievement, "faculty in the sciences are more likely to grade on a curve, which promotes competition among students . . . [and] discourages collaborative work, instead reinforcing the notion that individuals should take responsibility only for their own learning" (Shapiro & Sax, 2011, p. 8). The chilly climate reinforces societal suggestions that women do not belong in STEM fields. The practices that characterize the chilly climate are symptomatic of the institutional discourses, practices, policies, and procedures that inform and guide those practices.

Study Purpose

Calls for research at the institutional level have increased in order to re-make the STEM classroom into one in which women are welcome and comfortable. To challenge the existing social and scientific systems, this study uncovered and described the institutional practices of STEM education at a Midwest research university (hereafter referred to as MRU) from the standpoint of undergraduate women. This article reports on a portion of a larger institutional ethnography of STEM education at MRU; in this manuscript, we explored data collected on classroom and department-level teaching and learning practices (See Parson & Ozaki, 2017; Parson, 2018). Specifically, we asked what STEM teaching and learning practices and processes characterized the organization of the day-to-day work of being a math and physics student and if challenges emerged for undergraduate women as a result of those organizational processes.

Standpoint theory provides the theoretical foundation of an institutional ethnography, beginning data collection with women who are able to describe the practices and procedures that keep them oppressed because those forces directly affect their lived experiences (Smith, 2005). Guided by standpoint theory, we began our inquiry into the STEM in higher education institution by understanding the experiences and perceptions of undergraduate women in math and physics. Their experiences acted as a window to identify the institutional processes and discourses that coordinated their lives. Through the framework of feminist standpoint theory, we sought to shift the standpoint of knowing by recognizing women's ways of knowing as equally valid (Belenky, Clinchy, Goldberger, & Tarule, 1997; Hesse-Biber & Nagy, 2014) and asserting that knowledge develops from lived experiences (Harding, 2004; Hesse-Biber & Nagy, 2014). By exploring the institutional factors that coordinate the chilly classroom climate, this study extends understanding of the chilly climate to provide understanding of the discourses, policies, practices, and procedures that lead to the classroom practices that characterize the chilly climate.

Methods

Data collection and analysis focused on how the interface between undergraduate women and STEM education was organized as a matter of daily encounters between students and faculty inside and outside of the classroom. This exploration began with in-depth interviews of eight undergraduate women in math and physics and extended, as the institutional processes shaping their experiences were identified, to classroom observations, additional interviews of students and faculty, and analysis of the texts that mediated these processes (e.g., syllabi and student handbooks). Student and faculty interviews provided a majority of the data explored in this portion of the larger institutional ethnography guided by the research questions:

1. What STEM teaching and learning practices and processes characterize the organization of everyday work for women math and physics students?
2. Do challenges emerge for women undergraduate students as a result of those organizational processes? If so, how and where do they emerge?

Participants

In an institutional ethnography, the goal of interviews is not just to reveal subjective states, but to identify how individuals from different parts of an institution are connected. Data from initial data collection guides the next steps of an investigation in order to identify local processes that are similar because they are coordinated by the same (or similar) institutional practices (Campbell & Gregor, 2004). In order to identify these translocal processes, procedures, and discourses, participants were chosen from two departments, math and physics, instead of just one (Smith, 2006, loc 327). Undergraduate participants were identified by asking math and physics faculty to ask qualifying participants to contact us if they were interested in participating in the research. Undergraduate participants were four physics majors, three math majors, and one math/physics double major. In addition to student participants, eight faculty members participated in interviews and classroom observations: four faculty participants from physics and four faculty participants from math. Student and faculty interviews and observations occurred during Fall 2015.

Data Collection

Smith (2005) outlines institutional ethnographic data collection procedures as beginning with entry-level data collection, followed by the collection of level two data. In an institutional ethnography, entry-level data informs understanding of the lived experiences of participants (Campbell & Gregor, 2004). Level two data provides insight into the institutional practices that coordinate level one data, practices that are often invisible to participants (Smith, 2005). In this study, entry-level data, collected in student interviews, identified the components of the teaching and learning environment that were described by participants as challenging. Then, subsequent data collection illuminated the discourses, policy, and practices that coordinated participant's lives, referred to as level two data. Level two data helped us to understand how and why those challenges were coordinated by institutional processes, procedures, and discourses. Level two data was collected through interviews with undergraduate women, classroom observations, faculty interviews, and institutional texts.

Interviews. In-depth interviews were guided by the core question of an institutional ethnography: How do you do what you do? (Campbell & Gregor, 2004). Laura conducted a total of 21 undergraduate participant interviews. With six of the eight participants, Laura conducted three interviews after receiving informed consent: at the beginning, middle, and end of the Fall 2015 semester. In each interview, Laura asked students to provide rich detail describing their everyday activities, including in-depth descriptions of the different settings as well as of their work and the work of other students, which might include attending class, completing homework, studying with peers, and attending advising sessions. (Campbell & Gregor, 2004). The interviews were formal and in-depth and lasted between 30-90 minutes.

Laura also conducted shorter formal interviews with math and physics faculty after the first undergraduate interviews were conducted. Those interviews asked about the processes and policies that were identified in the undergraduate interviews and/or observations and provided information about how student work is coordinated at the department, college, and institutional level. Laura conducted a total of five interviews; three with physics faculty and two with mathematics faculty. The interviews lasted between 30-60 minutes and occurred in October 2015.

Data Analysis

Following Carspecken's (1996) critical ethnographic coding processes, initial data analysis began immediately after the transcription of interviews. We began with low-level coding, which included structural and descriptive coding (Saldana, 2013) that identified the work that was being done by undergraduate women (Smith, 2005). After the first and second undergraduate interviews, faculty interviews and classroom observations were transcribed and analyzed for low-level codes. After data collection was complete, we began high-level coding of the data by identifying and explicating themes in the teaching and learning practices, policies, and procedures that coordinated participant work (Smith, 2005; 2006). We looked specifically for the discourses, power relationships, language, and practices crafted practices that were either gendered or biased or neutral and normal (Campbell & Gregor, 2004). Finally, we reorganized codes into categories using code maps and analytic memoing (Saldana, 2013).

Trustworthiness and Ethics

To ensure the validity of data collection and analysis, we used triangulation, prolonged and persistent engagement, peer debriefing, and audit trails. For example, to seek data, methodological, and theory triangulation, we triangulated findings by comparing data across participants and different data sources (Onwuegbuzie & Leech, 2007). Additionally, throughout the data collection and analysis process, we revisited the literature to see how findings aligned with the literature and for additional insight and clarification (Creswell, 2013). Finally, we collected rich data through interviews and observations (Creswell, 2013; Maxwell, 2013; Onwuegbuzie & Leech, 2007) such as the use of repeated interviews of subjects to produce richer and more self-disclosing work.

We sought to collect and analyze data with a primary focus on ethics throughout the study, including data collection, data analysis, and reporting. First, we used in-depth interviews that were guided by the participant to empower women participants by being heard and validated as an authority. Second, our study received ethical approval from the MRU IRB board prior to beginning data collection (Rossman & Rallis, 2003). We obtained informed consent from all participants and conducted interviews and observations with the goal of ensuring privacy and confidentiality. Finally, we protected the identity of each study participant by using pseudonyms in interview transcripts, observations, and researcher memos and by removing all identifiable information from any published reports, including participant quotes (Creswell, 2013; Rossman & Rallis, 2003).

Limitations

First, much of the research on the undergraduate gender gap has focused on the experiences of undergraduate women in Math and Physics fields, and this study builds on that research. However, it is possible that the chilly climate and resultant discomfort reported by participants in this study is not uniquely related to gender but could create a chilly climate for all students, regardless of gender. Because this research was framed from the standpoint of women and this study only explores the experiences of undergraduate women in math and physics, we did not feel comfortable extending our conclusions beyond the parameters of this study.

Second, the literature and a faculty participant suggested that the discomfort expressed by women in STEM could be attributed to experiences in education prior to entering higher education (Sax & Harper, 2007). As a qualitative exploration, this study did not control for prior academic experiences when choosing participants in order to identify a causational relationship between experiences in higher education and causes for the chilly climate and leaky pipeline. That was not the intent of this study, and we do not intend to communicate broad generalizability. However, it is possible that negative emotions experienced by undergraduate participants were related to their prior experiences in math and physics and not to the environment in higher education.

Findings

The lived experiences of undergraduate participants in this study, women majoring in math and physics, provided insight into procedures and pedagogical decisions that led to discomfort in the STEM classroom and program in this study. First, participant descriptions of coursework defined the fields of math and physics as difficult. Second, assessment and grading practices, such as comprehensive exams and grading on a curve, reinforced the discourse of difficulty in STEM for participants. Third, participant interactions with faculty and instructional language formed an intimidating classroom environment. Finally, discourses of individualism and competitiveness were seen throughout the teaching and learning environment and created discomfort for participants.

"Physics is Hard": The Discourse of Difficulty

An overarching theme that repeated itself in every interview and from every participant was their perception that getting a math or physics degree was hard. Undergraduate participants explained that their coursework was hard because physics and math were, by nature, "really hard" and that courses were tough because the topics students were learning, such as quantum mechanics, abstract algebra, and linear algebra, were complicated and complex. For example, physics major Michelle explained, "They all warned me that it was going to be hard, and it was hard . . . like [this] teacher's really hard, he pushes you hard. He used to teach at Princeton. So, he had a very set idea of what homework should be, and it's the most grueling thing ever." Participants' descriptions of demanding coursework and complex subject matter were supported by faculty. Karl, a faculty member in physics, explained how he created physics exams, "I cannot ask quantum physics questions that they would get 95%. Then, my quantum physics class is a joke. Or they are genius. Topic is too hard. Very elaborate thing."

In addition to the challenging nature of math and physics content, coursework was made more difficult through unclear language and expectations. First, math and physics coursework was difficult, because the language used in assignments was unclear, which made figuring out what students were expected to do the first homework hurdle. For example, math major Emma described the coursework:

> You go to class and you're sitting in your classroom and your professor starts with his lecture and you're just like, okay, so I kinda understand some of the things that are going on and you just kinda nod your head, okay-oh, okay – and then you get to your assignment and you're just like I have no clue what's going on. Nothing in the lecture has prepared me for this assignment. I don't understand what's going on.

Participants described assignments that required participants to first understand what was being asked before they could work on the problem itself. Unclear language made it difficult for undergraduate participants to understand what a problem required of them. Additionally, homework and exam questions would often apply or extend the material covered in class, in ways that participants found difficult. As a result, participants described two challenges associated with coursework: figuring out what a question was requiring of them and then solving the problem.

Second, assignments that required large amounts of time to complete added to the difficulty of the coursework. Physics major Julie described the work she and her physics peers put into completing one homework assignment for one class:

> We worked on it every night and all day Saturday until about 4 o'clock when we finally finished it. It's just that there are so many things, and when you go ask, a lot [of] times he [the professor] will say, "Well, it's obvious. Just think about it!" It's frustrating, and we ended up going back through and looking stuff up online and bringing out our partial differential equations books and other books, our linear algebra book, to try to figure out what some of the problems were.

Coursework is time-consuming because of how hard the problems are and because of the resources students need to identify and search through relevant material that might help them determine how to complete their homework.

Because coursework requires so much work and time, math and physics majors perceived their work as different and harder than other majors. Darcy explained, “A lot of time you can run into the wee hours of the morning because like physics homework is really really different from any other major.” She described how her roommate would get frustrated because of the amount of time she spent on homework, perceiving that Darcy was procrastinating. Her roommate’s frustration prompted Darcy to explain that her math and physics coursework was difficult not only because the problems required more time to complete, but also because the relationship between time spent on an assignment and final grade were unrelated in physics. Darcy explained that a problem could take hours to complete; but, if she chose the wrong method to solve the problem, the work completed would be worthless. Like Darcy, participants described the time-consuming nature of math and physics coursework as a reason that their major was more difficult than other majors. The constant workload and pressure to meet deadlines led to anxiety and stress for student participants.

Difficult Exams

Finally, in addition to difficult and time-consuming coursework, exams were designed by faculty to be difficult because the subject matter was hard, as Karl explained previously. Math and physics exams were usually comprehensive exams, as described in a STEM syllabus, “Each exam is semi-comprehensive. And the final exam is fully comprehensive. This means that tests may contain information from throughout the semester.” The comprehensive exams in math and physics were difficult because they often had material not covered in class or the homework, and in some cases, were designed to be so time-consuming that they had to be taken outside regular course hours. These tests are intimidating to students and difficult to complete. For example, physics student, Julie, described her last physics exam:

> Um, the last test was pretty rough. Well, you know you’ve got to be worried when they schedule the test outside of class. So it was for a 2-hour period, and that should give you pause in the first place, you know? It’s like, okay this is going to be bad, isn’t it? And you prepare as well as you can, but he [the professor] is of the opinion that nobody should ever get a 100% on a test.

The legend of these difficult tests is conveyed to undergraduate physics majors. Olivia expressed anxiety prior to the beginning of the semester about tests she would encounter in her first semester as an upper level physics student. In her second interview, she confirmed that her fears were justified and that the tests were as hard as she had expected.

Participants described how difficult upper level exams were by their receipt of low grades. Math major Emma explained:

> Our second test, so there was a couple grad students in there, and our second test it was, our teacher wrote down the class statistics, and I think everyone walked out of the room saying, “Well, I think I guaranteed a 30% on that test,” and anyway, so we get our . . . he writes down the statistics on the board, and it’s just like 100%-1. We’re just like “who got that?” . . . and it was, uh, 90-99%-0; 80-89%-0; 70-79, there was like seven people; and the D, uh no, there must have been like five people, and the Ds there was probably like seven people, and then there were like 2 Fs.

Participants found exams to be difficult and receiving failing grades reinforced the difficulty of physics and math.

What is unique about the label of “difficulty” is how often it was repeated by participants using similar language. The difficult nature of the field served to guide faculty as they selected course content and to rationalize difficult and time-consuming coursework. Difficulty was also used to rationalize individualistic and competitive classroom practices, leading to intimidating environments. Physics professor, Myles, explained:

> If everyone got a 4.0 coming out of our department, people would laugh at us and you'd never get into grad school 'cause they know you're just giving away the degrees, essentially. Right? You're not learning anything. By its inherent nature, people find it very difficult when you need to learn. Not all of them, but most of them. The average is gonna be lower, right?

Math and physics must be difficult, faculty stated, because that was the very nature of the field. This was an illustration of how difficulty as a discourse is embedded into the institution of STEM in higher education.

Teaching Methods

Participants were additionally challenged by the teaching environment in math and physics courses. Undergraduate participants felt like they often left class without a clear understanding of what had been covered. First, participants described lecture as the most common teaching strategy used by math and physics faculty. While lecture was not universally disliked by undergraduate participants, the use of lecture allowed for very little student-instructor interaction. Physics major Michelle described how classes usually looked:

> The hardest teacher that we have, he would always start out class by filling one-fourth of the chalkboard right away. Before you even got there, he'd get there like 5 minutes early and start writing. And we'd have a little chitchat right at the beginning, and then we'd all start taking notes, and he'd explain things, and he'd ask questions, and most of the time our pauses were for, "What was that subscript that you wrote on that letter?" . . . Usually no one says anything. He goes really fast. Which sometimes just doesn't allow you time to think and keep up with him. And most of his questions will go unanswered just purely because of the fact that we didn't have time to think through what he just did. And he would skip steps regularly. He's been teaching this class for so many years, he knows the answer to an integral when you write that on the board. And there's like 15 steps to it. So he'd skip many steps, and we'd be just lost.

Michelle described a typical physics class as being lecture-based with very few student questions, which we also observed during classroom observations. Questions, when asked by faculty, were typically yes/no questions that received little or no response from students. Undergraduate participants explained that the use of lecture without student interaction required them to teach themselves, something they preferred not to do because they expressed a need to be taught because the material was so hard. Feeling like they had to teach themselves because they were not learning in class caused anxiety for students.

Grading and Assessment

In addition to difficult coursework, participants described an anxiety caused by grading and assessment practices. Their anxiety was caused by uncertainty about how their grade would be calculated, delayed or unclear feedback, and complicated grading processes.

"I Have No Idea How My Grade is Calculated." First, in both math and physics, students expressed uncertainty about how their final grade would be calculated. In some cases, this uncertainty was because faculty members did not have a grading scale published for students to review in the syllabus, on the Learning Management System (Blackboard), or through in-class descriptions. Darcy explained her interaction with one of her physics professors about how grades would be determined, "He doesn't know yet. I asked him that like a while ago. I was guessing he just hadn't uploaded that to Blackboard, so I was like, 'What's the grading?' And he's like, 'I need to figure that out!'" Similarly, Olivia described the expectations in an upper level physics course:

> We have tests. He didn't say how many tests. . . he doesn't have one [syllabus]. He just told us like, tests and homework. People have said that he doesn't actually grade things, or he doesn't actually keep your grades. They said like they never got their homework back, and essentially he just kind of picks how he thinks you're doing, and you get your grade based on that.

Lack of clarity about how grades were calculated led Olivia and other undergraduate participants to assume that the grading process was subjective. This assumption increased the pressure on them to perform because participants did not know how faculty wanted them to perform. In addition to not understanding their current grade, feedback from professors on assignments and tests was often delayed by weeks or even months. Grades were important to participants because they were an indicator of comprehension and sometimes influenced whether or not a student would receive continued scholarship funding and post-graduation work. As a result, not knowing where they stood as indicated by their grade increased stress and anxiety for each participant in this study.

Difference Between the Math and Physics Environment. While low grades were the norm for math and physics participants, grading practices in math and physics were different because math courses were less likely to grade on a curve. Darcy explained:

> Math is way more standardized. Like, if you get like, if you're doing well, you get a 90, where physics is a lot more like, they just really want to challenge you, so like they'll curve it, you know like they'll give a really hard test, and people get really bad grades, and then, you can curve it from there.

While physics was more likely to curve a grade, math was more likely to maintain the standard grading scale where 90 and above was an A and 50 and below was an F. While this adherence to the standardized math scale meant that math majors had a clearer understanding of the expectations regarding their grade, this also created additional pressure on participants to perform to a certain level. Additionally, participants reported that physics professors would tell students to expect low grades, setting an expectation for them that they would receive low grades. Where physics was more likely to make accommodations for a test that everyone failed; in math, that failing grade often directly reflected itself in a student's final grade even if the entire class failed the test. As a result, math participants often viewed low grades on a math exam as failure to understand the concepts presented in class. Physics students did not make that connection as frequently. This created challenges for math participants because while physics students reported understanding that low grades were expected and that their course grades would be curved to help their final course grades, math students perceived failing grades to be evidence they did not understand the content material and would fail the course. As a result, the very real feeling of failure further reduced the comfort level that math student participants felt with their ability to be successful in math.

Intimidating Environments

Intimidating environments created additional challenges for undergraduate participants. Participants perceived some interactions with faculty and fellow students to contribute to an intimidating environment.

Faculty. First, undergraduate participants described how they felt intimidated by faculty during class and from feedback received on assignments. For example, Olivia described her fear of interacting with one of her physics professors:

> He's very intimidating. We'll go to class, and we'll just like spend the whole time [thinking] please don't call on me or ask me something I don't know. 'Cause he's very mean to kids if they get it wrong, or they don't know it. Or, he'll always call on you if you do something wrong. Suddenly, he'll just call on you every time, no matter what. He gets very angry if you don't do something right. He'll put skull and crossbones on your homework if you do something wrong.

Fear of being called on in class and getting the answer wrong had Olivia so stressed that she spent extra time trying to anticipate what the professor might ask in class so that she could answer correctly. By her third interview, Olivia was less intimidated by the professor because she was doing well in the course, but still feared being called on in class.

Other professors were intimidating in a less aggressive way. Michelle explained how another physics professor would intimidate her during class lecture:

> He will sit on a desk right next to you, and ask you, directly, a question. You're in an entirely big class, and he'll sit next to you, and be like what do you think? And he'll like, sit there, and you will have to say the answer . . . So you're sitting there; and he's like, eye contact, like staring you down, like all your peers are next to you, and you're like, if I answer this wrong, I'm going to look stupid.

While not every class or professor was described as intimidating, the few that were created a challenge for undergraduate participants. Participants reported dreading their interactions with those faculty members and feared what would happen if they gave incorrect answers in class.

Fellow Students. In addition to intimidating professors, interactions with other physics and math majors can be intimidating as well. Michelle, a physics major, explained: "Like, if there's a new physics major that comes in, and we don't think that they're going to make it, we more often than not, we'll not really be close with them." New students, male and female, are judged by their peers. If they are perceived to not be smart enough, they are made to feel unwelcome. This sentiment also explained why participants were so worried about appearing stupid to their peers.

The unwelcome and intimidating environment was exacerbated by cissexist comments made by a few male students. Samantha described one time she felt unwelcome in her math class:

> I mean there's one dude there that has said some pretty sexist and racist things. I forget the joke he made, but I do know that once he made it, he looked at me and went, sorry. It was a joke about women being on their periods or something like that . . . And I guess we were on the topic of celebrities while we were on the way walking to calc. It was him and some other dude, and I think he said the words "Bruce Jenner." And then his friend was, "Don't you mean Caitlin Jenner?" And he's like no, no I don't . . .

Samantha felt that she could not disclose aspects of her identity as a woman to her male classmates because they might make similar comments about her. She felt like she needed to become inured to sexual language or comments that were derogatory to women in order to be successful in the male-dominated STEM environment.

Individualism. Like difficult coursework, the classroom environment in math and physics was characterized by individualism, as seen in instructional documents and interviews with faculty. First, the emphasis on the individual was seen in course documents, such as the syllabus. For example, a physics syllabus read, "Others may guide you in the acquisition of knowledge and skill, but in the end you teach yourself as a privilege and a responsibility." The onus was placed on the individual for learning and, while group work is not prohibited, this language made it clear that the individual was solely accountable for learning. This focus on the individual in instructional documents was intentional, as Karl explained, "I want them to see a really difficult problem, and I want them to try that without anybody's help. Alone. That is a good feeling because that's everything that I feel. There's a difficult problem. And, I deal with it." Individualism was promoted in the math and physics classroom through an emphasis on the responsibility of learning on the individual.

Competitiveness. Similar to individualism, the competitive nature of math and physics syllabi was seen in instructional documents and expressed by faculty in interviews. First, the competitive environment was exemplified by grading methods. For example, in upper level physics and some math courses, a majority of the grading was based on a curve. Grading on a curve was used to create a competitive environment because competition was seen as a component of the physics professional environment. Likewise, the competitive environment was described on a physics syllabus:

> We give grades for a variety of reasons, two of which are:
>
> It allows you to judge your performance on national and international scales;
>
> It is a motivational tool that "encourages" you to further develop your potential.

Physics and math courses were designed to be competitive as an evaluative and motivational tool.

Faculty used competitive grading methods to help students understand that they would be measured against their peers, which undergraduate participants had internalized. Darcy explained why competition through grading on a curve was necessary, "If you've made it to quantum mechanics, you are good at physics, you're good at math, you're a smart person, so if it wasn't made extra hard, which I think quantum was already inherently hard, then everyone would be getting the same grade." The importance of being able to compare themselves to their fellow students, both within MRU and nationally, was used as a rationale by faculty and students for difficult exams and for grading on a curve. Participants viewed competitive grading and classroom practices as necessary because students would be measured against their peers; and this would determine who received the best scholarships, who would be selected for competitive undergraduate research opportunities, and who would be accepted into graduate school.

Discussion

Much of the research on the chilly climate has focused on the impersonal nature of the STEM classroom environment and its relationship to the chilly climate and leaky pipeline (Morganson et al., 2010; Vogt et al., 2007), and those practices persisted for participants in this study. While these findings reconfirm prior research (Sidlauskiene & Butasova, 2013; Sinnes & Loken, 2014), they also serve as an alert that despite the implementation of interventions to improve the persistence of women in STEM in higher education, the chilly climate continues to persist. We extend prior research by suggesting that the chilly climate persists because the discourses that inform and guide teaching and learning practices and create a chilly climate are institutionalized within STEM education. As a result, because the discourses that inform a chilly class have not changed, the chilly climate persists for undergraduate women (Carnes et al., 2012; Linley & George-Jackson, 2013; Morimoto, Zajicek, Hunt, & Lisnic, 2013; Sidlauskiene & Butasova, 2013). The chilly climate for undergraduate women will persist until the institutionalized masculine discourses of individualism, difficulty, and competition are challenged and changed.

Discourse of Difficulty

First, similar to prior research on the impact of teaching and learning practices such as those seen in weed-out courses (Gasiewski et al.; Mervis, 2011), the discourse of difficulty created coursework expectations for participants that defined the nature of math and physics learning as exceptionally difficult. Difficult courses, especially when taken as an introduction to math or physics study, act like gatekeepers for students who are intimidated by the difficult, confusing, and time-consuming work (Gasiewski et al., 2012; Mervis, 2011). In this study, the discourse of difficulty was used to rationalize an array of classroom practices that contributed to the chilly climate including time-consuming homework and exams that were so difficult they had to be taken outside of normal class hours, with everyone in the course receiving a failing exam grade. These practices uniquely challenged high-achieving undergraduate women because it made them feel like they could not maintain personal standards of achievement, especially those standards measured by receiving high grades. These findings reinforce research that found that high grades are related to persistence in STEM for undergraduate women (Vogt et al., 2007). Similar to participants in this study, difficult work caused self-doubt, which led to higher levels of attrition for women (Mervis, 2011; Vogt et al., 2007). Identifying difficulty as the discourse that informed and often motivated teaching and learning practices in the STEM classroom contributes understanding to why those practices persist.

Individualism

Second, the masculine discourse of individualism guided an institutional environment where the responsibility for learning was placed on the individual, reinforcing prior research on the individualistic nature of STEM education (Morganson, Jones, & Major, 2010; Vogt, Hocevar, & Hagedorn, 2007). The discourse of individualism informed a teaching and learning environment that focused on individual success, "the view that people succeed because of superior abilities, dedication, and performance" (Acker, 2000, p. 630). The emphasis on individualism created anxiety for participants who felt that they did not have the knowledge to teach themselves. However, participants were reluctant to go to faculty for help (e.g., asking questions in and outside of class) because they feared that this would reinforce a perception that women could not be successful in math and physics. Lack of support created the bind described by Morganson et al., (2010) where women in STEM struggled because the coping strategies they were accustomed to were not supported by the college and STEM faculty. As a result, changing practices such as adding new support mechanisms was insufficient to remedy the chilly climate without changing the discourse of individualism. The discourse of individualism informs teaching and learning practices that place the onus on undergraduate women, reducing support (Morganson et al., 2010 Sartorius, 2010), and possibly increasing feelings of incompatibility between themselves and their major (Deemer et al., 2014; Herzig, 2010; Kreutzer & Boudreaux, 2012; London et al., 2011; Yakaboski, 2011).

Competition

Third, reinforcing prior research on the competitive STEM classroom environment (Mervis, 2011; Morganson et al., 2010; Shapiro & Sax, 2011), the masculine discourse of competition was promoted as a necessary part of STEM by faculty and student participants and led to teaching methods, grading practices, and classroom environments that were discomfiting for undergraduate participants. Related to the discourse of individualism, a competitive climate contributes to the leaky pipeline, because women do not find competition a meaningful way to receive feedback (Shapiro & Sax, 2011). As an accepted pedagogy in STEM education, competitive practices such as grading on a curve have been found to be contrary to women's need for collaboration and a collectivistic environment (Shapiro & Sax, 2011; Vogt et al., 2007). Reinforcing these findings and prior research (Carrell et al., 2010; Carrigan et al., 2011; Thomas, Bystydzienski, & Desai, 2014), undergraduate participants in this study described how important the student community was to their success and expressed a dislike of competitive practices, even when they acknowledged they were necessary to differentiate students for undergraduate research and graduate school applications. Faculty sought to preserve the competitive environment by grading on a curve and the larger STEM environment maintained a competitive environment through the processes of applying to graduate school and undergraduate research, the competitive environment persisted. In that way, competitive environments, especially without academic and social support from faculty, contribute to the chilly climate and leaky pipeline.

Conclusion

As a result of the masculine STEM teaching and learning environment, efforts to reduce the chilly climate have been unsuccessful, largely because the masculine discourses that motivate the chilly climate have not changed. The first step to improve the chilly climate in STEM fields requires revising the STEM institution from one that is masculine to one that is inclusive for non-man students. The goal is to create a STEM education environment that supports, validates, and gives women an equal voice (Sidlauskiene & Butasova, 2013). It is hoped that these recommendations can help to improve the experiences on women in STEM and, as a result, improve the recruiting and retention of women in STEM.

Recommendations

Recommendations to move toward a more equitable environment include empowering undergraduate women by giving them decision-making power, such as course enrollment choices, undergraduate research options, and in classroom projects. Similarly, the presence of women faculty can provide examples of a career progression path that demonstrates that women can be successful in STEM (Carrel et al., 2010; Charleston et al., 2014; DuPre, 2010; Gorman et al., 2010; Rosenthal et al., 2011; Tatum et al., 2013). Further, related to increasing the number of women faculty and students, departments need to improve support for undergraduate women from faculty, continuing research-based programs designed to support women until all faculty and staff practice the support provided by those programs. Programs that support women students should include social coping development and support (Morganson et al., 2010), promote self-efficacy (Brown, Garavalia, Fritts, & Olson, 2006), teach bias awareness (Suresh, 2006), and provide academic support (Yelamarthi & Mawasha, 2010). For example, mentoring has been found to promote the persistence and success of women in science (Borum & Walker, 2012; Campbell & Skoog, 2004; Griffin et al., 2010). Successful organized mentoring programs in STEM provide opportunities for women to be involved in undergraduate research and alerting students to the obstacles they were likely to face as women in STEM (Griffin et al., 2010).

Future Research

Future research must take into account the intersectional identities that influenced the experiences of women in STEM. While intersectionality was not the framework of this study and demographics at MRU do not represent the ethnic diversity of the United States, this study was not able to deeply explore the intersectionality that is particularly important in understanding how minorities are marginalized in STEM education. However, gender was not the only aspect of identity that affected participants' experiences in STEM; for participants, "multiple social identities shape the lives of oppressed individuals" (Museus & Griffin, 2011, p. 6). Intersectionality "promotes a greater understanding of how converging identities contribute to inequality" (Museus & Griffin, 2011, p. 10), and attention to intersectionality in future research is key to understanding how other aspects of their identity interacted to create different challenges in the STEM environment. Second, while the research was framed through feminist standpoint theory, beginning from the experiences of undergraduate women, the teaching and learning environment described could be perceived as chilly for all students, regardless of gender. Future research could include additional participant experiences to understand if and how experiences of the climate differ according to gender.

References

Acker, J. (2000). Gendered contradictions in organizational equity projects. *Organization*, *7*(4), 625-632.

Belenky, M. F., Clinchy, B. M., Goldberger, N.R., & Tarule, J. M. (1997). *Women's Ways of Knowing*. New York, NY: Basic Books.

Borum, V., & Walker, E. (2012). What makes the differences? Black women's undergraduate and graduate experiences in mathematics. *Journal of Negro Education*, *81*(4), 366-378.

Campbell, M. & Gregor, F. (2004). *Mapping Social Relations: A Primer in Doing Institutional Ethnography*. Walnut Creek, CA: AltaMira Press.

Campbell, A. & Skoog, G. (2004). Preparing undergraduate women for science careers. *Journal of College Science Teaching*, *33*(5), 24-26.

Carnes, M., Devine, P. G., Isaac, C., Manwell, L. B., Ford, C. E., Byars-Winston, A., & Sheridan, J. (2012). Promoting institutional change through bias literacy. *Journal of Diversity in Higher Education*, *5*(2), 63-77. doi:10.1037/a0028128

Carrell, S. E., Page, M. E., & West, J. E. (2010). Sex and science: How professor gender perpetuates the gender gap. *Quarterly Journal of Economics*, *125*(3), 1101-1144.

Carrigan, C., Quinn, K., & Riskin, E. A. (2011). The gendered division of labor among STEM faculty and the effects of critical mass. *Journal of Diversity in Higher Education*, *4*(3), 131-146.

Carspecken, F.P. (1996). Critical Ethnography in Educational Research: A Theoretical and Practical Guide [Kindle Reader version]. New York, NY: Routledge. Retrieved from http://www.amazon.com/Critical-Ethnography-Educational-Research-Theoretical-ebook/dp/B00FDR4P74/ref=tmm_kin_title_0?_encoding=UTF8&sr=8-1&qid=1419264649

ISSN:2149-8504 (online)

Charleston, L. J., George, P. L., Jackson, J. L., Berhanu, J., & Amechi, M. H. (2014). Navigating underrepresented STEM spaces: Experiences of Black women in U.S. computing science higher education programs who actualize success. *Journal of Diversity in Higher Education*, *7*(3), 166-176. doi:10.1037/a0036632

Creswell, J. W. (2013). *Qualitative Inquiry & Research Design*. Thousand Oaks, CA: Sage Publications.

Deemer, E. D., Thoman, D. B., Chase, J. P., & Smith, J. L. (2014). Feeling the threat: Stereotype Threat as a contextual barrier to women and science career choice intentions. *Journal of Career Development*, *41*(2), 141-158.

DuPre, C. (2010). Does being a good girl lead to being a good student? *Teaching English in the Two-year College*, *38*(1), 68-77.

Gayles, J. G., & Ampaw, F. (2014). The impact of college experiences on degree completion in STEM fields at four-year institutions: Does gender matter? *Journal of Higher Education, 85*(4), 439-468.

Gasiewski, J., Eagan, M., Garcia, G., Hurtado, S., & Chang, M. (2012). From gatekeeping to engagement: A multicontextual, mixed method study of student academic engagement in introductory STEM courses. *Research in Higher Education*, *53*(2), 229-261. doi:10.1007/s11162-011-9247-y

Gorman, S. T., Durmowicz, M. C., Roskes, E. M., & Slattery, S. P. (2010). Women in the academy: Female leadership in STEM education and the evolution of a mentoring web. Forum on Public Policy Online, 2010 (2).

Griffin, K. A., Perez, D. I., Holmes, A. E., & Mayo, C. P. (2010). Investing in the future: The importance of faculty mentoring in the development of students of color in STEM. *New Directions for Institutional Research*, (148), 95-103.

Harding, S. (2004). A socially relevant philosophy of science? Resources from standpoint theory's controversiality. *Hypatia*, *19*(1), 25-47.

Herzig, A. H. (2010). Women belonging in the social worlds of graduate mathematics. Montana Mathematics *Enthusiast*, *7*(2/3), 177-208.

Hesse-Biber & Nagy, S. J. (2014). *Feminist Research Practice: A Primer.* Thousand Oaks, CA: SAGE Publications, Inc.

Linley, J. L., & George-Jackson, C. E. (2013). Addressing underrepresentation in STEM fields through undergraduate interventions. *New Directions for Student Services*, *2013*(144), 97-102.

London, B., Rosenthal, L., Levy, S.R., and Lobel, M. (2011). The influences of perceived identity compatibility and social support on women in nontraditional fields during the college transition. *Basic and Applied Social Psychology*, 33, 304-321. doi:10.1080/01973533.2011.614166

Maxwell, J.A. (2013). *Qualitative Research Design: An Interactive Approach*. Thousand Oaks, CA: Sage Publications, Inc.

Mervis, J. (2011). Weed-out courses hamper diversity. *Science*, *334*(6061), 1333.

Morganson, V. J., Jones, M. P., & Major, D. A. (2010). Understanding women's underrepresentation in science, technology, engineering, and mathematics: The role of social coping. *Career Development Quarterly*, *59*(2), 169-179.

Morimoto, S.A., Zajicek, A.M., Hunt, V.H., & Lisnic, R. (2013). Beyond binders full of women: NSF advance and initiatives for institutional transformation. *Sociological Spectrum*, 33. 397-415.

Museus, S. D., & Griffin, K. A. (2011). Mapping the margins in higher education: On the promise of intersectionality frameworks in research and discourse. *New Directions For Institutional Research*, *2011*(151), 5-13.

Onwuegbuzie, A. J. & Leech, N. L. (2007). Validity and qualitative research: An oxymoron? *Quality & Quantity*, 41, 233-249.

Parson, L. (In Press, 2018). An institutional ethnography of higher education: The experiences of undergraduate women majoring in math and physics. Journal of Ethnographic and Qualitative Research.

Parson, L. & Ozaki, C. C. (2017). Gendered student ideals in STEM in higher education. NASPA Journal about Women in Higher Education. DOI: 10.1080/19407882.2017.1392323

Rosenthal, L., London, B., Levy, S., & Lobel, M. (2011). The roles of perceived identity compatibility and social support for women in a single-sex STEM program at a co-educational university. *Sex Roles*, *65*(9/10), 725-736. doi:10.1007/s11199-011-9945-0

Saldana, J. (2013). *The Coding Manual for Qualitative Researchers*. Thousand Oaks, CA: Sage Publications Inc.

Sartorius, K. C. (2010). Experimental autonomy: Dean Emily Taylor and the women's movement at the University of Kansas. *Kansas History: A Journal of the Central Plains*, 33, 2-21.

Shapiro, C. A., & Sax, L. J. (2011). Major Selection and Persistence for Women in STEM. *New Directions for Institutional Research*, (152), 5-18.

Šidlauskienė, V., & Butašova, K. (2013). Designing gender equality as institutional transformation at a higher education institution. *Gender Studies & Research*, 11, 50-69.

Sinnes, A. T., & Løken, M. (2014). Gendered education in a gendered world: looking beyond cosmetic solutions to the gender gap in science. *Cultural Studies of Science Education*, *9*(2), 343-364.

Smith, D. E. (2005). *Institutional Ethnography: A Sociology for People*. Lanham, MD: Altamira Press.

Smith, D. E. (2006). *Institutional Ethnography as Practice*. Lanham, MD: Rowman & Littlefield Publishers, Inc.

Tatum, H. E., Schwartz, B. M., Schimmoeller, P. A., & Perry, N. (2013). Classroom participation and student-faculty interactions: Does gender matter? *Journal of Higher Education*, *84*(6), 745-768.

Thomas, N., Bystydzienski, J., & Desai, A. (2014). Changing institutional culture through peer mentoring of women STEM faculty. Innovative Higher Education, (Preprints), 1-15.

Vogt, C. M., Hocevar, D., & Hagedorn, L. (2007). A social cognitive construct validation: Determining women's and men's success in engineering programs. *Journal of Higher Education*, *78*(3), 337-364.

Yakaboski, T. (2011). "Quietly stripping the pastels:" The undergraduate gender gap. *Review of Higher Education*, *34*(4), 555-580.

Journal of Research in STEM Education

Vol 3, No 1/2, December 2017, 48-68

RESEARCH REPORT

Elementary Teachers' Perceptions of Engineering and Engineering Design

Rebekah Hammack [a1],Toni Ivey[b]

[a]Montana State University, USA; [b]Oklahoma State University, USA

Abstract: *The Next Generation Science Standards (NGSS) call for the infusion of engineering practices beginning in Kindergarten, yet little is known about how prepared elementary teachers are to incorporate these standards. The purpose of this study was to identify (a) the perceptions that in-service teachers hold about the nature of engineering and engineering design and (b) how these perceptions compare with the engineering practices put forth in NGSS. This study is part of a larger explanatory sequential mixed methods design. Study participants included 542 K-5 public school teachers who were responsible for the science instruction of their students. During the first phase of the study, participants completed an online questionnaire consisting of Likert, selected response, and open-ended items. The results of the survey were used to finalize interview protocols for the second phase, which consisted of follow-up focus group and interview sessions with a subset of the survey participants. Findings indicated that participants were unfamiliar with engineering or engineering design and held stereotypical misconceptions about the work of engineers. Many participants reported having little experience teaching engineering and were not able to distinguish between examples of science and engineering activities. In short, findings indicated that teachers' perceptions of engineering and engineering design do not align with the engineering practices and disciplinary core ideas found in NGSS.*

Keywords: Elementary teachers, engineering education, teacher perceptions

Introduction

As the world becomes increasingly dependent on technology, nations' demands for workers in the areas of science technology, engineering, and mathematics (STEM) has increased (International Technology Education Association, ITEA, 2007). To help address these demands, the National Research Council (NRC, 2012) released A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas in which they identified key scientific and engineering practices that all students should learn during K-12 education. The Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) were developed based on the practices identified in the Framework. The NGSS call for the infusion of engineering practices into K-12 science classrooms; however, little is known about the preparedness of elementary teachers to incorporate these engineering standards. Available research suggests that elementary teachers feel unprepared to teach engineering practices (Banilower, Smith, Weiss, Malzahn, Campbell, &Weis, 2013; Sargianis, Yang, and Cunningham, 2012). One national survey indicated that only 4% of elementary teachers felt very well prepared

---

[1] Corresponding author. *Montana State University, Department of Education, Bozeman, Orlando, MT 59717* E-mail: rebekah.hammack@montana.edu

Hammack, R., & Ivey, T. (2016). Elementary teachers' perceptions of engineering and engineering Design. *Journal of Research in STEM Education*, 3(1/2), 48-68.

ISSN:2149-8504 (online)

to teach engineering to their students. This is considerably lower than the 39% who felt very well prepared to teach science and 77% for mathematics (Banilower et al., 2013).

Most teacher preparation programs do not prepare elementary teachers to incorporate engineering concepts and practices into their teaching, and in-service programs focused on engineering for elementary teachers are limited. Determining the perceptions that elementary teachers have of engineering, as well as their understanding of engineering design, will be vital to ensuring that teachers receive the proper professional development to successfully implement engineering concepts and practices in their classrooms. The development of such programs should be rooted in the research literature related to elementary engineering education, however, that body of literature is far from complete. The current study helps address gaps in the research literature by describing elementary teachers' perceptions of engineering and engineering design.

Purpose of the Study

The purpose of this study was to identify (a) the perceptions that in-service teachers hold about the nature of engineering and engineering design and (b) how these perceptions compare with the engineering practices put forth in A Framework for K-12 Science Education and Next Generation Science Standards. Specifically, the study sought to answer the following research questions: 1) How familiar are in-service elementary teachers with engineering and engineering design?, 2) What perceptions do in-service elementary teachers hold about engineers and engineering design?, 3) Are there differences in teachers' familiarity with engineering or perceptions of engineers between different demographic groups?, and 4) How do in-service elementary teachers' perceptions of engineering and engineering design compare with expectations set by K-5 engineering education standards?

Related Literature

Next Generation Science Standards (NGSS)

The NGSS are comprised of three dimensions: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. In NGSS, each of the standards is a performance expectation that incorporates all three dimensions. Table 1 presents the three dimensions of the Framework and NGSS as well as the components of each dimension. Table 2 presents the component ideas that make up Disciplinary Core Idea: Engineering, Technology, and Applications of Science (NGSS Lead States, 2013). The information presented in Tables 1 and 2 can be used as a framework to determine the knowledge K-12 teachers will need in order to implement engineering concepts and practices into their classrooms.

Table 1.

Dimensions of the Framework and NGSS

Science and Engineering Practices	• Asking questions (for science) and defining problem • Developing and using models (for engineering) • Planning and carrying out investigations • Analyzing and interpreting data • Using mathematics and computational thinking • Constructing explanations (for science) and designing solutions (for engineering) • Engaging in argument from evidence • Obtaining, evaluating, and communicating information
Crosscutting Concepts	• Patterns • Cause and effect • Scale, proportion, and quantity • Systems and system models • Energy and matter • Structure and function • Stability and change

Disciplinary Core Ideas	• Physical sciences • Life sciences • Earth and Space sciences • Engineering, Technology, and Applications of Science

Table 2.

Core and Component Ideas in Engineering, Technology, and Applications of Science

Disciplinary Core Idea	Core Idea	Component Idea
Engineering, Technology, and Applications of Science	ETS1: Engineering Design	ETS1.A: Defining and Delimiting an Engineering Problem
		ETS1.B: Developing Possible Solutions
		ETS1.C: Optimizing the Design Solutions
	ETS2: Links Among Engineering, Technology, Science, and Society	ETS2.A: Interdependence of Science, Engineering ,and Technology
		ETS2.B: Influence of Engineering, Technology, and Science on Society and the Natural World

Perceptions of Engineers

Many Americans do not understand what engineering is and often confuse the work of engineers with the work of scientists, construction workers, or mechanics (Oware, Capobianco, & Diefes-Dux, 2007). This lack of understanding leads to misconceptions that could prevent talented adolescents form entering the engineering pipeline. Studies employing the Draw-an-Engineer (DAE) instrument (Knight& Cunningham, 2004) highlight the stereotypical misconceptions that children hold about engineering. Children often perceive engineers as people who build and fix things and are much more likely to create drawings of white, male engineers who are working alone than drawings of women, minorities, or people working in groups (Pekmez, 2018; Newley, Kaya, Yesilyurt, & Deniz, 2017; Hammack and High, 2014; Karatas, Micklos, & Bodner, 2011; Fralick, Kearn, Thompson, & Lyons, 2009).

Adults are prone to similar preconceptions about the nature of engineering (Liu, Carr, & Strobel, 2009). In fact, K-12 teachers are more likely to believe that engineers are the people constructing a building than the ones supervising the construction (Cunningham, Lachapele, & Lindgren-Stricher, 2006). Additionally, when asked to describe engineering, few K-6 grade teachers described engineering as being linked to science and mathematics, involving teamwork and communication, or being creative (Lambert, Diefes-Dux, Beck, Duncam, Oware, & Nemeth, 2007), all of which are related to the three general principles of engineering education put forth by the Committee on Standards for K-12 Engineering (2010).

Research findings indicate that teachers' perceptions toward science influence students' perceptions toward science, and likewise, it is expected that teachers' perceptions of engineering will influence students' perceptions of engineering (Lambert et al., 2007). Teachers' limited understanding of engineering impacts their perceptions of engineering (Yasar, Baker, Kurpius-Robinson, Krause, & Roberts, 2006) which can be passed on to their students. Due to a limited understanding of engineering, elementary teachers often do not view engineering as an appropriate career choice for all students (Brophy et al., 2008), believing that only "super smart" teachers and students can learn engineering concepts (Cunningham, 2009), and place less value on teaching engineering design than secondary teachers do (Yasar et al., 2006). In fact, Van Haneghan, Pruet, Neal-Waltman, and Harlan (2015) found that even middle school teachers do not believe that the majority of their students have the ability to achieve competency in engineering content. This may result in teachers focusing their efforts on content they feel will benefit all students and not just the few who they view as capable of becoming engineers (Brophy, Klein, Portsmore, & Rogers, 2008). Additionally, teachers who have a narrow view of engineering might misrepresent engineering careers to their students, thus missing the opportunity to encourage students to enter the STEM pipeline (Yasar et al., 2006)

Teaching Engineering Design

Teachers are uncomfortable teaching what they do not know or are unfamiliar with (Brophy et al., 2008). Because many pre-kindergarten through eighth grade teachers have limited STEM content knowledge (Brophy et al., 2008), they may avoid teaching engineering. While working with teachers in Scotland, Harlen and Holroyd (1997) determined that elementary teachers employed coping strategies when they did not feel confident in their abilities to teach science content. Examples of the coping strategies included: (a) placing as little of the content as possible in the weekly lesson plans so the content could be the first item removed if the class is behind schedule; (b) compensating for low confidence areas (e.g. physical science) by teaching more high confidence content (e.g. life science); (c) relying heavily on worksheets or kits that have step-by-step instructions; and (d) emphasizing teacher-centered instruction with little opportunity for student questions or discussions (Harlen & Holroyd, 1997). It is expected that teachers would employ similar coping strategies when faced with teaching engineering content with which they are unfamiliar.

Regardless of grade level or subject taught, effective classroom instruction requires the teacher to possess subject matter content knowledge (SMCK), curricular knowledge (CK), and pedagogical content knowledge (PCK) (Shulman, 1986). SMCK refers to knowledge of the component facts and concepts of a subject as well as the ways in which the facts and concepts are arranged and validated. CK refers to a knowledge of the instructional resources available for teaching a subject. Shulman (1986) defined PCK as "the ways of representing and formulating the subject that make it comprehensible to others" (p. 9). PCK includes an understanding of what makes particular concepts difficult to understand and the preconceptions and misconceptions students have about a subject.

Design is the fundamental activity of engineering (Petroski, 2003) and teaching engineering design requires SMCK, CK, and PCK. Teachers who are unfamiliar with the nature of engineering design will be unable to address engineering design standards or identify ways to infuse engineering into their curriculum (Baker, Yasar-Purzer, Kurpius, Krause, & Roberts, 2007). The open-ended nature of engineering design means that design challenges do not have a single solution. Teachers must assess engineering design activities not only by how well the developed design solution solves the problem, but also by the processes the students went through to develop the solution (Brophy et al., 2008). Teachers with greater PCK are better able to determine children's understandings by observing their behaviors and performances, and use that information to modify class instruction (Bischoff, 2006). Many elementary teachers have never taught using open-ended problems that do not have a single "correct" answer (Cunningham, 2009) and may lack the PCK to effectively teach using open-ended engineering design challenges.

SMCK and PCK are required for teachers to understand real-world applications of content and to design effective instruction (Davis, 2003). Engineering design is an iterative process (Schunn, 2009; Silk & Schunn, 2008), and when students are given the opportunity to redesign, they develop a more complete understanding of the related engineering concepts (Schunn, 2009). Short duration exposures to engineering are not likely to lead to meaningful learning (Schunn, 2009) because they do not provide students with the opportunity to learn from their mistakes. In order to facilitate redesign activities, however, teachers must possess appropriate knowledge to help students identify the weaknesses in their original designs and ways to improve upon those designs. Additionally, it is critical that design lessons require the application of math and science and are situated within real-world contexts (Guzey, Tank, Wang, Roehrig, & Moore, 2014) which require teachers to possess SCMC, CK, and PCK related to engineering.

Method

The current study is part of a larger mixed methods research study. Mixed methods research refers to any study that involves the collection, analysis, and interpretation of both qualitative and quantitative data (Creswell & Plano Clark, 2011). Both quantitative and qualitative data were used to compare the results from different phases of the study and provide greater insight into the problem being studied than by using a single method.

During the first phase, participants completed an online questionnaire containing both open and closed-ended questions. Concurrently, the Next Generation Science Standards document was reviewed to determine the knowledge required for elementary teachers to implement the engineering components required by the standards. The results from Phase 1 were used to finalize the interview protocols used during the individual and focus group sessions that took place during Phase 2 of the study. Data from both phases were triangulated to answer the research questions related to teachers' perceptions of engineering and engineering design and how these perceptions compare with the expectations set forth in NGSS.

Measures

Because the researchers were unable to identify a validated instrument that would fully answer each of the proposed research questions in the full study, subscales from existing validated instruments were combined. These included the Teaching Engineering Self-efficacy Scale (TESS) (Yoon et al., 2014); Design, Engineering, and Technology Scale (DET) (Yasar et al., 2006); and Engineering Design Self-efficacy Instrument (EDSI) (Carberry et al., 2010). Only those subscale questions which were pertinent to answering the current research questions are included in this study. The data analyzed in the current study come from the Familiarity with Design Engineering and Technology and Stereotypical Characteristics of Engineers subscales from the Design Engineering and Technology Survey (Appendix A), as well as two open-ended researcher generated questions (What words or phrases would you use to describe the characteristics of a typical engineer? and What do engineers do as part of their work?).

Design Engineering and Technology Survey (DET)

The DET was originally developed by Yasar, Baker, Robinson-Kurpius, Krause, and Roberts (2006) and later re-evaluated and revised by Hong et al. (2011). The DET contains 40 items on a five point Likert scale, and is used to measure teachers' perceptions of engineering and familiarity with teaching engineering, engineering design, and technology. Exploratory factor analysis using a new sample of 405 participant teachers resulted in a 40-item four-factor instrument with an overall Cronbach's $\alpha = 0.88$. The resulting factors were Importance of DET (19 items, $\alpha = 0.91$), Familiarity with DET (8 items, $\alpha = 0.81$), Stereotypical Characteristics of Engineers (7 items, $\alpha = 0.77$), and Barriers to Integrating DET (6 items, $\alpha = 0.68$). The Familiarity with DET subscale and Stereotypical Characteristics of Engineers subscale were the only DET subscales included in the current study.

Participants

A link to the questionnaire was emailed to all Oklahoma K-5 public school teachers (n=16,546) whose information was on file with the Oklahoma State Department of Education, however 1,008 emails were returned undeliverable. The questionnaire was completed by 542 participants resulting in a 3.5% response rate. Table 3presents demographic information for the sample. Oklahoma encompasses a large geographic region with both urban and rural populations, and the researchers wanted to ensure that the sample was representative of the geographic distribution of the state population. The Oklahoma State Department of Education has assigned all school districts in the state to one of eight geographic regions, which were used to evaluate the geographic distribution of the sample. The data in Table 3 reveal that the sample was representative of the state population of elementary teachers with regard to geographic distribution of teachers, gender, education level, grade level taught, and years of work experience.

Table 3.

Demographics of Oklahoma K-5 Teacher Population and Study Sample

		Population		Sample	
		Number	Percentage	Number	Percentage
Oklahoma Geographic Region					
	1	670	4.03	26	4.80
	2	1181	7.10	48	8.86
	3	3538	21.28	159	29.34
	4	2180	13.11	55	10.15
	5	1049	6.31	18	3.32
	6	1384	8.32	37	6.83
	7	1058	6.36	30	5.54
	8	5567	33.48	169	31.18
Gender					
	M	698	4.20	16	3.00
	F	15929	95.80	526	97.00
Highest Education Level					
	Bachelor's	13090	78.73	381	70.30
	Master's/Education Specialist	3498	21.04	157	28.97
	Doctorate	36	0.22	4	0.74
	N/A	3	0.01	0	0.00
Work Experience					
(Years)	1 to 5	4926	29.63	163	30.07
	6 to 10	3501	21.06	111	20.48
	11 to 15	2506	15.07	85	15.68
	16 to 20	2224	13.38	69	12.73
	21 to 25	1613	9.70	48	8.86
	26 to 30	912	5.49	38	7.01
	31 to 35	534	3.21	15	2.77
	36-40	323	1.94	10	1.85
	over 40	88	0.53	3	0.55
Certification Type					
	Traditional	15951	95.93	491	90.59
	Nontraditional	676	4.07	51	9.41
Grade Level Taught					
	K	3176	19.10	91	16.79
	1	3638	21.88	98	18.08
	2	3601	21.66	102	18.82
	3	3658	22.00	112	20.67
	4	3370	20.27	120	22.14
	5	3527	21.21	98	18.08

Data Analysis

Quantitative data from the questionnaire, qualitative data from the questionnaire, and the NGSS document were analyzed separately and then triangulated to look for convergence or divergence of findings (Creswell & Plano Clark, 2011). Additionally, the qualitative data from the interviews and focus group sessions collected during Phase 2 were analyzed independently of the other data and then triangulated with the Phase 1 data to further explain and expand the analysis from Phase 1.

Quantitative Data Analysis

Participant responses for the DET questions were transferred to SPSS and analyzed. Cronbach's α was computed to determine the internal consistency of each DET subscale. Computed values for Familiarity with DET ($\alpha = .90$) and Stereotypical Characteristics of Engineers ($\alpha = .85$) were higher than those reported by Hong et al. (2011). The researchers analyzed the DET subscale data to yield frequencies of respondents choosing each response category. Box and whiskers plots were created to visually display DET subscale data. Researchers used one-way ANOVA to determine if any significant differences existed on subscale scores of different demographic groups including grade level taught, gender, pathway to certification, ethnicity, grade level taught, education attainment level, geographic region, and years of teaching experience. ANOVA assumes equality of variance, therefore, the Levene's test for equality of variance was run before interpreting the results of the one-way ANOVA. When the assumption of equal variances was violated (Levene's test less than .05), the Welch test, which does not assume equal variances, was used.

Qualitative Data Analysis

Qualitative data included the open-ended questionnaire responses and focus group and interview transcripts.

Open-ended questionnaire responses

Responses to the two open-ended questions "What words or phrases would you use to describe the characteristics of a typical engineer?" and "What do engineers do as part of their work?" were printed onto cards which were used during the coding process (Creswell, 2007). First, attribute coding was used to log essential demographic information about the participants for future reference (Saldana, 2013). Each card was coded with the participant's gender, ethnicity, years of teaching experience, education attainment level, geographic region, pathway to certification, and grade level taught. Next, a Wordle (www.wordle.net) was created for each open-ended question and used to create an initial visual representation of the data and identify the most salient words to use as initial codes. In a Wordle, words that appear more frequently in the data set are displayed using a larger font. This provides a quick visual representation of the frequency with which different words are used. However, Wordles are impacted by spelling, punctuation, and conjugates of words, which impact the visual display. For example, problem solver and problem solving would not be grouped together because they are not exact matches. McNaught and Lam (2010) found that word clouds, such as Wordles, are useful tools for preliminary qualitative data analysis, however they should not be used as the only method of analysis due to the way in which the word clouds are generated.

After generating Wordles, the researchers used the initial code list to complete a round of descriptive coding as described by Saldana (2013). During this first round of descriptive coding, additional codes were generated and added to the initial code list and code frequencies were determined. As suggested by Namey, Guest, Thairu, and Johnson (2008), the frequencies with which each code appeared in the data were based on the number of participants who used a particular code, not the number of times that the code appeared.

Focus groups and interviews

Upon completion of the online questionnaire, participants were redirected to an unlinked survey where they could provide contact information if they wished to participate in a follow-up interview or focus group. Based on individual availability, three focus groups were scheduled in two different large cities in the state, with seven to ten individuals scheduled for each session. Actual focus group attendance was low, with four individuals participating in the first focus group and the last two focus group sessions becoming individual interviews. A total of 11 individual interviews were conducted, two in person, and nine over the phone. The researchers wrote field notes during each session, reviewed the notes immediately following each follow-up session, and used the field notes to write a reflection over the session.

All focus group and interview sessions were audio recorded and transcribed verbatim by the researcher who conducted the interview (Oliver, Serovich, & Mason, 2005). To ensure that the findings remained true to the participants' perspectives, each participant was provided with a copy of the transcript to allow for member checking. Changes were made to the transcripts based on participants' feedback. During transcript analysis, the researchers did not force the data into predetermined categories. Rather, they inductively coded the individual transcripts using a data-driven approach (Brinkmann, 2013) during which they developed codes as they read over the raw data transcripts. Later, focused coding was used to organize the initial data into categories and compare the codes across participants' transcripts (Saldana, 2013).

Trustworthiness and Credibility

Creswell (2007) identifies eight validation strategies for qualitative research – prolonged engagement in the field; triangulation; peer review; negative case analysis; clarifying researcher bias at the beginning of the study; member checking; rich, thick descriptions; and external audits – and recommend the use of at least two of them in every qualitative study. In the current study, the researchers used provided participants with the opportunity to review the researchers' written description and interpretation of the interviews and focus group sessions (member checking) and triangulation. According to Merriam (2009), there are four processes of triangulation that can be implemented during a study: a) the use of multiple methods, b) the use of multiple sources of data, c) the use of multiple investigators, and/or d) the use of multiple theories to confirm emerging findings, through which validity and reliability can be achieved. For this study, triangulation was achieved through the use of multiple methods (quantitative and qualitative), multiple sources of data (NGSS document, survey data, interview and focus group transcripts), and the use of multiple reviewers, known as investigator triangulation. Investigator triangulation is defined as the process of using two or more reviewers to review and define the codes and themes in order to establish inter-rater reliability (Merriam, 2009). The researchers established inter-rater reliability by independently analyzing qualitative data, compare the resulting codes and themes, and discussing resulting codes and themes until consensus was reached.

Results

When answering our research questions, we first analyzed the qualitative and quantitative data separately and then merged the two to come to a deeper understanding of the underlying phenomena. Our findings are presented in a similar manner, with the qualitative and quantitative findings reported separately in the results section and then merged and described in the discussion section.

Quantitative data

Figure 1 provides box and whiskers plots of the Familiarity with DET and Stereotypical Characteristics of Engineers subscale data. Seventy-five percent of participants had a mean subscale score at or below 2.5 on the Familiarity with DET subscale. This, combined with the overall mean score of 1.99 on the Familiarity with DET subscale, suggests that participants were not very familiar with design, engineering, and technology. The mean score on the Stereotypical Characteristics of Engineers was 4.30 and 95% of participants scored at least 3.0, indicating that participants held stereotypical views of engineers. Pearson correlation reveal that Familiarity with DET and Stereotypical Characteristics of Engineers were significantly correlated with each other (r = .13, p = .002), however the small r value may indicate low practical significance. ANOVA revealed that male participants had significantly higher Familiarity with DET than female participants, F (1, 541) = 9.828, p = .002, η2 = .01. No other significant differences were found between demographic groups.

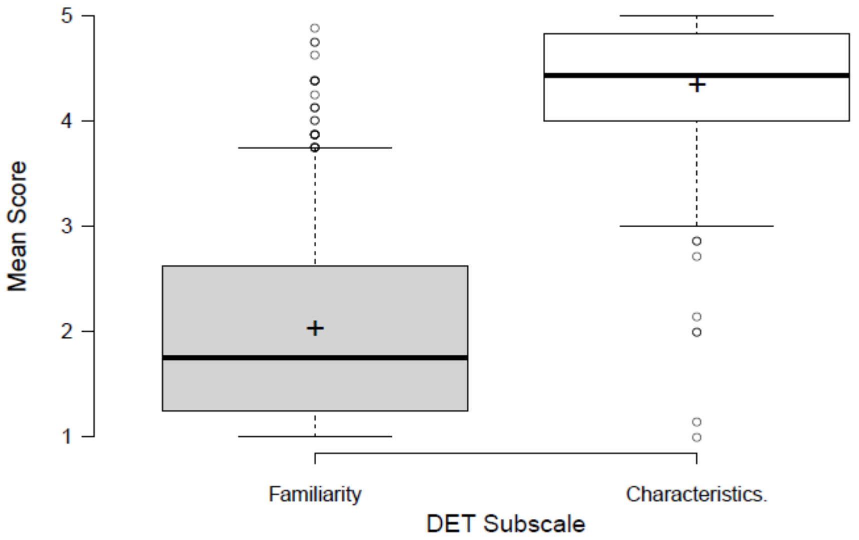


Figure 1. Mean Design/Engineering/Technology (DET) subscale data. The whiskers extend from the 5th to 95th percentile scores and the "+" represents the mean.

Figure 2 provides a breakdown of participant responses by Likert level for each of the questions on the Familiarity with DET subscale. Please refer to Appendix C for a full list of subscale questions. The responses clearly illustrate that the majority of participants did not have preservice coursework for DET and left their preservice curriculum not feeling prepared to teach engineering. The majority of participants also rated their DET confidence low, reported that they did not use DET activities in their classrooms, and did not have a support system at school to help them implement DET activities.

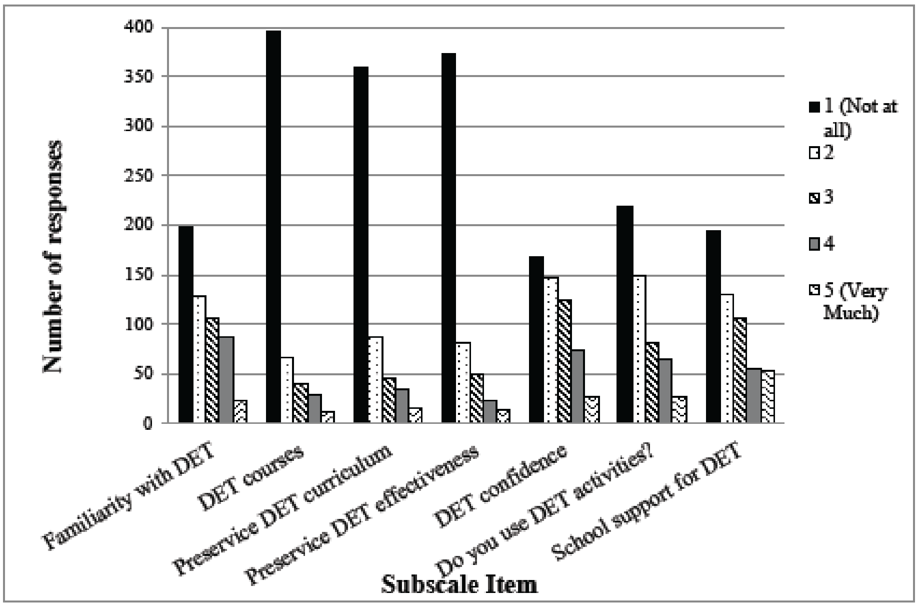


Figure 2. Participant responses for each item on the Familiarity with Design/Engineering/ Technology subscale.

Figure 3 provides a breakdown of participant responses for each item on the Stereotypical Characteristics of Engineering subscale of the DET instrument. Visual inspection of the individual items in Figure 3 reveals that participants viewed engineers as people who have good math and science skills, earn good money, and like to fix things. However, fewer participants strongly agreed that engineers work well with other people and have good communication skills (verbal and written).

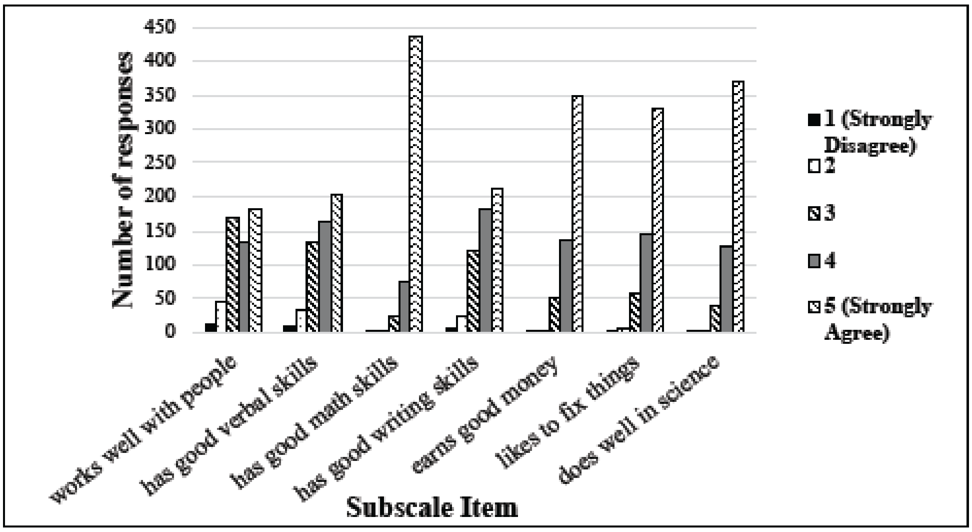


Figure 3. Participant responses for each item on the Stereotypical Characteristics of Engineers subscale.

Qualitative Data Analysis

Open-ended responses

Most participant responses to the open-ended questions fell within one or more of the following nine categories – Engineers as Thinkers, Engineers as Creators, Engineers as Doers, Engineers as Managers, Engineers are Motivated, Engineers are Tech Savvy, Engineers as Social Beings, Types of Engineers, and Uncertainty. It was common for a participants' responses to fall into multiple categories. Table 4 presents a description of each category and examples of representative codes that fell within each category.

Table 4.

Category descriptors and illustrative codes for open-ended responses

Category	Description	Codes (and frequencies) in category
Engineers as Thinkers	Response focuses on the use or application of knowledge	problem solver (n = 307), math (n = 222), intelligent (n = 127), research (n = 109), science (n = 79), analytical (n = 52), logical (n = 37), critical thinker (n = 23), optimize (n = 22), curious or inquisitive (n = 21), spatial reasoning (n = 20), thinking outside of the box (n = 17), high level of education (n = 14), methodical (n = 6), reasoning abilities (n = 5), intuitive (n = 4), systematic thinkers (n = 3), pragmatic (n = 2)
Engineers as Creators	Response focuses on creative processes	designer (n = 273), creative (n = 249), innovative (n = 81), inventive (n = 46), develop ideas (n = 7), visual and artistic (n = 6)
Engineers as Managers	Response describes engineers as those who oversee work OR describe qualities needed to manage	planner (n = 73), detail oriented (n = 43), leads/oversees (n = 31), organized (n = 27), safety (n = 12)
Engineers as Doers	Response describes the engagement in hands-on or physical work	work on structures (n = 55), Construct/make/build (n = 22), maintain/repair/fix things (n = 20), mechanically inclined (n = 20), work with hands (n = 15), use tools (n = 3)
Types of Engineers	Response describe work done by different types of engineers OR mentions there are different types of engineers	types of engineers (n = 63)
Engineers are Tech Savvy	Response refers to the development or use of computers or other high tech gadgets	Computers (n = 28), technology (n = 19)
Engineers as Social Beings	Response describes engineers as either working with or communicating with others OR describes personality traits	team work (n = 31), communication (n = 7), nerdy (n = 2), anti-social behaviors (n = 2), corky (n = 1), introverted (n = 1), out of touch (n = 1), shy (n = 1), geek (n = 1)
Engineers are Motivated	Response describes engineers as being	Hardworking (n = 22), motivated/ determined (n = 16)
Uncertainty	Response demonstrates that participant does not know how to respond OR questions the response	I don't know (n = 9), questions own answer (n = 4)

Table 6 is arranged such that the categories are listed in order by frequency of occurrence, with the most frequently occurring category listed at the top of the table. Figures 4 and 5 display the Wordles that were generated from the participants' responses to the open-ended survey responses

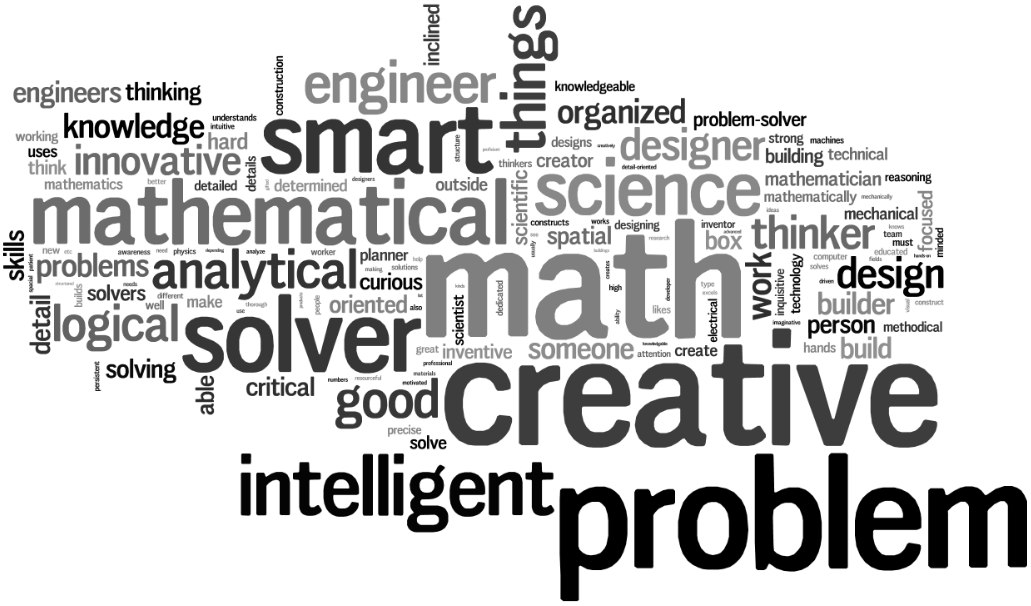

problem
creative
math
intelligent
mathematical
solver
smart
science
analytical
logical
thinker
engineer
things
good
designer
design
innovative
knowledge
organized
problems
someone
builder
person
engineers
thinking
solving
critical
curious
spatial
inventive
oriented
work
build
detail
skills
able
problem-solver
knowledgeable
inclined
mathematician
mechanical
technical
building
box
focused
methodical
creator
solvers
hard
think
working
uses
mathematics
detailed
determined
outside
scientific
scientist
planner
precise
solve

Figure 4. Wordle generated from participant responses to the survey question "What words or phrases would you use to describe the characteristics of a typical engineer?"

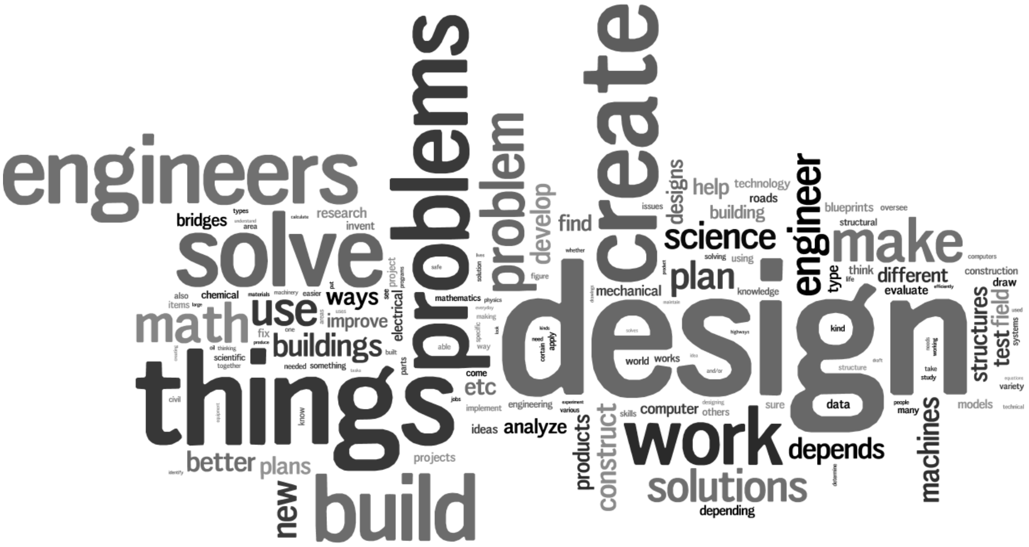

design
problems
create
things
solve
engineers
build
work
engineer
make
problem
math
science
plan
solutions
use
buildings
develop
construct
products
machines
structures
test
field
designs
depends
analyze
ways
improve
better
plans
new
etc
find
help
technology
building
different
computer
bridges
research
invent
mechanical
electrical
data
evaluate
construction
draw
blueprints
roads
ideas
projects
depending

Figure 5. Wordle generated from participant responses to "What do engineers do as part of their work?"

Engineers as Thinkers

Words or phrases falling under the category of engineers as thinkers occurred 1,070 times. Participants described engineers as intelligent and mentioned engineers' abilities to use scientific knowledge. More than half of the participants described engineers as needing to know and use mathematics, writing things such as

"Mathematical-minded; intelligent; likes to figure things out (a thinker!)" and "applying mathematical formulas to help solve problems." Engineers were frequently described as problem solvers, often in conjunction with the application of mathematics or science knowledge. Additional illustrative quotes were:

> "An engineer is an individual who uses science and math to develop new technologies and products. An engineer must be well-educated in these fields in order to adequately design new equipment or materials. An engineer must be able to think creatively to come up with new innovations for old problems."
>
> "A typical engineer applies scientific knowledge and math to creatively solve technical, commercial (ie infrastructure/bridges) and societal problems (Human engineering)."
>
> "An engineer is a scientist who can build and solve problems. He/she is someone that works with numbers and science daily."

Engineers as Creators

The majority of responses in this category were single word answers or very short phrases that described engineers as being creative, designers, and inventors. Participants wrote statements such as "Create and design buildings," "Engineers are creators," "A person who creates things," "An engineer has creativity," and "Innovative."

Engineers as Doers

Responses in this category focused on physical or mechanical aspects of engineers' work. Many participants described engineers as people who construct, make, or build things; work on structures; or maintain and repair things. Example responses included "Engineers like to build things," "Build things and if it breaks, figures out a way to fix it," and "A person who builds engines."

Engineers as Managers

Engineers were also described as overseeing projects or as possessing the skills required to manage projects (i.e. organization, safety). Participants responses included "They are responsible for designing projects and overseeing their completion," "To be in charge and to manage or direct a group," and "Oversee that the project is going as planned."

Engineers are Motivated

Engineers were also described as hard working, determined, and motivated. Responses in this category were often single words or very short phrases, such as "Self-motivated," "Determined and a hard worker," and "The ability to scrap it and start again."

Engineers are Technologically Savvy

Engineers were described as being able to program or work with computers and good with technology. For example, engineers "Use computers to analyze and produce designs," "Develop computer programs," and "Have excellent computer skills to produce and analyze designs."

Engineers as Social Beings

This category included words or phrases that describe perceived personality traits or the ways that engineers interact with others. The perceived personality traits were often negative stereotypes, such as "Nerdy," "Anti-social behaviors," "Introverted," and "Out of touch." However, engineers were also described as "Team players" and "A team member who must communicate and listen accurately."

Types of Engineers

Sixty three participants mentioned that there are different types of engineers and their jobs vary depending on the type of engineer they are. Example responses in this category include:

> "It depends. They can be an engineer for the railroad, armed services, or robotics."
>
> "It completely depends on the type of engineer. For a generalization I would say they come up with 'things' (depending on the type of engineer) and they test them. They have to be able to solve technical problems."
>
> "I would imagine that an engineer would be in charge of chemical testing, design, instruction, and implementation of design. It would all depend on the field of study ie chemical, mechanical, or petroleum engineer."
>
> "Engineer can mean many different things, depending on the field the engineer works in. A civil engineer and a chemical engineer do different tasks, but I believe both are focused on mathematics, science, and problem-solving."
>
> "There are different types of engineers: some who design/create, some technical (who implement)."

Uncertainty. Some participants did not know how to describe engineers or the work they perform, making statements such as "Not really sure" and "I honestly do not know." Others gave responses but questioned their own statements, such as "Change things and make them better? I really don't know" and "Science and math calculations????" One participant quoted a TV character, "'Engineers are the oompah loompahs of the science world.' – Sheldon Cooper." Another participant indicated that his/her participation in the study was due to a lack of understanding of engineering, "The term engineer is not clearly defined. That is why I decided to participate in this survey. I think that engineer is replacing the title of scientist, but I am not sure. Other teachers are not sure."

Follow-up sessions

Qualitative data from follow-up focus groups and interviews are presented below. For ease of reading, follow-up data are presented by the question being answered.

What comes to mind when you think of an engineer?

Responses to this question fell within the same categories as the open-ended survey questions, with most responses falling within multiple categories. One participant's response fell within Engineers as Thinkers, Engineers as Doers, Engineers as Social Beings, Engineers are Tech Savvy, and Types of Engineers, "Kind of nerdy but in a good way. I have some friends who are engineers. Really smart, building things, like civil engineers involved with water and dams and other types of engineers who build buildings and those types of things but again I have a friend who is a computer engineer and does computer stuff, so just kind of a whole lot of things." During the focus group, one participant mentioned that engineers are problem solvers, and another participant followed up with, "I had only heard that an engineer was a problem solver at a conference that I had been to, and I had never even thought of it in that way until you said that [referring to another focus group member] and then you think of all the different lines of engineering and that is the one thing that is in common is problem solving and so that kind of opened my eyes up too. That's been kind of a process for me to think about it in that way because you think about it more as building things, making things, or testing things, whether or not it's going to work before you actually do something."

How would you describe your understanding of engineering?

When asked to describe their personal understanding of engineering, most participants described their understanding as limited or developing, "Fairly limited. I've not taken any upper science. That's not something I took in my education or even my college years, so I would say it would be limited." One participant rated her knowledge on a scale, "On a scale from like 1 to 10, I would say I'm about a 5. I'm familiar with it. I can't tell you in depth about it." Two participants said their personal understanding of engineering was enhanced because their spouses were engineers, "Probably broader than most kindergarten teachers and early childhood teachers because of my husband. He comes home and talks about work."

Do you use engineering activities in your classroom?

To gain a better understanding of how familiar participants were with engineering, they were asked to describe any engineering activities they use in their classrooms. Most participants said they did not use any engineering activities with their students, other than using building blocks during centers. One participant described a unit on weights and measures as engineering, while another described a lab over phase changes as being engineering. One participant described an egg drop project she used. When asked if she talked about engineering during the egg drop project she responded, "I don't know that I have actually used the term engineering. We've talked about the science elements of what we are doing, like the energy side of it and building a structure that will withstand the forces you are trying to put on it, but I don't know that I have ever really used the term engineering with them."

What do you know about the engineering design process?

Most participants said that they knew very little or nothing at all about the design process. One participant stated, "I know nothing. I read it over and over again on the science standards and say okay engineering means that you find out that you need something, you need to design it, you need to create it, you need to find out what the flaws are, you need to redesign, but I don't know how to do that. I can say it but how do you put it into practice." Others were unsure of what the design process was and asked if it were similar to a scientific process, "Probably not a lot because I'm not familiar with what that is. Is it maybe kind of like a science process?" Another participant stated, "The scientific method is that what you're talking about? If it is different from the scientific method, then, I don't know." A few participants said that they felt they understood what the design process was but that they did not have the terminology required to teach it to their students. "I feel like I have enough knowledge…I think that a lot of the knowledge I need to teach it isn't specific enough. I need more help with the specific vocabulary…I feel like I have an understanding of the process they go through but to actually walk you through the steps and know what they are called, no." Another participant stated that the standards did not clearly describe what the design process was, "I probably do it and don't know it…I think terminology is the big issue. You know when I read through the standards last year when they started throwing them up my first reaction was 'What are they even talking about.' They wrote the standards for a Kindergarten teacher as if they were talking to PhD engineers. No, no, no, use the terminology that we are going to use and incorporate with our kids because otherwise you just scare and intimidate everybody."

Discussion and Conclusions

As previously stated, the purpose of this study was to (a) identify the perceptions that in-service elementary teachers hold about engineering and engineering design and (b) how those perceptions compare with the engineering practices described in NGSS. Findings are organized by research question.

Research Question 1: How familiar are in-service elementary teachers with engineering and engineering design?

Overall, K-5 teachers are unfamiliar with engineering or engineering design. Teachers reported their own knowledge of engineering as limited and scores on the Familiarity with DET subscale showed that participants had little previous coursework or training in engineering. Further, most participants said they were unfamiliar with what the engineering design process. Additionally, very few teachers reported using DET activities in their classroom. This was also seen in follow-up sessions when participants described the engineering activities they used in their classrooms. Of the few follow-up session participants who reported using engineering activities, most described activities that were actually science activities (e.g. weights and measures, phase changes) or described building with blocks. Building with blocks could fall under engineering if the teachers provided students with a problem they had to solve using the blocks, but none of the teachers who talked about blocks mentioned anything other than "building." Collectively, these results indicate that many K-5 teachers are not using engineering activities in the classroom and are not familiar enough with engineering to properly identify examples of engineering activities. This is not unexpected given that a previous national study only reported that 4% of elementary teachers felt prepared to teach engineering (Banilower et al., 2013). Further, because teachers are not comfortable teaching what they are unfamiliar with (Brophy et al., 2008) it is not surprising that few teachers in the study used engineering activities.

Research Question 2: What perceptions do in-service elementary teachers hold about engineers and engineering design?

Overall, elementary teachers in this study held stereotypical views about engineering as indicated by their responses on the DET, the open-ended questionnaire responses, and the follow-up sessions. Teachers often viewed engineers as being super smart with great math and science skills. Arguably, many engineers are intelligent and do well in math and science, however, it is interesting to note that fewer teachers identified engineers as having good communication skills and some mentioned negative social stereotypes such as "nerdy." When describing the work of engineers, many participants mentioned that engineers design or create, but it was also common for teachers to focus on physical aspects such as building and fixing machines. Likewise, Cunningham et al. (2006) found that K-6 teachers often viewed engineers as builders. Further, many teachers questioned their own understanding or stated that they did not know what engineers did for their work. Similar to the findings of previous studies (Hsu, Purzer, & Cardella, 2011; Cunningham et al., 2006), elementary teachers in the current study had limited understanding of engineering design. Most of the follow-up participants stated that they did not know what engineering design was or they confused it with the scientific method. Others stated that they had read the standards but didn't understand what they meant or how to enact them. Together, these findings indicate that many elementary teachers hold misconceptions about engineers, engineering, and engineering design.

Research Question 3: Are there differences in teachers' familiarity with engineering or perceptions of engineers between different demographic groups?

ANOVA results for the Familiarity with DET and Stereotypical Characteristics of Engineering subscales were used to answer this question. The only significant difference for Familiarity with DET was gender, with males being more familiar with DET than females. While there was a large difference in sample sizes between males and females, the sample sizes were representative of the population and thought to be reliable. The significant difference found between males and females was not surprising, as previous research indicates that gender role socialization leads to boys having more STEM experiences than girls. Many family members, peers, teachers, and counselors reinforce masculine stereotypes of science (Ashbacher et al., 2010) and technology and encourage girls to pursue more feminine activities (Farmer, 2008). Counselors often steer girls into career paths that are more traditionally female and do not encourage as many girls to take advanced math, science, and technology courses (Farmer, 2008).

There were no significant differences between demographic groups for perceptions of engineers, as measured by the Stereotypical Characteristics of Engineering subscale, indicating that teachers in this study held the same misconceptions about engineers regardless of demographic group. This suggests that stereotypical misconceptions of engineers are widespread and need to be addressed across all demographic groups.

Research Question 4: How do in-service elementary teachers' perceptions of engineers and engineering design compare with expectations set by K-5 engineering education standards?

NGSS analysis revealed that the engineering standards to be taught in K-5 classrooms fall under the topics of engineering design and engineers' impact on society. In order to teach these standards, teachers must understand engineering design as well as pedagogical strategies for implementing design activities into the classroom. They must also have a basic understanding of how the work of engineers impacts society. Participants' responses on the questionnaire and follow-up sessions revealed that elementary teachers hold misconceptions about engineering which may impact the way they view the work of engineers and impact the way they teach engineering to their students. Teachers also have a limited understanding of engineering design, as well as limited experiences using engineering design with their students. Having fewer experiences using engineering design activities limits teachers' opportunities to build the pedagogical strategies required to successfully implement the standards related to engineering.

Implications and future research

Findings form this study indicate that elementary teachers are not prepared to incorporate engineering practices in their classrooms. Teachers are unfamiliar with the work of engineers and the engineering design process and have little experience teaching engineering design. Before teachers can successfully incorporate engineering practices into their classrooms they will need training in how to distinguish between science and engineering practices, as well as how to infuse engineering design elements into developmentally appropriate lessons that also incorporate science content, knowledge of engineers, and career awareness. This will require professional development experiences to support teachers in strengthening their content knowledge, curricular knowledge, and pedagogical content knowledge related to engineering. Further research is needed to determine the ways to best deliver engineering focused professional development to elementary teachers. In the meantime, teacher preparation programs and providers of professional development need to identify current engineering education training programs that are available for teachers as well as work to develop and pilot programs that target these areas of need. Further, administrators need to be aware of these findings and work to identify available resources for their teachers as well as ways to fund needed training.

With the need to ensure that all students are provided multiple opportunities to develop STEM literacy and problem-solving skills, it is imperative that elementary teachers receive proper training in order to successfully implement engineering content and practices into their classrooms. This will require quality ongoing training that addresses what engineering is and how to differentiate between science and engineering activities, as well as provide teachers with the tools to incorporate engineering into their classrooms and go beyond teaching engineering as building with blocks.

Disclaimer: The views and opinions of the authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

References

Aschbacher, P. R., Li, E., & Roth, E. J. (2010). Is science me? High school students' identities, participation and aspirations in science, engineering, and medicine. *Journal of Research in Science Teaching*, *47*(5), 564-582. doi:10.1002/tea.20353

Baker, D., Yasar-Purzer, S., Kurpius, S., Krause, S., & Roberts, C. (2007). Infusing design, engineering and technology into K-12 teachers' practice. *International Journal of Engineering Education*, *23*(5), 884-893. Retrieved from http://www.ingentaconnect.com/content/intjee/ijee

Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). *Report of the 2012 national survey of science and mathematics education*. Chapel Hill, NC: Horizon Research, Inc.

Bischoff, P. J. (2006). The role of knowledge structures in the ability of preservice elementary teachers to diagnose a child's understanding of molecular kinetics. *Science Education, 90*(5), 936-951. doi: 10.1002/sce.20155

Brinkmann, S. (2013). *Qualitative interviewing: Understanding qualitative research*. New York, NY: Oxford University Press.

Brophy, S., Klein, S., Portsmore, M., & Rogers, C. (2008). Advancing engineering education in P-12 classrooms. *Journal of Engineering Education*, *97*(3), 369-387. doi: 10.1002/j.2168-9830.2008.tb00985.x

Carberry, A. R., Lee, H.-S., & Ohland, M. W. (2010). Measuring engineering design self-efficacy. *Journal of Engineering Education*, *99*(1), 71-79. doi: 10.1002/j.2168-9830.2010.tb01043.x

Committee on Standards for K-12 Engineering (2010). *Standards for K-12 Engineering Education?* Washington, DC: The National Academies Press.

Creswell, J. W. (2007). *Qualitative inquiry & research design: Choosing among five approaches (2nd ed.)*. Thousand Oaks, CA: Sage Publications.

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research (2nd ed.)*. Los Angeles, CA: Sage Publications.

Cunningham, C. (2009). Engineering is elementary. *The Bridge: Linking Engineering and Society*, *39*(3), 11-17. Retrieved from http://www.nae.edu/TheBridge

Cunningham, C., Lachapele, C., & Lindgren-Stricher, A. (2006). *Elementary teachers' understandings of engineering and technology*. Proceedings of the 2006 American Society for Engineering Education Annual Conference & Exposition, Chicago, IL.

Cunningham, C. M., Lachapelle, C. P., & Lindgren-Streicher, A. (2005). *Assessing elementary school students' conceptions of engineering and technology*. Paper presented at the ASEE Annual Conference, Portland, OR.

Davis, E. A. (2003). Knowledge integration in science teaching: Analyzing teachers' knowledge development. *Research in Science Education*, *34*(1), 21-53. doi: 10.1023/B:RISE.0000021034.01508.b8

Farmer, L. (2008). *Teen girls and technology: What's the problem, what's the solution?* New York, NY: Teachers College Press.

Fralick, B., Kearn, J., Thompson, S., & Lyons, J. (2009). How middle schoolers draw engineers and scienctists. *Journal of Science Education and Technology*, *18*(1), 60-73. doi: 10.1007/s10956-008-9133-3

Guzey, S. S., Tank, K., Wang, H. H., Roehrig, G., & Moore, T. (2014). A high quality professional development for teachers of grades 3-6 for implementing engineering into classrooms. *School Science and Mathematics*, *114*(3), 139-149. doi:10.111/ssm.12061

Hammack, R., & High, K. (2014). Effects of an after school engineering mentoring program on middle school girls' perceptions of engineers. *Journal of Women and Minorities in Science and Engineering*, *20*(1), 11-20. doi: 10.1615/JWomenMinorScienEng. 2014006726

Harlen, W., & Holroyd, C. (1997). Primary teachers' understanding of concepts of science: Impact on confidence and teaching. *International Journal of Science Education*, *19*(1), 93-105. doi: 10.1080/0950069970190107

Hsu, M.; Purzer, S.; and Cardella, M. E. (2011). Elementary teachers' views about teaching design, engineering, and technology. *Journal of Pre-College Engineering Education Research*, *1*(2), 31-39. doi: 10.5703/1288284314639

Karatas, F. O., Micklos, A., & Bodner, G. M. (2011). Sixth-grade students' views of the nature of engineering and images of engineers. *Journal of Science and Education Technology*, *20*, 123-135. doi: 10.1007/s10956-010-9239-2

Knight, M., & Cunningham, C. (2004). *Draw an Engineer Test (DAET): Development of a tool to investigate students' ideas about engineers and engineering*. Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition, Salt Lake City, UT.

Lambert, M., Diefes-Dux, H., Beck, M., Duncan, D., Oware, E., & Nemeth, R. (2007). *What is engineering? – Am exploration of P-6 grade teachers' perspectives*. Proceedings of the 2007 American Society for Engineering Education Annual Conference & Exposition, Milwaukee, WI.

Liu, W., Carr, R., & Strobel, J. (2009). Extending teacher professional development through an online learning community: A case study. *Journal of Educational Technology Development and Exchange*, *2*(1), 99-112. Retrieved from http://www.sicet.org/journals/jetde/jetde09/wei.pdf

McNaught, C., & Lam, P. (2010). Using wordle as a supplementary research tool. *The Qualitative Report*, *15*(3), 630-643. Retrieved from http://nsuworks.nova.edu/tqr/vol15/ iss3/8

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. San Francisco, CA: Jossey-Bass.

Namey, E., Guest, G., Thairu, L., & Johnson, L. (2008). Data reduction techniques for large qualitative data sets. In G. Guest & K.M. MacQueen (Eds.), *Handbook for team-based qualitative research* (pp. 137-61). Lanham, MD: AltaMira Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states.* Washington, DC: The National Academies Press.

Newley, A., Kaya, E., Yesilurt, E. & Denzin, H. (2017). *Measuring engineering perceptions of fifth-grade minority students with the draw-an-engineer-test (DAET)*. Proceedings of the 2017 American Society for Engineering Education Annual Conference & Exposition, Columbus, OH.

Oliver, D. G., Serovich, J. M., & Mason, T. L. (2005). Constraints and opportunities with interview transcription: Towards reflection in qualitative research. *Social Forces*, *84*(2), 1273-1289. Retrieved from http://www.jstor.org/stable/3598499

Oware, E., Capobianco, B., & Diefes-Dux, H.A. (2007). *Young children's perceptions of engineers before and after a summer engineering outreach course.* Presentation at the 37th Annual ASEE/IEEE Frontiers in Education Conference, Milwaukee, WI.

Patten, M. L. (2001). *Quantitative research: A practical guide (2nd ed.)*. Los Angeles, CA: Pyrczak Publishing.

Pekmez, E. (2018). Primary school students' views about science, technology and engineering. *Educational Research and Reviews*, *13*(2), 81-91. doi: 10.5897/ERR2017.3429

Petroski, H. (2003). Engineering: Early education. *American Scientist*, *91*(3), 206-209. Retrieved from http://www.jstot.org/stable/27858205

Saldana, J. (2013). *The coding manual for qualitative researchers (2nd ed.)*. Thousand Oaks, CA: Sage Publications.

Sargianis, K., Yang, S., & Cunningham, C. M. (2012). *Effective engineering professional development for elementary educators*. Proceedings of the 2012 American Society for Engineering Education Annual Conference & Exposition, San Antonio, TX.

Schunn, C. (2009). How kids learn engineering: The cognitive science. *The Bridge: Linking Engineering and Society, 39*(3), 32-37. Retrieved from http://www.nae.edu/TheBridge

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4-14. Retrieved from http://www.jstor.org/stable/1175860

Silk, E. M., & Schunn, C. D. (2008, January). *Core concepts in engineering as a basis for understanding and improving K-12 engineering education in the United States*. In National Academy of Engineering/ National Research Council workshop on k-12 engineering Education, Washington, DC.

Van Haneghan, J. P., Pruet, S. A., Neal-Waltman, R., & Harlan, J. M. (2015). Teacher beliefs about motivating and teaching students to carry out engineering design challenges: Some initial data. *Journal of Pre-College Engineering Education Research*, *5*(2), 1-9. doi: 10.7771/2157-9288.1097

Yasar, S., Baker, D., Kurpius-Robinson, S., Krause, S., & Roberts, C. (2006). Development of a survey to assess K-12 teachers' perceptions of engineers and familiarity with teaching design, engineering, and technology. *Journal of Engineering Education*, *95*(3), 205-216. doi: 10.1002/j.2168-9830.2006.tb00893.x

Yoon Yoon, S. Evans, M. G., & Strobel, J. (2014). Validation of the teaching engineering self-efficacy scale (TESS) for K-12 teachers: A structural equation modeling approach. *Journal of Engineering Education*, *103*(3), 463-485. doi: 10.1002/jee.20049

Appendix A

DET Questions

Definition of Design/Engineering/Technology (DET) The term "technology," as used in the national science standards, implies the design, engineering, and the technological issues related to conceiving, building, maintaining, and disposing of the useful objects and/or processes in the human-built world. Sometimes this term is referred to as "technological education," but, please note that it is separate from the use of computers and educational technology in the classroom. It is also distinctly different from job training or vocational education. In this questionnaire, we use the term "Design/Engineering/Technology" or DET, synonymously with what the national science education standards (NRC, 1996) call "technology." DET encompasses a number of concepts and skills, including the ability to: identify a problem or a need to improve on current technology, propose a problem solution - solutions may be conceptual or physical objects, identify the costs and benefits of solutions, select the best solution from among several proposed choices by comparing a given solution to criteria it was designed to meet, implement solutions by building a model or a simulation, communicate the problem, the process and the solution in various ways. Examples of different Design/Engineering/Technology (DET) functions include: Designing activities for a school outing. Building a paper bridge that will support a weight, Designing the layout of a new playground, Inventing a new device or process, Designing and piloting a new device or process, Analyzing the economics of two different types of paper towels in absorbing water, Building working models of devices or processes					
Please answer the following questions, choosing the most appropriate answer (1 = Not at all, 5 = Very Much).					
How familiar are you with Design/Engineering/Technology as typically demonstrated in the examples given on the previous page?	1	2	3	4	5
Have you had any specific courses in Design/Engineering/Technology outside of your preservice curriculum?	1	2	3	4	5
Did your preservice curriculum include any aspects of Design/Engineering/Technology?	1	2	3	4	5
Was your preservice curriculum effective in supporting your ability to teach Design/Engineering/Technology at the beginning of your career?	1	2	3	4	5
How confident do you feel about integrating more Design/Engineering/Technology into your curriculum?	1	2	3	4	5
Do you use Design/Engineering/Technology activities in the classroom?	1	2	3	4	5
Does your school support Design/Engineering/Technology activities?	1	2	3	4	5
To what extent do you agree that a typical engineer…(1 = strongly disagree, 5 = strongly agree)					
Works well with people	1	2	3	4	5
Has good verbal skills	1	2	3	4	5
Has good math skills	1	2	3	4	5
Has good writing skills	1	2	3	4	5
Earns good money	1	2	3	4	5
Likes to fix things	1	2	3	4	5
Does well in science	1	2	3	4	5

J-STEM

Journal of Research in STEM Education

j-stem.net