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EDITORIAL

STEM Education: A New Journey

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Politicians, national education committees and industry have linked the quality of STEM education in K-12 to continued scientific leadership and economic progress across many developing and developed countries (ALLEA Working Group Science Education, 2012; Rocard et al., 2007; Dufaux, 2012; Fortus, Mualem, & Nahum, 2009; Jones, 2013; Ministry of Education, Science and Technology (S.Korea), 2009; National Research Council, 2012; Norwegian Ministry of Education and Research, 2010; OECD, 2007; Sjøberg, 2002; Turkish Ministry of Education, 2013). Several reports published in the last two decades have conveyed the public concern that 1) our schools fail to prepare students for the changing demands of the emerging economy: many workers lack the essential STEM knowledge and skills, critical thinking and problem solving skills, 2) the achievement gaps between subgroups of students continue to persist, 3) schools fail to graduate sufficient number of STEM majors in developed countries and 4) that STEM curriculum must become relevant to students' everyday lives.

In response to these challenges, developing and developed countries have initiated several STEM focused projects. Some projects focus on recruiting talented students to STEM fields, some focus on broadening participation of historically marginalized subgroups of students in STEM fields, and others focus on curriculum innovation. The emerging curricular innovation discussions focus on the integration of science, technology, engineering and mathematics (STEM) at the K-12 level.

Integrated STEM Education has been at the forefront of current discussions in STEM education, yet limited research has explored the state of current practices in STEM education, and whether in its current state, STEM education is addressing the concerns that motivated the emergence of STEM as a model to fix the reported problems and to drive the design and study of future teaching and learning.

If STEM education is to continue to grow and develop further, we reason that it should initiate issues at the forefront of educational research and to anticipate future directions, rather than continually trying to play scholarly "catch-up" with research trends. It should anticipate and critique future approaches that seek to address new and persistent questions in education in innovative ways.

In the inaugural issue of J-STEM, colleagues make contributions to the discussion with an eye toward anticipating future questions. The articles span a variety of settings and draw on different frameworks to study questions related to STEM. Yoon et al (2015) introduce a professional development model to better prepare teachers to teach STEM. Ghandi-Lee et al. (2015) explore STEM faculty's perceptions of factors that influence success in STEM fields. Lamberg and Trynadowski (2015), for their part, seek to develop an understanding of elementary teachers' views of STEM in order to develop future research designs and profession development to support STEM learning. Continuing with a focus on K-12 education, Vainikainen, Salmi, and Thuneberg (2015) examine motivation in the context of informal STEM learning. Carroll et al. (2015) present the findings of a project on STEM communication that informs STEM teaching and learning in the 21st century, and finally Khoo and colleagues (2015) focus on an engineering education project in Australia through a research brief.

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Common themes that cut across these articles include aligning practices and curricula in school with students' informal knowledge and interests and the notion that interests and STEM learning are social constructions that draw on individuals, resources, and discourse. Tensions include how the field of STEM is conceived as an integrated entity versus a reflection of two or more content areas.

In considering the current and future state of STEM education, we are reminded of a quote by Geertz (1983) about the field of Anthropology. It "... is a science whose progress is marked less by a perfection of consensus than by a refinement of debate"(p. 58). We hope that this journal offers a forum for such productive, ongoing debates about STEM education and seek your contribution in future issues.

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RESEARCH REPORT

Designing Curriculum and Instruction for Computer-Supported Complex Systems Teaching and Learning in High School Science Classrooms

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Abstract: *While research on teaching and learning about complex systems has achieved solid grounding in the learning sciences, few educational studies have focused on articulating design features for classroom implementation that can serve a modular purpose for building curricular and instructional experiences. Furthermore, despite the fact that several studies describe important roles for teachers in constructing successful classroom learning experiences, only a few of them examine how teachers' instructional practices, knowledge, and beliefs influence student learning outcomes and the extent to which teachers are interested and willing to teach through complex systems approaches. Furthermore, we do not know what supports teachers themselves say that they need to teach about complex systems in their classrooms. In this study, we present a curriculum and instruction framework that outlines how teaching and learning about complex systems in high school science classroom contexts can be done. We articulate the features of the framework and provide examples of how the framework is translated into practice. We follow with evidence from an exploratory study conducted with 10 teachers and over 300 students aimed at understanding change in teachers' instructional practices; the extent to which students learned from the activities; what teachers' perceptions were in terms of utility and usability; and what other supports teachers needed.*

Keywords: Complex Systems, Curriculum and Instruction, Science Education, Professional Development

The study of complex systems in the natural and social sciences has become increasingly essential to understanding disciplinary and interdisciplinary content and practices (The National Academies, 2009). Systems concepts are also featured prominently in the *Next Generation Science Standards* (NGSS) for K12 science in the U.S. Complex systems can be found in structures and behaviors in all aspects of our world. At the micro scale, an example of a complex system is a single fertilized egg developing to create differentiated cells that eventually become a human form. Macro-scale complex systems include businesses, cities, animal populations, and ecosystems. Although complex systems vary in their physical components, a common feature of all complex systems is the presence of multiple interconnected elements, parts, or individuals that communicate in nonlinear ways. The interactions among the parts form a collective network of relationships that exhibit emergent properties not observable at subsystem levels. When perturbations occur, the network may self-organize in unpredictable ways, allowing new properties to emerge. The manner in which complex systems communicate, respond to perturbations, and self-organize is understood by studying the evolution of dynamic processes (Yoon, 2008; 2011).

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While research on teaching and learning about complex systems has achieved solid grounding in the learning sciences (Hmelo-Silver & Kafai, 2011), few educational studies have focused on articulating design features for classroom implementation that can serve a modular purpose for building complex systems curricular and instructional experiences. Furthermore, despite the fact that several studies describe important roles for teachers in constructing successful classroom learning experiences (e.g., Perkins & Grotzer, 2005), only a few of them examine how teachers' instructional practices, knowledge, and beliefs influence student learning outcomes (Yoon et al., 2013; Randler & Bogner, 2009) and the extent to which teachers are interested and willing to teach through complex systems approaches. Furthermore, we do not know what supports teachers themselves say that they need to teach about complex systems in their classrooms. Addressing these gaps will be critical in the next few years in order to meet NGSS requirements.

In this paper, we respond to these needs by presenting a curriculum and instruction framework that outlines how teaching and learning about complex systems in high school science classroom contexts can be designed and implemented. We articulate the features of the framework and provide examples of how the framework is translated into practice for classroom implementation and for professional development (PD). We follow with evidence from an exploratory study aimed at understanding: 1) To what extent teachers thought the PD was usable; 2) To what extent teachers' instructional practices changed as a result of participating in the PD based on the framework; and 3) To what extent students learned from these curriculum and instruction activities. We also provide information in the discussion about what other supports teachers felt they needed.

Complex Systems in Science Education

Over the last 15 years, about 65 empirical studies have appeared in journal articles on the topic of complex systems in K12 education and of those, a large majority, have been geared toward science learning. Although an extensive review of the focus of these studies is beyond the scope of this paper, there are a number of themes that emerge in the research base such as understanding how students reason about complex systems (Assaraf et al., 2013; Grotzer, 2012; Levy & Wilensky, 2008), pedagogical approaches to supporting learning (Hmelo-Silver et al., 2000; Yoon, 2008), computational tools to build complex systems understanding (Azevedo et al., 2005; Klopfer et al., 2009; Yoon, 2011); and models for curriculum construction (Danish, 2014; Gobert & Clement, 1999). Despite this prevalence, no studies exist that investigate how pedagogical approaches, computational tools, and models for curriculum can work in the situated context of the science classroom where variables such as ability to address content standards are primary concerns for teachers. Likewise, very few studies have examined the role of the teacher in influencing student-learning outcomes. In a quasi-experimental study comparing two different instructional approaches to teaching complex ecological content, one study by Randler and Bogner (2009) showed that the teacher's teaching style had a strong impact on student academic learning and when probed, teachers preferred their traditional curriculum over the complex systems-focused one. In our own study (Yoon & Klopfer, 2006) we looked at the supports teachers needed in carrying out computer-supported complex systems curricula in their classrooms. Teachers' lack of comfort with computer programming and pedagogical expertise, and the desire to connect with other practicing teachers, necessitated modifications in the PD activities we offered, which led to improved project implementation.

However, these studies stand as a rare examples of research investigating the teacher's role and variables that effect classroom implementation. In other science education research, we do know that teacher attitudes, beliefs, knowledge, and skills can significantly influence the success of an intervention and even whether an intervention is adopted (Jones & Carter, 2007; Wallace & Kang, 2004). Clearly, more research is needed that includes designs to incorporate classroom and teacher variables to understand how new reform programs like the NGSS can work to improve science education in real classrooms.

To address this need, we constructed a complex systems curriculum and instruction (C&I) framework, depicted in Figure 1, in which teacher knowledge of context variables and content standard demands factored prominently in the design along side tools and practices known to improve student complex systems understanding. There are 4 major categories of the framework that are additionally aligned with the literature on needs and best practices for STEM teaching and learning. The first category is *Curricular Relevance,* which focuses on developing 21st century competencies (NRC, 2012), ensuring standards alignment (Desimone, 2009), and collaboration with teachers to promote teacher ownership (Ertmer et al., 2012, Mueller, 2008; Thompson et al., 2013). The second category, *Cognitively-Rich Pedagogies*, involves pedagogies that address situated needs in individual classrooms (Penuel et al., 2011), social construction of knowledge through collaboration and argumentation (Osborne, 2010), and constructionist learning by constructing models (Kafai, 2006). The third category, *Tools for Teaching and Learning*, builds knowledge with computational modeling tools (Epstein, 2008), teacher guides and student packets that provide scaffolds for learning (Quintana et al., 2004), and off-computer participatory simulations to support students' understanding of modeling and complex systems (Colella, et al., 2000). The fourth category, *Content Expertise*, builds deeper content understanding in complex systems (Yoon, 2008), biology (Lewis & Wood-Robinson, 2000), and computational thinking (NRC, 2010).

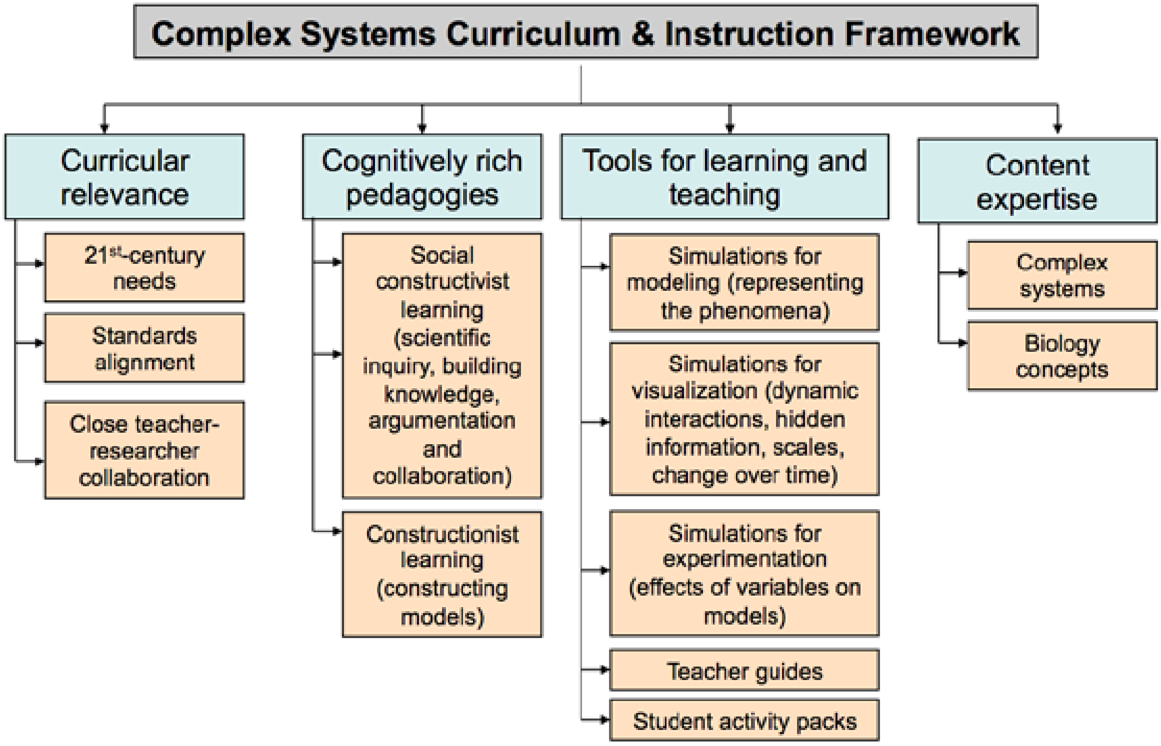

Figure 1. Teaching and learning about complex systems C&I framework

Based on the framework, our project engages teachers and students in learning experiences that build knowledge of scientific practices, complex systems, and biology using computational models. The project has built instructional sequences for five high school biology units – Genetics, Evolution, Ecology, the Human Body, and Animal Systems. Participants use an agent-based modeling platform called StarLogo Nova that combines graphical blocks-based programming with a 3-D game-like interface. The curricular materials take two or three days to complete. Examples of curricular and instructional activities built on this framework are found in Table 1.

Following the construction of the tools and curricula, we trained teachers in summer and school year PD workshops. We worked closely with teachers to understand implementation challenges and iteratively re-designed project resources to meet their classroom needs. In the next section, we discuss the context of the PD underpinned by the C&I framework, and provide evidence from an exploratory study that illustrates its impact in the classroom.

Table 1.

BioGraph C&I framework categories and activities

BioGraph Categories	Activities/Strategies
Curricular relevance	Curricular emphasis on building 21st-century skills in problem solving, critical thinking, and self-directed learning.
	Close alignment with content, practices, and crosscutting themes in the NGSS (e.g., systems).
	Collaboration with teachers as research partners through continual feedback about challenges in classroom implementation and collective problem solving to improve the project and to promote optimal implementation. Peer sharing facilitated through an online database where teachers post lesson plans and comments on implementation details.
Cognitively-rich pedagogies	Consideration of and response to situated teaching contexts such as high ESL populations (e.g., generation of more visual aids to improve cognitive engagement).
	Curriculum and instructional strategies anchored in social constructivist pedagogies (e.g., students working in teams co-constructing ideas through argumentation).
	Using StarLogo blocks-based graphical programming language with a low-level learning threshold, students learn to build simulations to construct understanding of scientific phenomena.
Tools for teaching and learning	Student interaction with models that are visual representations of scientific ideas.
	Visualization of dynamic processes of systems, such as self-organization and emergence, using StarLogo models. Visualization of system states at multiple scales.
	Student experiments using the models, collection and analysis of data, and drawing evidence-based conclusions.
	Easy-to-use teacher guides and student activity packs to promote teacher and student autonomy. Teacher guides for adapting and extending practice.
	Off-computer participatory simulations to engage teachers and students physically in systems that provide additional sensory and cognitive input for learning.
Content Expertise	Popular and academic literature about complex systems for teachers and students. Short movies, PowerPoint presentations, and detailed definition lists to develop systems understanding in the classroom.
	Student interactions with StarLogo models that explore biology content in detail. Some strategically selected content (e.g., evolution) to remediate known robust misconceptions.
	Models set up to allow students to explore the program that executes the model with the goal of developing skills related to computation, such as algorithmic thinking. Some models that require students to manipulate the program and construct their own systems.

Methodology

Context

In order to ensure that the utility of the project's resources could be optimally investigated, we also wanted to take care in constructing PD experiences that would support the efforts. To that end, we designed and conducted the PD following professional judgments about what constitutes state of the art characteristics of high quality PD: (a) aligned content; (b) active learning opportunities; (c) coherence with professional demands; (d) at least 20 hours in duration and spread over a semester; and (e) collective participation of teachers from the same school, grade, or subject (Desimone, 2009; Garet, Porter, Desimone, Birman, & Yoon, 2001). Of these five characteristics, we considered active learning to be particularly important. Due to the well-documented, steep learning curve teachers experience in adopting new technologies in their classroom (Aldunate & Nussbaum, 2013; Ertmer et al., 2012), we emphasized exposure to computers (Mueller et al., 2008) and extensive training on computers (Pierson, 2001). We also incorporated the other characteristics judged to be important for a quality intervention. For example, we achieved coherence with professional demands by providing close teacher-researcher collaboration. We delivered 40 hours of face-to-face PD. We also focused on collective participation by working only with high school biology teachers and, in some cases, working with several teachers from the same school. Figure 3 provides the scope and sequence of professional development activities conducted in the summer 2012 workshop. In this exploratory study, we were interested in understanding what teachers learned and understood about the utility of the activities in terms of classroom practice and whether students' learning improved.

Participants

We recruited 10 teachers from Boston area public schools– seven females and three males. The teachers came from a diverse set of schools. For example, the percent of students who were from minority race/ethnic groups ranged from 3 to 75; the percent who were eligible for free or reduced priced lunch ranged from 11 to 83; and the percent who scored at the proficient or advanced level on the state standardized science test ranged from 54 to 89. On average, the teachers had 7.7 years of teaching experience, with a range of 3 to 18 years. We collected student data from a total of 352 students (mainly comprised of freshman biology students).

Data Collection and Analysis

We conducted a mixed methods evaluation of the project implementation after the summer 2012 PD workshop and throughout the 2012 and 2013 school year. We collected a range of surveys, interviews, and classroom observations of students and teachers to investigate the research questions. First, to investigate teachers' perceptions of the utility of project resources, we administered an 18-item Likert-scale and 8 short answer usability survey at the end of the summer workshop. Questions probed whether they believed the resources were useful to them, whether they would recommend the workshop to other colleagues, and whether they thought the PD was successful. Simple means are reported to illustrate teachers' perceptions of usability and interest in the project.

	Monday	Tuesday	Wednesday	Thursday	Friday
8:00 - 8:15	Room Open - Snacks and Coffee				
8:15 - 8:30					
8:30 - 8:45	Welcome and Participatory Sim - Paper Catchers	Welcome and Participatory Sim - Red	Welcome and Participatory Sim - Angles	Welcome and Participatory Sim - Kids as	Welcome and Participatory Sim - Gamblers Dilemma
8:45 - 9:00					
9:00 - 9:15		Why Construct? Why Argue?	Why Model?	Plan Admin Day and Scale Up	
9:15 - 9:30	Complexity Intro Video and Complex Systems Matrix with BioGraph Examples				
9:30 - 9:45					Calendaring Session
9:45 - 10:00					
10:00 - 10:15		Research Findings			
10:15 - 10:30	Differentiation Sessions (Teacher Presenter)				
10:30 - 10:45	BREAK				
10:45 - 11:00	StarLogo Nova - Catching Flies	StarLogo Nova - Ecology Activity	Buffet of Complex Systems Resources/Pedagogy and Lesson Plan Construction	Working Groups - Differentiation and Assessment	Online Resource Forum
11:00 - 11:15					
11:15 - 11:30					
11:30 - 11:45			Argumentation and Collaboration Resources		
11:45 - 12:00					
12:00 - 12:15			Lunch - Radix Demo	Lunch - Stat	
12:15 - 12:30	Lunch	Lunch			Lunch
12:30 - 12:45					
12:45 - 1:00					
1:00 - 1:15	BioGraph Activity & Next Generation Science Standards - Sugar Transport (Argumentation)	Argumentation and Collaboration Resources	BioGraph Activity and Next Generation Science Standards - Enzymes (Argumentation)	BioGraph Activity and Next Generation Science Standards - Evolution (Argumentation)	Sharing of Assessment and Differentiation Work
1:15 - 1:30					
1:30 - 1:45		Student Assessment and Data Collection			
1:45 - 2:00					
2:00 - 2:15					
2:15 - 2:30	Further Complexity	Parallel Session 1 - Assessment (Working Group)/ Parallel Session 2 - Differentiation of Lessons (Working Group)	Model Building/Programming Extensions - Differentiated Session for Teachers	Assessing BioGraph Students' Argumentation Skills	Exit Surveys and Next Steps Check List
2:30 - 2:45					
2:45 - 3:00					Celebration!
3:00 - 3:15					
3:15 - 3:30					
3:30 - 3:45					
3:45 - 4:00	Daily Wrap-Up				

Color Coding Key	
Blue	Pedagogy
Green	Complex Systems
Orange	Argumentation
Purple	Computation Thinking/Modeling
Red	Break/Lunch
Teal	Research
White	Wrap-Up/Celebration

Figure 3. Scope and sequence of professional development activities in the summer workshop

To understand how teachers' instructional practices changed, we used two data sources, pre-intervention and post-intervention surveys administered to students, which probed the extent to which they participated in learning through computers and simulations, and student learning using scientific practices that aligned with the project goals. The survey encompassed 44 items on a 5-point Likert-scale that ranged from no participation (1) to a lot of participation (5). A repeated-measures analysis of variance (ANOVA) was applied to the data to understand impact on instructional practices. We also administered year-end interviews with teachers to gather information about their perceptions of the project resources, how their knowledge and skills improved, to determine what aspects did or did not contribute to this improvement, and to understand how to redesign project resources to help teachers further improve. The interviews lasted for 45 minutes and were qualitatively mined by the research team to probe for indicators of project impact.

To determine the extent to which students learned while participating in the project, we administered two surveys to students. The first was a 14-point multiple-choice test that measured biology content related to the project. The second was two open-ended questions that provided scenarios about changes in biological complex systems. Students were asked to rationalize why the changes had occurred. Responses were scored on a scale of 1 (not complex) to 3 (completely complex) in four different categories of complex systems components (e.g., emergence of new properties at different scales). Repeated measures ANOVAs were also conducted on the data. In selected classrooms, student focus group interviews were also held to collect information about what they thought about learning biology through project activities and tools. Although more extensive mining of the interview response data is yet to be completed, we report on initial themes that emerged.

Results

Evidence that the PD was usable by teachers

Responses on all 18 Likert-scale items ranged between 4 (agree) and 5 (strongly agree). For example, teachers felt the workshop topics were relevant to the grades they taught (5); the information presented was useful to them (4.9); the information could be put into practice immediately (4.6); instructional guides were useful to their own learning (4.8); the exposure to agent-based modeling technology was useful to them (4.9); they would be able to use ideas about complex systems in their teaching (4.6); and they planned to share complex systems ideas with their colleagues (4.7). When asked whether they believed the PD was successful (and if so, why), teachers overwhelmingly responded positively referencing aspects of the PD they thought were particularly important in their learning:

> "Ample instructional supplies and resources."
>
> "Provision for teacher input and collaboration; great materials and instructional team."
>
> "Practicing each activity and facilitation."
>
> "I have used many simulations before but they don't drive home the major ideas. The StarLogo lessons, I feel do. Our hands-on activities were extremely helpful."
>
> "I learned a lot and will be able to confidently implement the program because we ran through and discussed them all, we talked a lot about…complex systems…"

Evidence of teachers' instructional practices and improved knowledge and skills

On the survey that investigated students' classroom experiences in the two main project factors, learning through computers and simulations (α = .872), and student learning using scientific practices (α = .739), student population responses indicated modest but significant gains in their classroom experiences. On the 5-point scale, responses showed an increase from 3.0 to 3.5 ($p < .001$) for learning through computers and simulations and 3.4 to 3.6 ($p < .001$) for learning using scientific practices. In teacher interviews, teachers felt that these instructional changes did not come at the expense of covering their standard science curricula, as evidenced in the following interview response from one teacher: "I feel like [with] the standards alignment… it was really easy to substitute out something that was old with something that was new. That was very easy."

To understand how teachers' knowledge and skills changed or improved, we asked teachers in the year-end interviews to talk about which of the project's curriculum and instruction components were the most important for their biology students to learn from and which component they used the most in class and why. Teachers said that learning about how to use the visualization tools to help students learn the science content was important. For example, one teacher remarked, "It's really hard for the kids to kind of visualize and understand…but a lot of them kind of had that aha or I get it now moment." Other teachers discussed how their use of scientific practices, such as argumentation, changed. One teacher stated,

> So when they come to me, it's the first time that they see it. And by now, I've got most kids stating a claim, gathering evidence and understanding some difference between evidence and reasoning…and actually the thing that has helped the most this year on it, is that I am requiring all answers to questions that I ask in that framework, even if the framework isn't the greatest for the question, I am actually getting better answers from the students.

Teachers also talked about pedagogical benefits and how the project helped them to work with modeling tools effectively:

> I loved the tools, the StarLogo for modeling and for visualization and simulation. It was fantastic because…a lot of times…if you said here's StarLogo, I wouldn't have had a clue on how to develop any kind of plans or lessons or inquiry based activities. So to have them start off the simulations and then to go backwards and do the modeling…[was great].

Overall, teacher interviews unanimously demonstrated interest in the project for themselves and their students. They identified four main areas of benefit for student learning: (a) student-centered scientific investigations; (b) interaction with computer models; (c) development of evidence-based reasoning skills through argumentation; and (d) multiple resources for developing complex systems understanding (e.g., models).

All 10 teachers have requested opportunities for continued involvement beyond the life of the grant, signaling strong support for the program. More concretely, in their interviews, they identified five affordances of the project related to their own learning and engagement: (a) relevant and multiple resources to engage in real content learning and pedagogical training; (b) access to expert facilitation; (c) peer sharing and collaboration; (d) numerous opportunities to develop teaching skills through hands-on participation and practice; and (e) a sense of identity and community aimed at reforming science education.

Evidence that students showed learning gains in biology and complex systems understanding

For the 14-point biology content test, student scores increased significantly from pre- to post-assessment—from a mean of 6.67 to 8.40 where $F(1, 344) = 32.23$, $p < .001$ and an effect size = .38 (Cohen's d). Students' complex systems understanding measured through the two open-ended questions also showed positive significant growth moving from a mean of 1.48 to 1.61, where $F(1, 350) = 96.03$, $p < .001$ an effect size = .39 (Cohen's d). We do not know how much of this gain would have occurred in the absence of the intervention particularly for the biology content test because we did not have a comparison group. We are also aware that the actual gains in their scores on both measures were relatively small. However, we believe that the moderate significant gains in effect sizes are encouraging results especially for complex systems understanding as the curriculum was new to students and teachers.

From student focus group interviews, several themes emerged that demonstrate the utility of the project activities and curricula to support the development of complex systems understanding. Almost all students mentioned the affordances of interactivity, repeatability, student-centeredness, and visualizations of the simulations. The more interesting ideas in the interviews came in the form of students' abilities to transfer knowledge of complex systems to explain other phenomenon. For example, one student states:

> Well I think they're trying to say everyone or every living thing has a part, and the parts interact as we have like kind of a system. Everyone has their own initiative of what they are trying

> to accomplish or do, or how they work. Then everything working together creates one thing or not even just one thing. It has a lot of different effects in their own ways.

Here the student makes inferences about the general nature of systems that she gleaned from her participation in the project's collective learning activities. She later states:

> Well every time we did a lab it was like saying - the one about the lactose…you had one part that started something, but connected to another part, and all of these parts connecting made up the system that did one thing. Every part was programmed to move a certain thing or have this one objective, but all combined they did one overall thing that wasn't necessarily what each part did.

This student is articulating the complex systems ideas of emergence, self-organization, and scale, which are essential components of complex systems understanding.

Discussion

Education has become ripe with policy, scholarship, and resources to support the study of complex systems. For example, all seven of the crosscutting concepts in the new NGSS reflect important aspects of complex systems such as *Scale,* and *Structure and Function*. This has raised challenges for educators who must follow the NGSS alongside other contextual and professional demands. Thus, understanding optimal methods for constructing educational experiences is critical. Equally important in this effort is focusing on teacher change, their role in adopting these reforms, and how they can be further supported in the classroom.

Although a good deal of research has been conducted in K12 science education on various complex systems-related topics, surprisingly few frameworks and studies have considered teaching contexts and teachers (Randler & Bogner, 2009; Yoon & Klopfer, 2006). In this paper, we introduced a framework for teaching and learning about complex systems that addressed needs in designing approaches for classroom implementation and teacher change in addition to designing activities for student learning. Working closely in PD activities with our teachers, we gathered information about whether their instructional practices changed and investigated reasons for how and why they changed. The results indicated that teachers used more computers and simulations and also increased the use of scientific practices in their instruction. They identified several affordances of the project's design in supporting their own learning, which included relevant and multiple resources, peer sharing, and hands-on participation and practice. Student learning in both biology and complex systems content significantly improved and teachers collectively said that project resources were useful to them in their classroom practice. However, in interviews, teachers said that they themselves learned about complex systems but acknowledged that they needed more time to learn how to reinforce the ideas in their lessons. Teachers discussed a similar need for more time to become pedagogically confident about programming the StarLogo simulations and, for some teachers, fully implementing the argumentation process. We continued to work with teachers to develop more resources to help them teach in these three areas. Teachers also shared their teaching strategies with each other in Saturday PD sessions during the school year. Teachers told us that these opportunities to continue practicing integrating the ideas into their instruction, to access more resources, and to learn from other teachers were invaluable to their growth.

As we move forward in adopting and translating the NGSS into classroom experiences, the teacher's knowledge, skills, and attitudes will be crucial to successful implementation. Wilson (2013) suggests that helping teachers become knowledgeable and skilled in the requirements of the NGSS is a daunting task—one that will require high quality PD that is embedded in real problems of practice in different contexts, and based on an understanding of teacher learning and training as a complex endeavor. Working as research and design collaborators with us, teachers provide invaluable feedback about their perceptions of the utility of the resources and the value added to instruction. Importantly, they provide essential information about how to improve the design based on their professional and contextual expertise, which we must incorporate into future implementation iterations if reforms are to take a hold in the science classroom. We believe that the significance of this study lies not only in articulating design characteristics that work in concert with each other to improve student learning and teacher instructional outcomes but also in examining teachers as the recipients of these complex systems reforms which research has yet to seriously investigate.

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RESEARCH REPORT

Situational Interest and Learning in a Science Center Mathematics Exhibition

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Abstract: *Educators have been increasingly interested in teaching mathematics in informal settings. However, there is little research on the actual learning outcomes of out-of-school mathematics instruction or the role of interest in explaining the outcomes. In this study, 793 12-year-old pupils were taken into a science center mathematics exhibition in Latvia and Sweden, measuring their prior knowledge of the contents of the exhibition, general cognitive competences and individual interest in school mathematics before the visit, and their situational interest and learning outcomes after the exhibition. In the exhibition, the pupils learned how to form concrete, hands-on geometrical models and physical structures based on abstract instructions. The results showed that both boys and girls learned during the exhibition, but contrary to the expectations, there were no gender differences in either learning outcomes or interest. Individual interest predicted situational interest, which was a positive predictor of learning outcomes. It was concluded that more attention should be paid to how situational interest and motivation, which are typical in out-of-school learning contexts, can be utilized in enhancing learning outcomes of children of all age groups.*

Keywords: Science center; Learning outcomes; Out-of-school mathematics education; Situational interest; Individual interest

Educators have been increasingly interested in teaching mathematics in informal settings and using cross-disciplinary methods due to the recent changes in the society (Fenyvesi, Koskimaa, & Lavicza, 2015). It is assumed that utilizing out-of-school learning environments would be useful particularly for pupils who face difficulties in traditional learning situations in the classroom. This assumption has over the recent decades been supported by a large body of evidence from the fields of interdisciplinary and inquiry-based mathematics (Artigue & Blomhøj, 2013). According to Resnick (1987), this is because the practice-oriented tool manipulation approach and contextualized reasoning facilitate the learning of contents that are typically taught using mentation and symbol manipulation. Also, out-of-school environments may produce effects on pupils' motivation or interest and thereby on their learning (Braund & Reiss, 2004; Csikszentmihalyi & Hermanson, 1995; Frantz-Pittner, Grabner, & Bachmann, 2011; Salmi 2003; Thuneberg, Salmi, & Vainikainen, 2014). However, there is relatively little research on the actual learning outcomes of teaching mathematics outside the school walls and how interest is related to learning in out-of-school settings. To study this interesting phenomenon, 793 12-year-old pupils were taken into a science center mathematics exhibition in Latvia and Sweden, measuring their prior knowledge of the contents of the exhibition, general cognitive competences and individual interest in school mathematics before the visit, and their situational interest and learning outcomes after the exhibition. In the present article we take a look at how individual interest in school mathematics and situational

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interest in the science center mathematics exhibition influenced the learning outcomes of the pupils who visited the exhibition and discuss in detail gender differences in interest and learning in an out-of-school learning situation.

Theoretical Framework and Review of Relevant Literature

Interest and learning

Interest is an important cognitive and affective motivational factor guiding attention and facilitating learning in different contexts (Renninger & Hidi, 2011). Interest is at least indirectly related to learning and achievement outcomes even when controlling for prior ability and it typically accounts for approximately 10 % of the variance of performance (Ainley, Hidi & Berndorff, 2002a; Schiefele, Krapp, & Winteler, 1992; Van Yperen, 2003). Ainley and colleagues (2002a) showed that the mechanism of the influence is relatively complex, with interest being related to affective response, the affective response to persistence, and the persistence to learning outcomes. Interest may be a particularly important factor when trying to understand mathematic performance and possible gender differences in it as students tend to sustain an aversion towards mathematics (Ma & Kishor, 1997; Gomez-Chacon, 2000) while remaining largely ignorant of how deeply mathematics is embedded in the world around them (Hannula, 2012). The connection between attitudes and interest with mathematic performance has been showed by earlier meta-analyses (Ma & Kisher, 1997) as well as by recent large-scale assessment studies (OECD, 2013). It has also been shown that regardless of the minimal or even opposite gender differences in school grades and performance, boys report more interest and enjoyment in mathematics than girls (Frenzel, Goetz, Pekrun, & Watt, 2010; Frenzel, Pekrun, & Goetz, 2007).

The interest development of school-age children can be supported by the tasks and the organization of the learning environment (Renninger & Hidi, 2011). The dilemma faced by the science exhibitions is whether they are capable of managing to orient and enhance the momentary, strong situational interest and motivation into a long-lasting intrinsic motivation. This is also one of the biggest challenges for open learning environments, such as science centers (Salmi 1993, 2003; Salmi, Sotiriou and Bogner 2009). As Hidi and Ainley (2009) put it: “Whereas the potential for interest resides in the person, the content and the environment may determine the direction of interest and contribute to its development”. Therefore, studying the effects of interest in learning outcomes in the context of the present study is important.

There are several theories about the different forms of interest and its development (see Renninger & Hidi, 2011, for a review). Interest can be conceptualized as a part of intrinsic motivation, which refers to engaging in activities for the activity itself (Urdan & Turner, 2005). On the other hand, it has been claimed that interest as such is never entirely either intrinsically or extrinsically motivated but it varies depending on the phase of interest development and the situation (Hidi & Harackiewicz, 2000). Many theories regarding interest development recognize the distinction between individual and situational interest. Individual interest can be defined as a psychological state characterized by focused attention, increased cognitive and affective functioning, and persistent effort, which can be seen as an individual’s predisposition to attend to certain stimuli, events, and objects – including school subjects (Ainley et al., 2002a). Situational interest, on the other hand, depends on aspects of the environment including the ways the learning situation is organized (Ainley et al., 2002a). Situational interest is based on an affective reaction, which can include a broad range of emotions, and there is a great variation in how this reaction is maintained (Ainley et al., 2002a). In addition, Ainley and colleagues write about triggered topic interest, which seems to have both individual and situational aspects. In the present study, interest is measured in two contexts: pupils’ general interest in learning mathematics in school is used as an indicator of their individual interest, whereas situational interest is measured as their experience of learning mathematics during the science center visit.

According to Hidi and Renninger (2006), interest develops in four stages, but measures for distinguishing them empirically are still under development (Renninger & Hidi, 2011). The first stage is triggered situational interest, which can evolve into maintained situational interest. Emerging individual interest can then develop out of the second stage, and finally it can lead to a well-developed individual interest (Hidi & Renninger, 2006). In a novel learning situation, pupils with a more developed individual interest have been shown to have better possibilities to experience related situational interest (Renninger & Hidi, 2011). On the other hand, situational sources of interest are particularly important when dealing with pupils who do not have prior individual interest in school activities (Ainley et al., 2002a) even if pupils with only a triggered interest are not always able to purposefully identify goals for learning or decide to self-regulate in order to learn (Renninger, Sansone, & Smith, 2004). There is evidence from young adults that students with less interest for mathematics responded positively to task novelty, but novelty had a negative influence for those with more interest for mathematics (Durik & Harackiewicz, 2007). In general, school-age pupils' individual interest for school subjects has been shown to decrease when they get older, but it can also develop positively if assignments and the learning environment support it (Renninger & Hidi, 2011).

There are some important gender differences in interest, which need to be taken into account in the present study. In their study on gender differences in interest, Ainley, Hillman and Hidi (2002b) review literature which suggests that boys can be more vulnerable to the effects of task characteristics, and interesting tasks – or in the case of the present study an interesting learning environment – can enhance their performance significantly. Accordingly, in the study of Schiefele and colleagues (1992), interest was more strongly related to achievement for boys than for girls. Girls were in the study of Ainley and colleagues (2002b) much more persistent even though the task content was evaluated as uninteresting. They reflected the result against other studies, concluding that boys and girls tend to be similar on high interest material or situations, but with low interest material boys perform poorer, which is likely due to reduced effort. It has to be noted, however, that their study was about reading texts of different topics, and girls have constantly had an advantage in reading tasks (Halpern, 2000). Indeed, Thuneberg and colleagues (2014) found that in the science center context, the novelty of the situation produced stronger effects on girls' on learning outcomes indirectly via their situation motivation. Thus, it is likely that also in regard to interest, gender differences are partially topic-specific and in the context of a mathematics exhibition girls who often are less oriented in mathematics at least during their later school career (Eccles, 2011), may benefit more from the situational factors.

Out-of-school education, learning and interest

Informal education – as it is defined since the 1960s' mainly by the UNESCO report Learning to be (Faure et al., 1972) – means learning taking place outside the formal education system. It was considered until the 1990s very often only as a criticism against the school (Gardner, 1991; Illich 1971). Since the 1990s it has become a widely accepted and integrated part of school systems in many countries especially in regard to science education (Fenichel & Scheinburger, 2010). Despite this development, there is relatively little theoretical or empirical research on it (Osborne & Dillon, 2008) and the beliefs about its effectiveness in enhancing learning and not only motivation is mainly based on anecdotal evidence (see Thuneberg et al., 2014).

The terminology of formal education and informal learning has been clearly defined in the literature for decades (e.g. Bitgood, 1988; Coombs, 1968). However, these terms do not completely cover education that happens during school time and according to the curriculum, but uses settings and institutes outside the physical school building. Out-of-school education is a term included in school legislation in several countries, and it refers to using informal education sources for formal education. It forms a pedagogical link between formal education and informal learning (Braund & Reiss, 2007; Rennie, Feher, Dirking & Falk, 2003; Salmi, 1993). The context of the present study, science centre education, is one form of out-of-school education.

The methods of informal education have traditionally been used in teaching natural sciences, for example biology, geography or science (e.g. Braund & Reiss, 2004; Rennie et al., 2003). For mathematics there has only been few activities related to out-of-school education and learning (Fenyvesi, Koskimaa & Lavicza 2015). There is some evidence from earlier decades that informal sources may have strong effects on learning (Maarschalk, 1986), but especially regarding science center education the studies have mainly concentrated on its effects on motivation (Salmi 1993, 2003; 2010; Tan Wee Hin & Subramaniam, 2003; Osborne & Dillon, 2008;

Fenichel & Scheingruber, 2010). The results show that science centre education has positive effects on motivation, but very little is known about whether it enhances learning too (cf., Thuneberg et al., 2014), especially in the context of mathematics. There is also little research on how situational interest or motivation, which is often awakened in the science center context (Salmi, 1993), influences learning outcomes, even though this is a perfect context for instructors to "catch" and also "hold" pupils' interest by manipulating the learning environment as suggested by Urdan and Turner (2005). The present study provides a unique opportunity to study the effects of situational factors on learning outcomes as mathematics is a subject which many pupils find unpleasant or uninteresting (Wang, 2012). The 2011 TIMMS study (Mullis, Martin, Foy & Arora, 2012) shows that nearly half of the fourth grade pupils internationally liked learning mathematics but the proportion of them dropped to 31 % by the eighth grade. Thus, the sixth graders of the present study are at the age when liking of and interest in mathematics in general is declining. Moreover, as pupils proceed further in their school career they begin to do more gendered choices based partly on motivational and social factors (Eccles, 2011), and mathematics has been traditionally been considered as boys' domain (Halpern, 2000) – even if recent research shows that at least at this age, girls outperform boys also in school mathematics (Kenney-Benson, Pomerantz, Ryan & Patrick, 2006) and more general mathematical thinking skills (Vainikainen, 2014) mainly due to their more positive attitudes.

The present study

The context of this study was a mobile interactive mathematics exhibition "Discover the Art of Math", to which entire school classes were taken to as a part of their mathematics instruction. The pupils visited it and participated in experimental learning session in order to acquire knowledge and skills that would support the curricular mathematics learning goals of 12-13-year-old sixth graders. The exhibition was based on and inspired by the works of Theo Jansen, a Dutch artist who has created many projects that involve art, math and technology. In 1990, he began what he is known for today: building large animals out of animated works are a fusion of art and engineering – PVC-plastics that are able to "live" on their own. The exhibition consisted of eight interactive, "hands-on" exhibition objects, which the students were allowed to use, test, explore and learn by their own will during 45 minutes time. After that they attended a 45 minutes workshop, in which they were allowed to build their own structures and creatures using small "lego" type of pipes and circles. Pupils learned how to build concrete geometrical models and physical structures based on abstract instructions, for example how to create a 3D box based on a 2D square.

The individual work was combined into group work by putting together different items. The exhibition guide was in an introductory and tutorial role. The classroom teacher was just responsible for practical arrangements, not as an active pedagogist. The exhibition was partly funded by NorPlus – education program and it was created by Energiakeskus. It was touring from August 2013 to October 2014 in Innovatum Science Centre, Trollhättan, Sweden; Technical Museum, Stockholm, Sweden; Z(in)OO Science Centre, Cesis, Latvia; and Energiakeskus Science Centre, Tallinn, Estonia. The present study reports only of the Trollhättan and the Latvian exhibition visits as the assessment data for the later visits were not yet available at the time of writing this article.

Research questions and hypotheses

The aim of the present study is to evaluate, whether individual and situational interest influences the learning outcomes of 12-years-old pupils in a science center mathematics exhibition, and whether the pattern is similar for girls and boys. This is done by fitting a structural equation model on the data of 793 sixth graders from Latvia and Sweden. The research questions and the hypotheses to be tested are:

Q1: Does individual interest in mathematics predict better topic-specific knowledge prior to the science center visit and higher performance in the post-test after the visit when the effect of general cognitive competences is taken into account?

H1: Interest in mathematics predicts positively both pre- and post-test results, but the effect is weak when cognitive competences are controlled for (Ainley, Hidi & Berndorff, 2002a; Van Yperen, 2003).

Q2: Does individual interest predict situational interest? Does situational interest predict topic-specific knowledge after the science center visit beyond individual interest?

H2: Higher individual interest predicts situational interest (Renninger & Hidi, 2011). Situational interest has an additional effect on post-test performance as science center visit may be a positive experience also for pupils who are in general not very interested in mathematics (Ainley et al., 2002a; Durik & Harackiewicz, 2007).

Q3: Are the learning outcomes and the effects of individual and situational interest on them similar for girls and boys?

H3: Boys have a slight advantage in the pre-test but girls close both gaps in the post-exhibition assessment (Thuneberg et al., 2014). Boys experience stronger situational interest (Ainley et al., 2002b), but situational factors may have a stronger influence on learning for girls (Thuneberg et al., 2014).

Methodology

The data were drawn from a study, in which sixth and seventh grade school classes were taken into a mathematics exhibition which toured in three countries. The present study reports of the first two data collections that were done in Sweden in the autumn 2013 and in Latvia in the spring 2014. Afterwards, the exhibition continued to Estonia and back to Sweden, but those data were not yet available for the present study.

Participants

The participants were 793 sixth or seventh graders from Latvian (N=408) and Swedish (N=385) schools. The participating classes were randomly selected from all school classes that expressed their interest in visiting the exhibition. 384 of the pupils were girls and 397 boys (the information was missing from 12 pupils). The mean age of the pupils at the time of the pre-test was M=12.39, Sd=.99.

Measures

Two weeks before the science exhibition visit, the pupils completed a pre-knowledge test and a test measuring general cognitive competences, and a questionnaire regarding their attitudes towards learning mathematics in school. Seven to eleven days after the exhibition, they completed a post-test and questionnaire regarding their experiences about learning mathematics in the exhibition.

General cognitive competences. Pupils' general cognitive competences were measured by Raven Standard Progressive Matrices, which addresses the capacity to learn and the capacity to embrace and remember the knowledge once learned in the context of visuo-spatial reasoning (Raven, Raven, & Court, 2000; 2003). In each item, pupils were asked to identify the missing element, which completes a pattern. The test consisted of five sets of twelve items, which were to be completed within a predefined time limit. The items were coded dichotomously as correct or incorrect (including the items not reached). The final test score was calculated as a sum of correctly solved items within the time limit. The reliability of the test was good (α=.89).

Pre- and post-tests for topic-specific mathematical knowledge. Pupils' prior topic-specific knowledge and learning outcomes were measured by a test designed for the present study. Originally developed through a pilot study in Finland, the test consisted of 26 items measuring pupils' understanding of mathematical phenomena, which were covered by the science center mathematics exhibition (e.g. understanding Pythagoras law, pyramidal structures, symmetric plates, strings, and rotating bodies). Pupils were presented short verbal stimuli followed by one to four statements, and the pupils' task was to judge whether the statements were correct or incorrect. They also had the option to say that they do not know the answer, but for the present study those answers were coded as incorrect. All the items were coded dichotomously. Preliminary analyses using Item Response Theory revealed that two very difficult items had a poor discrimination value, so they were omitted from the further analyses. The final test scores for pre- and post-test were calculated by summarizing the remaining 24 items together. The reliability for the pre-test score was α=.74 and for the post-test α=.81.

Individual and situational interest. The Semantic Differential method (Osgood, 1964) was used for measuring pupils' attitudes towards learning mathematics in school settings (pre-test) and in the mathematics exhibition (post-test). The method has been widely used for measuring children's experiences of different learning contexts especially when the results of informal learning and formal education have been compared (Salmi 2012). The 14-item scale consisted of three factors, of which only the interest factor was used in the present study. The pupils had to evaluate three pairs of adjectives on a five-point scale (e.g. Learning mathematics in school is/in the science center was interesting… boring). The reliability of the interest scale was $\alpha=.64$ for the pre-test and $\alpha=.73$ for the post-test.

Data Analyses

Descriptive statistics were calculated with SPSS22 and item parameters for the preliminary analyses in Mplus. Gender differences in performance were initially studied by repeated measures ANOVA in SPSS22. The hypotheses about the effects of interest on learning outcomes were tested by structural equation modelling (SEM) in AMOS22 as this method allows the simultaneous testing of all the relations, taking into account the effects of other variables in the model (see Kline, 2005). The third hypothesis about gender differences was tested by multiple-group SEM, which additionally allows the testing of group differences in both the level of variables and the relations of them. A prerequisite for both multiple-group and repeated measures analyses is measurement invariance of the latent factors. Therefore, measurement invariance of the interest scales across time points and gender groups was checked by constraining first the factor loadings, then intercepts equal, and comparing the change of fit indices to the baseline model (Byrne & Stewart, 2006). Since the deviation from normality of all variables was within the recommended limits (Kline, 2005), maximum likelihood estimation was used in all the analyses. The models were considered having a good fit with CFI and TLI > .95, and RMSEA < .06. χ^2-values are also reported but due to the sample size significant p-values were to be expected.

Results

First, descriptive statistics were calculated for the whole data and for girls and boys separately. The means and the standard deviations are presented by gender in Table 1.

Table 1
Descriptive statistics of the variables used in the modeling for girls and boys

Measure	N	Min	Max	Mean	Sd
Pre-test					
Raven progressive matrices	353 | 362	0 | 8	51 | 54	34.28 | 33.71	8.31 | 7.56
Mathematical knowledge	360 | 355	0	20 | 21	9.54 | 9.75	4.61 | 4.48
Individual interest in mathematics - item 1	346 | 346	1	5	3.60 | 3.60	1.15 | 1.28
Individual interest in mathematics - item 2	343 | 344	1	5	4.23 | 4.22	1.06 | 1.07
Individual interest in mathematics - item 3	337 | 337	1	5	3.66 | 3.55	1.00 | 1.13
Post-test					
Mathematical knowledge	334 | 348	0	22	10.99 | 11.39	4.81 | 4.99
Situational interest in exhibition - item 1	320 | 336	1	5	3.90 | 3.97	1.11 | 1.13
Situational interest in exhibition - item 2	315 | 334	1	5	3.77 | 3.79	1.03 | 1.06
Situational interest in exhibition - item 3	298 | 327	1	5	3.93 | 3.89	1.04 | 0.98

The values for girls and boys are separated by a vertical bar

N= Number of respondents, Min= Minimum value, Max= Maximum value, Sd= Standard deviation

Before testing how interest influences learning, the development of girls' and boys' performance in the knowledge test was analyzed without covariates by using repeated measures ANOVA. The results are presented in Figure 1. The improvement of performance in the test was statistically significant (Wilks' Lambda = .868, F=94.546, df=1, p<.001) but the small gender difference in favor of boys in the post-test (t=-1.057, p=.291) or the interaction were not (Wilks' Lambda = .996, F=2.603, df=1, p=.107). Thus, both girls and boys knew more about the topics of the exhibition after the visit compared to the situation prior to the science center visit and – contrary to our third research hypothesis – there were no gender differences in the level of knowledge.

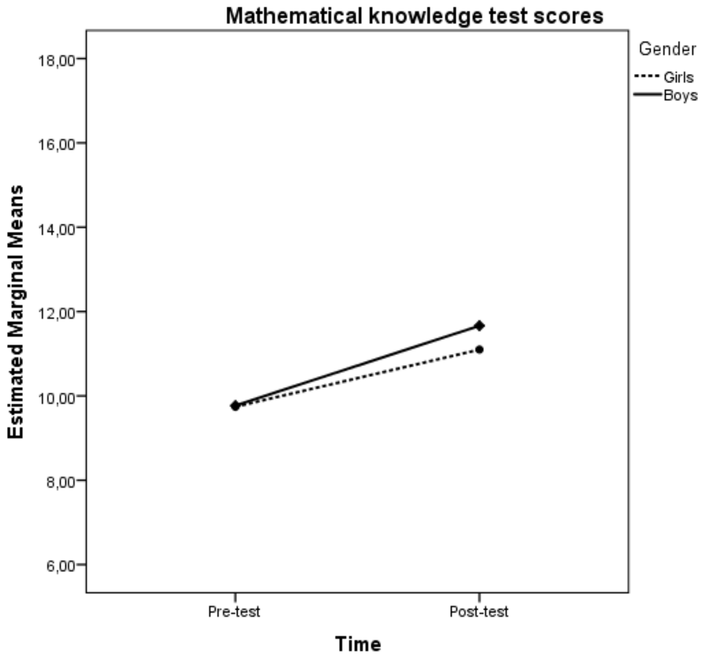

Figure 1. *Girls' and boys' performance in the pre- and post-test for topic-specific knowledge covered by the mathematics exhibition. The improvement of knowledge is statistically significant but the small gender difference or the interaction are not.*

Next, measurement invariance of the interest scale across the two situations (school mathematics in general and mathematics in the exhibition context) and the two gender groups was tested in two stages. In the first stage the analyses were performed using the whole data. First the factor loadings and then the intercepts across the pre- and the post-tests were constrained equal. The changes in the fit indices are presented in Table 2. The table shows that constraining factor loadings influenced the indices only minimally but constraining all the intercepts caused the fit indices to drop. Therefore the intercept of the second item was released. This is an acceptable procedure when the focus of the study is not in latent mean comparison but in studying the relations of the variables (Steenkamp & Baumgartner, 1998). At the second stage the data was divided by gender, and measurement invariance was tested simultaneously across time and gender (see Table 2). The scale was measurement invariant across gender groups but the intercept of the second item had to be released because of the problems in the first stage of testing. The table also shows that constraining the latent means equal across gender groups did not influence the indices but doing it across the time points did. Thus, contrary to our third research hypothesis there were no statistically significant gender differences in interest either but the pupils reported somewhat higher levels of situational interest than interest in school mathematics.

Table 2
Measurement invariance and statistical significance of the latent mean differences of the interest scales

Model	χ^2	*df*	CFI	TLI	RMSEA	*p*
Across pre- and post-tests						
Baseline model	20.217	8	.987	.965	.044	.010
Factor loadings constrained equal	27.234	10	.981	.960	.047	.002
Measurement intercepts constrained equal except for item 2	27.236	11	.982	.966	.043	.004
Latent means constrained equal	69.840	15	.936	.888	.078	<.001
Across gender groups and pre- and post tests						
Baseline model	22.601	16	.992	.980	.023	.125
Factor loadings constrained equal	33.367	22	.987	.975	.026	.057
Measurement intercepts constrained equal except for item 2	36.720	25	.987	.978	.025	.061
Latent means constrained equal across gender	37.623	27	.987	.979	.022	.084
All latent means constrained equal	79.922	28	.941	.911	.049	<.001

CFI= Comparative fit index, TLI=Tucker-Lewis index, RMSEA=Root mean square error of approximation

When the factors were concluded sufficiently measurement invariant, a structural equation model was built for testing the relations of the variables. Individual interest and prior knowledge of the contents of the mathematics exhibition were used in predicting situational interest and mathematical knowledge test results after the exhibition, controlling for the effects of general cognitive competences (the Raven test). Raven turned out to be unrelated to situational interest, so the path was removed from the model. Similarly, the pre-test for mathematical knowledge did not predict situational interest and the path was removed. Moreover, contrary to the first research hypothesis, individual interest was unrelated to prior mathematical knowledge. As there was no gender difference in the latent means in the invariance testing, they were constrained equal across gender groups. Accordingly, constraining the means of all the manifest cognitive variables equal across gender groups even slightly improved the fit indices, so – as already shown by repeated measures ANOVA – there were no gender differences in any of the cognitive measures either. Finally, all the paths were constrained equal across gender groups and again the fit indices even improved. The final trimmed and constrained model (CFI=.977, TLI=.969, RMSEA=.024, χ^2=96.000, df=67, p=.012) is presented in Figure 2. The path coefficients for girls and boys are separated with a vertical bar, but none of the small differences was statistically significant.

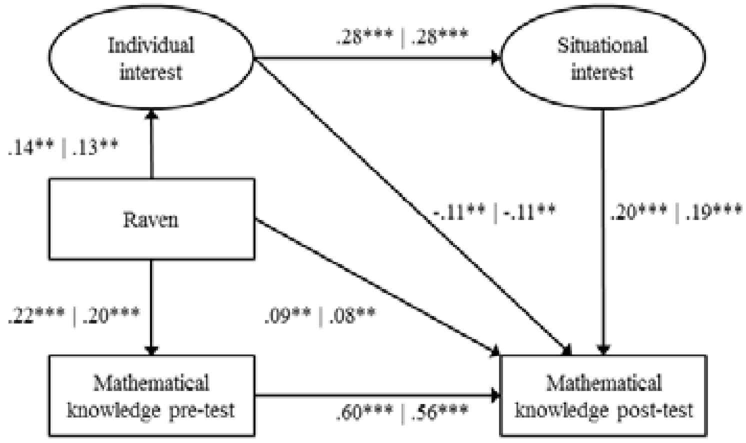

Figure 2. The final structural equation model used in the study. The individual factor indicators and disturbances are not displayed. Factor loadings and intercepts except one are constrained equal across time points and gender groups. All means and paths are constrained equal across gender groups. The path coefficients of girls and boys, respectively, are separated with a vertical bar. ***p<.001, **p.<01. The model explained 43 % of the variance of the post-test for girls and 38 % for the boys.

The figure shows that the absolutely strongest predictor of the post-test for mathematic knowledge was prior knowledge of the contents of the exhibition. Prior mathematical knowledge, in turn, was as expected positively predicted by general cognitive competences as measured by the Raven test. In addition, the Raven test scores predicted weakly but statistically significantly the mathematical post-test scores, which means that pupils with higher general cognitive competences learned slightly more in the exhibition.

The Raven test predicted also weakly but statistically significantly the pupils' individual interest in school mathematics, so pupils with higher cognitive competences were more interested in mathematics. Individual interest was a moderate predictor of situational interest, which in turn had a moderate positive effect on the mathematical post-test scores. Thus, the second research hypothesis was supported. Individual interest, however, predicted the post-test scores negatively albeit very weakly ($\beta=-.110$, $p=.033$). As this was contrary to all the expectations, including the first research hypothesis, this needed further analyses to confirm the interpretation. Therefore, it was tested whether this unexpected effect could be due to so called suppression, which means that another variable in a model extracts the relevant variance of the variable in question, producing a controversial side effect (see Cheung & Lau, 2008). Indeed, without other variables in the model there was absolutely no connection between the individual interest factor and the post-test performance ($\beta=-.018$, $p=.712$), so only the part of the variance which was not related to the situational interest factor explained the slightly negative coefficient. As the model anyways fit the data better with this path than without it, it was kept in the model, but the suppression needs to be taken into account when interpreting the results.

Discussion

The aim of the present study was to evaluate, whether individual and situational interest influences the learning outcomes of 12-years-old pupils in an out-of-school learning context. Almost 800 12-years-old pupils were taken into a science centre mathematics exhibition in Latvia and Sweden, measuring their prior knowledge of the contents of the exhibition, general cognitive competences and individual interest in school mathematics before the visit, and their situational interest and learning outcomes after the exhibition. In addition to studying the learning outcomes and the role of interest in them in general, special attention was paid to possible gender differences in them. As initial analyses showed that the pupils really learned during the exhibition – that is, they got higher scores in the knowledge test measuring the content areas of the exhibition after the visit compared to their performance prior to the visit (cf., Salmi, Thuneberg & Vainikainen, submitted; Thuneberg et al., 2014) – we proceeded to testing our research hypotheses regarding the role of interest and the gender differences in it.

In the first hypothesis we expected that individual interest in school mathematics would predict both pre- and post-test results positively. In other words, we assumed that pupils who are more interested in mathematics would know more of the exhibition topics already beforehand and that they would also learn more during the exhibition. The analyses proved both assumptions incorrect: Individual interested turned out to be uncorrelated with knowledge test scores both before and after the exhibition, and in structural equation modelling there was even a slightly negative relation between individual interest and performance after the exhibition caused by so called suppression (Cheung & Lau, 2008). This means that some other variable in the model, in this case situational interest, extracted the relevant variance of individual interest, producing a controversial direct side effect. Regardless of this, it can be concluded that individual interest was unrelated with both pre- and post-test scores. This was contrary to our expectations, even though we did not expect the effects to be strong due to the young age of the participants (cf., Vainikainen, 2014) and the fact that we had controlled for both prior content-specific knowledge (cf., Ainley et al., 2002a; Schiefele et al., 1992; Van Yperen, 2003) and the pupils' general cognitive competences (cf., Vainikainen, 2014). The results showed, however, that general cognitive competences predicted both better pre-test performance and higher individual interest, and that pupils with higher cognitive competences also learned slightly more during the exhibition. This corresponds the earlier results of Thuneberg and colleagues (2014), showing that a science center exhibition produces stronger effects on the learning outcomes for pupils on above the average performance level. Like in their study, also here the strongest predictor of performance for both boys and girls was prior topic-specific knowledge.

In the second hypothesis we assumed that higher individual interest would predict situational interest and that situational interest would have an additional effect on post-test performance. The results proved both assumptions correct: Just as in the studies reviewed by Renninger and Hidi (2011), which were, however, not about out-of-school learning specifically, pupils with higher individual interest in school mathematics also developed stronger situational interest in the mathematics exhibition. Situational interest in the present study predicted higher performance in the post-test of topic-specific knowledge even when prior knowledge and general cognitive competences were taken into account. On the one hand, these results fit together with Renninger's (2007) assumptions about the mechanisms of interest and learning in informal settings: it is possible that also with the 12-years-olds of the present study, a more developed interest is related to more task-specific goals and better self-regulation capacity, which influences their participation in the situation and is visible in their learning outcomes. On the other hand, individual interest did not predict learning and there were clearly other factors besides it that explained the variance of situational interest, so it seems that a less developed interest can also be beneficial (cf., Ainley et al., 2002; Durik & Harackiewicz, 2007) in out-of-school learning contexts. In this, the results are somewhat controversial with how Renninger (2007) describes the role of developed interest and motivation almost as prerequisites for active participation instead of "aimless" experience seeking in informal learning settings. But this is maybe due to the small but important distinction between informal education and out-of-school education: The mathematics exhibition as an out-of-school learning situation had nevertheless a clear structure and predefined learning goals, and the pupils also received some formal-like instruction during the visit. Therefore, based on the results of the present study compared to the earlier research, more research is clearly needed in how the mechanisms of situational interest and motivation work in the science center context specifically.

In our third hypothesis we expected to find gender differences in both learning outcomes and situational interest. As boys have traditionally been more oriented towards mathematics (Eccles, 2011) and more interested in it (Frenzel et al., 2007: 2010), we expected them to know more about the contents of the mathematics exhibition before the visit. However, as the novelty aspect of a science center visit has in previous studies produced stronger learning effect for girls (Salmi et al., submitted, Thuneberg et al., 2014), we did not expect to find any gender differences in the post-test situation – regardless of the evidence showing that boys may experience stronger situational interest (Ainley et al., 2002b).

The results showed that there were no gender differences in either learning outcomes or interest. That is, girls and boys had equal prior knowledge about the contents of the mathematics exhibition before the visit and they also learned equally much during the exhibition. Similarly, both girls and boys experienced somewhat stronger situational interest in the exhibition compared to individual interest in school mathematics, and there were no statistically significant gender differences in the relations between the variables either. The results were controversial with the earlier results obtained the science center context (Salmi et al., submitted, Thuneberg et al., 2014) in that girls did not have any gap to close when they came to the science center. This may be due to the relatively unusual topic of the exhibition (cf., Fenyvesi et al., 2015), so called 4D-mathematics, which was based on art and handicrafts by Theo Jansen. After all, girls have during the last decade begun to perform better than boys also on the traditional male-dominated school subjects like mathematics (Kenney-Benson et al., 2006). Besides the learning outcomes, the results were controversial with earlier research also regarding the strength and the role of interest in explaining learning. Boys' interest was not related to performance stronger than it was for girls (cf., Schiefele et al., 1992) but on the other hand, the science center learning situation itself was generally interesting, which has been shown to reduce performance differences between girls and boys (Ainley et al., 2002b). However, unlike in the study of Thuneberg and colleagues (2014), we did not find the novelty effect being different for the two genders either. It has to be noted, however, that our measure addressed the novelty of situation only indirectly within the situational interest measure, whereas in the other study it was much more straightforwardly defined as visiting a science exhibition for the first time ever.

Our study had other limitations as well. Even though exactly the same exhibition toured in the two countries, there may be differences in the practical organization of it which could not be addressed in this study. Therefore, further research is needed regarding the implementation effects. Also, the fact that individual interest was hardly at all related with performance can be partially due the limited measures of interest used in the present study. We used a three-item factor from a semantic differential scale for measuring the pupils' experiences of learning mathematics in general and in the science center exhibition context, but other approaches might have been more accurate here. But as Renninger and Hidi (2011) state in their comprehensive review, "Constructing such measures [for differentiating between the stages of interest] is difficult because of the changing and individual nature of the relation among affect, value, and knowledge that is the presumed basis of movement between phases of interest." Also, measurement of the psychological state of interest should preferably be done during the learning process (Ainley et al., 2002a), not before or after it as was done here. However, as often in larger-scale studies, real-time data collection was in the present study not possible due to practical reasons.

Interest and motivation

The present study has concentrated on interest and its role in learning in the science centre settings, but there is a significant overlap between interest and motivation (Durik & Harackiewicz, 2007). Therefore, the results of the present study can be reflected against what is known about motivation and informal learning. In the science center learning context it has been claimed that interest could be the link bridging situation and intrinsic motivation (Salmi, 2003) and the results of the present study support this idea even though motivation was not directly assessed. Interest-based, self-determined forms of learning motivation provide the most favorable learning outcomes, and on the other hand organization of the learning environment can spark interest before personal motivation develops (Fenichel & Schweingruber, 2010; Renninger & Hidi, 2011). Thus, out-of-school learning – formal-like teaching in an informal context – can provide an excellent opportunity for enhancing pupils' interest and motivation towards learning science and mathematics.

Novelty is the key factor to create the interest and situation motivation in the science centers. The shock of a new setting can be addressed by the so called "sniff around corners" method (Balling & Falk, 1981). It works also as a "head-start" for the learning process, and the self-determination theory (SDT; see Reeve, Ryan, Deci & Jang, 2008) underlines the fact that the students must perceive fulfillment of their psychological needs, autonomy, competence, relatedness, during instruction. It has also a clear link to intrinsic learning motivation.

The content of the exhibition is essential: the meaningful experiences are closely connected with a positive development of interest in the subject. Of course, the starting point of this process of growing interest lies within the person, but the content and interaction define the development of situational and individual interests (Hidi & Renninger, 2006). The conflict between earlier knowledge and capacities and the goals that can be reached by own learning activities start this process (Salmi 1993; 2003). The classroom discourse intervention on teachers' practice and students' motivation to learn mathematics and science has given recently very encouraging results (Kiemer, Groschner, Pehmer, & Seidel, 2015). However, informal learning settings might be interest-based and thus motivate also the students who otherwise are not very academically oriented.

Conclusions

There has been a lot of anecdotal evidence related to learning mathematics via informal education and science center exhibitions. However, there has been a clear lack of studies measuring the actual learning outcomes of children visiting mathematics exhibitions. This study gives some of the very first, encouraging results of that teaching mathematics in a science center setting can be fruitful both in regard to learning outcomes but also as a trigger of interest in mathematical phenomena. The standard methods and measurements presented in this study offer common ground for comparative international results. This study also supports earlier findings about interest-enhancing strategies, of which "doing a repetitive task in many different ways" is central in an out-of-school learning context (see Reeve et al., 2008). An open learning environment – a science center exhibition – gives all kinds of pupils an opportunity to utilize functioning strategies and help them to self-regulate (enhance) their interest, engagement, perseverance, and emotional well-being.

This mathematics exhibition gave the students an opportunity to apply hands-on activities utilizing also arts and handicrafts. This clearly predicted higher interest and learning both for girls and for boys. To take the next step beyond the findings of the present study, more attention should be paid to how this kind of situational interest and motivation can be utilized in enhancing learning outcomes of children of other age groups in other learning environments. More research is also needed from science center contexts about exhibitions of different mathematical contents. The present study took the first important step in this direction, opening a new path for studying the mechanisms of interest and learning in out-of-school settings.

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RESEARCH REPORT

Faculty Perceptions of the Factors Influencing Success in STEM fields

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Abstract: *The recent decline in the number of graduates in the fields of Science, Technology, Engineering and Mathematics (STEM) has significant implications for the nation's economic and societal well-being (PCAST, 2012). Because university faculty members' interactions with students—both in and out of the classroom—have a significant impact on student recruitment and retention and because faculty beliefs have a significant impact on faculty practices (Astin & Astin, 1992), we have interviewed university faculty members in order to examine their perceptions of successful STEM students. Here, we report faculty members' perceptions of the characteristics of successful tertiary STEM students, as well as their perceptions of the major obstacle to student success in STEM courses and programs of study. While faculty perceptions of the characteristics of successful STEM students generally align with the research literature, faculty did not mention experiences or instructional strategies they could implement in their classrooms to help students develop these characteristics. The results of the current study could inform the design of faculty professional development to ensure that faculty are aware of the various ways they can support student success in STEM fields.*

Keywords: STEM pipeline, Recruitment & Retention, Perceptions, Faculty, Student characteristics

The economic and societal progress of the U.S. relies on producing innovative minds to meet the developmental demands of tomorrow. As such, the more recent decline in graduates in the fields of science, technology, engineering, and mathematics (STEM) has significant implications for the nation's economic and societal well-being (Ashby, 2006; Commission on Professionals in Science and Technology [CPST], 2007; Hall *et al.*, 2011; Lowell & Regets, 2006). In his 2012 State of the Union address, President Obama reported that there were twice as many job openings in STEM fields as there were workers to fill those jobs (State of the Union, 2012). According to the 2012 report of the President's Council of Advisors on Science and Technology (PCAST, 2012), the U.S. must increase STEM degree graduates by 34% annually in order to produce the approximately 1 million more STEM professionals needed over the next decade. These circumstances call for a national prioritization of STEM education, as well as a systemic evaluation of the factors impacting recruitment and retention in STEM education.

Our interest is the recruitment and retention of undergraduate STEM students. Research indicates that there is significant attrition among STEM majors (Rask, 2010; Seymour & Hewitt, 1994; Tobias, 1990). Studies have examined the factors that promote student recruitment and retention in STEM courses and programs of study (Astin & Astin, 1992; Chang *et al.*, 2014; Hall *et al.*, 2011). These studies have found that faculty play an instrumental role in how students understand and experience STEM fields, especially in the early years of college (Astin & Astin, 1992; Kuh & Hu, 2001; Newman, 2011; Rask, 2010), the most important for recruitment and retention of STEM majors (PCAST, 2012).

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Faculty beliefs about their students and their students' abilities ultimately influence what happens in STEM classrooms (Fang, 1996; Kember, 1997; Nespor, 1987; Pajares, 1992), and what happens in STEM classrooms influences the recruitment and retention of STEM majors (Maltese and Tai, 2011; Watkins & Mazur, 2013). Despite this fact, very little research has examined university STEM faculty perceptions of the characteristics of successful STEM students or of the roadblocks to STEM students' success. With the current study, we attempt to address this gap in the literature.

Review of Relevant Literature

Previous research has examined the correlation between specific student characteristics and experiences and the likelihood that students choose STEM majors and persist in STEM fields. In order to situate university STEM faculty perceptions of the characteristics of successful tertiary STEM students, we first review this literature, identifying factors that are known to contribute to recruitment and retention in tertiary STEM programs of study. We will discuss factors that fall into four major themes: characteristics that are internal to the student; student interactions with faculty; student interactions with peers; and, finally, classroom environment.

In addition, because the current study involves an examination of faculty perceptions of their students, and because these perceptions influence what instructors do in their classrooms, we briefly review the literature about the connection between teacher beliefs and classroom practice.

Factors Affecting Undergraduate STEM Retention

Characteristics Internal to the Student. Some of the factors that are known to correlate with students' choice of or persistence in a STEM field are internal or characteristics of the students themselves. The most common of these is students' orientation toward math. This orientation has two components. First, mastery of math content is a predictor of student success in undergraduate STEM courses and programs of study (Astin & Astin, 1992). Perhaps more significantly, students with high math self-efficacy were more likely to choose a science major in college (Astin & Astin, 1992; Betz & Hackett, 1983).

In addition to strong abilities and self-efficacy in math, student intention and interest in STEM are strong predictors of their persistence to graduation in STEM disciplines. Sullins *et al.*'s 1995 study found that student interest in biology was directly related to their intention to major in biology. Astin and Astin (1992) found that student intentions to major in STEM fields as freshmen were the strongest predictor for those who completed degrees in science and engineering.

Student interactions with faculty. Previous research reports the influence of certain external factors on student retention in STEM programs of study. A significant factor that is particularly relevant to the current study is the role that faculty members play in the persistence of undergraduates in STEM fields. Studies have found that faculty can impact student interest in, performance in, and attitudes about STEM disciplines in a number of ways, both positive and negative. Sullins *et al.* (1995) describe general student/faculty contact as being beneficial to students' persistence in STEM. Other studies go further to address three specific types of faculty interactions with students that can contribute to student persistence in STEM courses and programs of study: interactions in the classroom, interactions in which the faculty member acts as a research advisor for the student, and interactions in which the faculty member acts as a mentor for the student.

At the tertiary level, daily classroom teaching practices can have a significant effect on whether students persist in STEM courses and programs of study. Watkins and Mazur (2013) suggest that a single positive experience—even one as simple as an instructor's demonstrating enthusiasm for teaching the course—could have a significant long-term impact on a student's decision to persist in STEM disciplines. Conversely, student-perceived poor classroom teaching is often given as a reason for students leaving science, ranking just behind loss of interest in science and growing interest in another field (Seymour & Hewitt, 1997).

Maltese and Tai (2011) described ways in which faculty affected student persistence in science through their classroom practices. Some important faculty practices inside the classroom were (1) teacher enthusiasm for the subject matter, (2) contextualizing content in subject matter important to students, (3) stimulating lessons, and (4) discussion about careers and issues in science. Active teaching methods such as these afford the instructor a greater opportunity to listen and interact with students than do more traditional, didactic methods (Watkins & Mazur, 2013).

Outside of the classroom, faculty members can have direct impact on STEM student retention by engaging students in undergraduate research (Astin & Astin, 1992). Undergraduate research programs foster positive relationships between students and faculty (Bounous-Hammarth, 2000) that lead students to view faculty as mentors, rather than simply as instructors (Astin & Astin, 1992). The relationships developed through undergraduate research retain students in STEM disciplines and, in fact, increase the likelihood that students will pursue graduate school (Thiry, Laursen, & Hunter, 2011).

Even if STEM faculty do not act in the formal role of research advisors to undergraduate students, they are still positioned to be meaningful mentors to novice students. These more informal mentoring relationships can lead to students' persistence in STEM fields as well. As mentors, faculty can effectively advise students about their coursework and program of study (Bounous-Hammarth, 2000); they can set high expectations for students' success and demonstrate a high level of concern for individual students (Sullins *et al.*, 1995); and they can exhibit and help students develop an enthusiasm for the field (Walden & Foor, 2008).

Interactions with peers. Interactions between instructor and student are not the only influential relationships a student experiences during their program of study. Previous research has found peer relationships to be important to the selection of and persistence in STEM disciplines. Students' academic interactions, which might include interactions with their peers, instructors, or academic advisors, help align their academic aspirations with their choices (Wang, 2013). For example, Astin and Astin (1992) found that students were more likely to graduate in the physical sciences if their peers also chose a physical science major. Graduation was also more likely for physical science students who tutored or peer-taught other students. Watkins and Mazur (2013) studied peer-to-peer instruction in the physics classroom. They found that students who were taught in traditional instruction classrooms, focused on faculty-to-student instruction, were more than twice as likely to transfer out of a STEM major than students who participated in the peer instruction classrooms.

Classroom environment. The STEM classroom environment has also been shown to have an impact on students' likelihood to major in STEM. In the classroom, Maltese and Tai (2011) found that undergraduates who enjoyed an introductory science course were more likely to major in a STEM discipline. Sullins *et al.* (1995) described more specific characteristics of a successful STEM classroom environment. These programs had small class sizes, a low student-to-faculty ratio, a high level of cooperation among students, and an emphasis on research.

Relevance to current study. The importance of this discussion of factors influencing persistence of tertiary students in STEM courses and programs of study is apparent when considering the potential role of faculty in the experiences of students in STEM disciplines. Engaged faculty members have the ability to directly impact students through their interactions in and out of the classroom. In the classroom, faculty can show enthusiasm for their field, demonstrate concern for students both individually and as a group, promote peer-to-peer interactions through in-class group work, and cultivate interest in the field through the teaching practices they choose to implement. Outside of the classroom, an undergraduate research program provides the opportunity for faculty to interact with students as mentors, enable peer-to-peer collaboration, and facilitate students working as STEM professionals on meaningful research programs.

It is clear from the preceding discussion that faculty have the potential to positively influence students' persistence in tertiary STEM courses and programs of study, based on how they interact with their students. Current research suggests that the ways faculty choose to interact with their students are influenced, at least in part, by their beliefs about teaching, learning, their students, and the context in which they teach.

The Impact of Faculty Beliefs on Classroom Practice

A number of studies have indicated that the beliefs of K-12 teachers play a major role in their decision-making about curricula and the instructional strategies they employ in their classrooms (see, for example, Fang, 1996; Kember, 1997; Nespor, 1987). In fact, Pajares (1992), who reviewed the literature about K-12 teachers' beliefs, stated that beliefs are the "best indicators of the decisions that individuals make throughout their lives" and that "few would argue that the beliefs teachers hold influence their perceptions and judgments, which, in turn, affect their behavior in the classroom" (p. 307). The research about university academics' beliefs, although more limited than that about K-12 teachers, shows a similar trend: beliefs influence practice (see, for example, Brown *et al.*, 2006; Fang, 1996; Kember, 1997; Sunal *et al.*, 2001).

Teachers' beliefs about teaching and learning and their perceptions of the abilities of their students affect what actually happens in the classroom (Brown *et al.*, 2006; Johnson & Hall, 2007; Laplante, 1997). According to Johnson and Hall (2007),

> In addition to the beliefs teachers hold about teaching and learning are their perceptions of the students they teach. Both teacher beliefs about learning and perceptions about their students translate into classroom instructional practice. These practices in turn, shape the dynamics of student learning. (p. 1)

These two belief sets are often at odds with each other. For example, an instructor might believe that, in general, students learn STEM content best as they participate in student-focused, inquiry-based activities that require them to find and explain patterns in raw data. Despite having this belief, if the instructor also believes that the particular students in his classroom do not possess the mathematical and critical thinking skills necessary to make sense of data, he may resort to more teacher-focused, didactic approaches in the classroom. The teaching strategies employed in a classroom, then, result from a negotiation between an instructors' idealized beliefs about teaching and learning and their perceptions of their students' abilities and other context-based factors, such as a need to cover a large amount of information in a limited amount of time or the culture and expectations of their schools and departments (Brown *et al.*, 2006; Fang, 1996; Mansour, 2009; Sunal *et al.*, 2001).

Purpose of the Current Study

The purpose of the current study is to examine the perceptions university STEM faculty have of their students. There are two reasons we considered this an important population for examination. First, university STEM faculty are the "experts at the end" of a STEM educational experience. As such, STEM faculty should have a valuable perspective on the characteristics of successful STEM students. An understanding of those characteristics could inform the development of learning experiences in primary and secondary education. Second, in many cases, university faculty could be seen as the final "gatekeepers" of STEM pathways (Venville *et al.*, 2013). In order for students to progress toward STEM-related careers, they often have to successfully negotiate the courses and programs run by these faculty members. Indeed, research shows that faculty can have both positive and negative influences on students' recruitment and retention into STEM-related fields and careers. For example, positive student/faculty interactions are cited as a major factor related to students' decisions to remain in STEM-related majors (see the discussion in the previous section). On the other hand, several studies have indicated that poor teaching in introductory STEM courses may be driving off students who would otherwise be interested in STEM-related careers (Lichtenstein *et al.*, 2007; Seymour & Hewitt, 1994; Sunal *et al.*, 2001; Tobias, 1990). Given that faculty beliefs about students influence how they interact with students and the methods they choose to employ in their courses, it also is important to examine faculty beliefs about the abilities of their current students.

We developed the following research questions to guide our examination of university faculty members' perceptions of successful STEM students.

1. What are faculty perceptions of the characteristics of successful STEM students?
2. What are faculty perceptions of the major barriers to students' success in STEM courses and programs of study?

Methodology

We chose to use phenomenography as the theoretical framework for this study. Phenomenography is an empirical research tradition that was designed to answer questions about thinking and learning, especially in the context of educational research (Marton, 1986; Orgill, 2007). Its objective is to define the different ways in which people experience, interpret, understand, perceive, or conceptualize a phenomenon or certain aspect of reality.

In order to determine how university STEM faculty perceive their students and their students' abilities, we interviewed 27 STEM faculty, representing multiple disciplinary areas, at a Southwestern research university (Figure 1). As participation in the current study was voluntary, the distribution of faculty members interviewed is not representative of the university. All interviews were semi-structured and conversational in style, lasting approximately 30-45 minutes each. We began each interview by asking faculty to tell us about their educational background, the type of research they do, and the classes they typically teach. We continued by asking faculty about the preparedness of students for the classes they teach. Then we asked faculty to define the desirable characteristics, skills, and knowledge base of students who are successful in their fields and how they thought students could develop those skills. The major focus of the current manuscript will be on the faculty members' perceptions of the characteristics of their successful STEM students, although we will comment briefly in the Discussion section about how faculty members perceive that students can develop these characteristics.

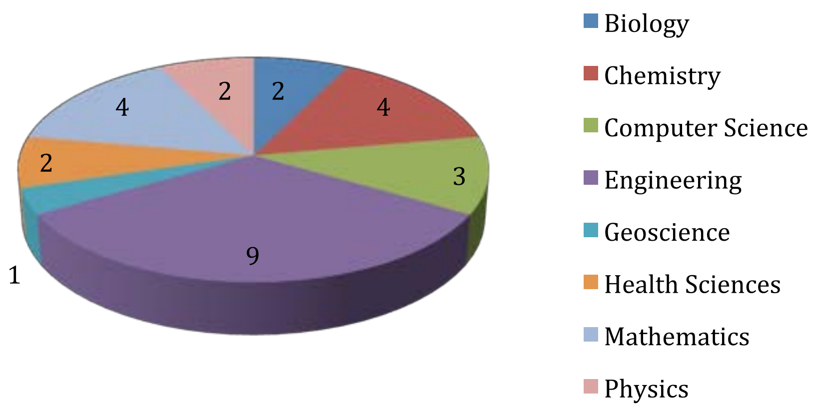

Figure 1. Distribution of faculty participants by STEM-related discipline.

We transcribed each of the interviews verbatim. Based on an initial reading of the transcripts and their knowledge of the literature, three authors (EG, HS, and MO) identified themes they felt merited further analysis. They chose to examine transcripts for evidence of faculty members' perceptions of the following: (1) the characteristics of successful tertiary STEM students, (2) the desirable knowledge base of successful tertiary STEM students, and (3) reasons why students are not always successful in university STEM courses. The three aforementioned authors independently coded each of the transcripts, making a list of categories—supported by evidence from the transcript—under each theme (e.g., specific characteristics of successful tertiary STEM students) while, at the same time, looking for evidence of themes that had not been initially considered. No additional themes manifested during this analysis. Discussion of the codes led to the grouping of themes 1 and

2 named above, because faculty did not distinguish between the characteristics and desirable knowledge base of successful tertiary STEM students in their responses to interview questions. Over multiple meetings, the same authors met to discuss their combined categories under each theme group. During those meetings, they developed common language to describe the categories, coming to consensus on each category description. At this point, they used the category descriptions to code the interview transcripts, making note of the number of responses that corresponded to each category. As a final level of analysis, they developed two theme-based assertions describing faculty perceptions of (1) the characteristics of successful tertiary STEM students and (2) the major obstacle that keeps tertiary STEM students from being successful. In the sections that follow, we provide supporting evidence for each of these assertions. All faculty members are referred to using assigned pseudonyms.

Results

Assertion 1

Faculty identified a number of characteristics of successful students in STEM courses and programs. The majority of the identified characteristics were not discipline-specific, but more general and applicable across disciplines.

As previously mentioned, university STEM faculty function as some of the “experts at the end” of many STEM educational pathways. Through their interactions with the students in their programs, faculty members become aware of the characteristics, skills, and knowledge base of their successful students. As researchers who are interested in promoting STEM education and in encouraging more students to enter STEM-related fields and careers, we wanted to know the characteristics of successful tertiary STEM students in order to develop programs and curricula that would cultivate these same characteristics in students who were progressing through their primary and secondary education.

Each of the 27 faculty members we interviewed perceived general traits and skills—like curiosity and problem solving skills—as being important characteristics of successful tertiary STEM students. Only six faculty members perceived discipline-specific knowledge and skills—like understanding the functions of the organelles in a eukaryotic cell—as being critical to the success of STEM students. In fact, five of the faculty we interviewed indicated that they could help students develop the more discipline-specific skills, characteristics, and understandings as long as the students possessed certain general skills and characteristics—skills that are applicable across STEM disciplines.

The skills and characteristics of successful STEM students that faculty described fell into three broad categories. Overall, faculty members asserted that *personality traits* such as curiosity, inquisitiveness, and a strong work ethic are important for successful STEM students. Most faculty also agreed that successful students have key *academic skills*, like the ability to synthesize information, good written and oral communication skills, and good problem-solving abilities. Finally, faculty in this study described successful STEM students’ *affective qualities*: that they have positive attitudes toward STEM fields and practices and, more importantly, that they are keenly interested and engaged in finding STEM in the world around them.

Personality traits of successful tertiary STEM students. Certain personality traits were seen as being important contributors to the success of tertiary STEM students. Across disciplines, a majority of faculty (20 of the 27 interviewed) perceived that successful tertiary STEM students tend to be innately curious about and interested in their field of study. Faculty believed that curiosity is a trait that is especially valued in science because it fosters engagement.

> What I want is a curious human-being, who doesn’t take anything for granted, who comes and I teach her or him something and she immediately questions, starts questioning, “Why? You told me that you want me to remember this or learn this. Why?” (Dr. Scott, Engineering)

Faculty felt that curiosity and inquisitiveness are important driving forces for student learning in STEM disciplines. Faculty in this study perceived that inquisitive students are more interested in STEM content and more attentive about the concepts being discussed in their courses than students who do not have an inquisitive nature. Dr. Singh (Biology) suggested that inquisitiveness reflects students' thirst for knowledge and helps them excel in challenging STEM disciplines. When we asked him to describe the characteristics of successful STEM students, he said:

> They're inquisitive. They're asking questions, of everything, all the time; and they're never satisfied with the answers they get. Not that they're dismissing the answers, but they want to know more. And, it's not that they're just asking the questions and then giving up, it's that they're asking and then going and finding the information. And I think in today's world that's even easier for students to do because they can hop on their iPad or their iPhone.

Finally, and equally pertinent for faculty members, was the work ethic that students carry into their classroom and research practices. According to eleven faculty members, students who are willing to work will succeed in STEM courses and programs. Moreover, STEM faculty perceive that they are more able to help—and interested in helping—students who are willing to work than students who are not willing to work. Dr. Newman (Engineering), for example, indicated that a strong work ethic was essential to success in an engineering program: "They have to want to work. I can do wonders with that."

Academic skills of successful tertiary STEM students. Twenty-two of the faculty members interviewed named key skills that students who succeed in their fields possess. The most frequently-cited skill was the ability to independently solve problems. Nine faculty members felt this skill was important. Seven faculty members named the ability to synthesize information as key to student success. Six faculty members thought that a student's ability to communicate was important. For example, Dr. Singh (Biology) explained that successful students in his field are able to take information from different sources and synthesize it into a coherent whole:

> They've taken their curiosity and they've translated that to, essentially, a scholarly level, where they're engaged in trying to, not just understand the world, but to, to define new ways to understand the world. I think that actually is the transition that a student goes through, sometime between the end of their sophomore year and graduating, is that they go from learning facts to synthesizing answers.

Many faculty members also identified strong written and oral communication skills as being essential for success in STEM-related fields and careers and, thus, for success in tertiary STEM courses and programs. Dr. McGuire (Engineering), for example, said that successful students have "an ability to communicate their ideas, to express themselves in writing and orally." Despite communication being an important skill, many faculty members in this study worried that students do not start their tertiary education with this skill.

Good synthesis and communication skills were not seen as sufficient for success in tertiary STEM fields, however. Of all the academic skills that faculty identified in their successful students, the one that seemed to be most important was a willingness and an ability to independently identify and solve problems. When we asked Dr. Peyton (Geoscience) to identify the characteristics of his successful students, he said that they are better at "identifying that there's a problem and then…picking at it from different directions." Dr. Peyton elaborated, saying that it was important for students to be willing and able to solve problems *independently*: "Willingness to do—solve their own problems. […] A willingness to simply attack a problem and find out whatever information you need in order to actually do it." Many faculty agreed with Dr. Peyton's assessment, stating that their successful students tend to be eager to solve problems without being given all the information or steps to do so. This is not to say that students must be able to correctly solve all problems on their own; however, they must demonstrate a willingness to try. Most faculty we interviewed were willing to help students make additional progress once the students had invested time and effort into solving problems on their own.

Affective characteristics of successful tertiary STEM students. Affective factors such as attitude and engagement have received serious attention in the field as indicators of achievement in science and mathematics (Singh, Granville, & Dika, 2002). Three faculty members said that students who are engaged in the community and in their field are more likely to succeed in STEM. Two faculty members described a positive attitude about work and learning as important to STEM success.

In fact, nine faculty perceived that students with an interest in STEM concepts are easier to teach and have an easier time learning and progressing in STEM courses and programs. They stated that they can help any student who is interested and who has a willingness to work to learn STEM concepts. Dr. Delgado (Computer Science) stated "If you come, and you're interested, and you want to work for it, we'll teach it to you." Dr. Rogers (Physics) also emphasized the importance of students having a desire to learn:

> They have to have the desire to learn. […] I tell this to my own students, "I'm creating conditions for you to learn, but I can't force you to learn." You can take the horse to water, but you can't force him to drink.

While faculty perceived and described several traits and skills that contribute to students' success in STEM disciplines, they also identified a number of factors that they perceived as being barriers to students' success. By far, the most common theme among the barriers faculty members described was the novice student's relationship with mathematics. Interviewees' discussion of this factor is described in greater detail in the following section.

Assertion 2

All faculty perceived mathematics as being the major obstacle to students' success in tertiary STEM courses and programs.

All of the faculty interviewed in the current study identified a lack of mathematical knowledge and skills as being the major roadblock to student success in tertiary STEM courses and majors. Faculty from all disciplines represented in this survey, including the life sciences—which might be considered less reliant upon math as a foundation—agreed that deficiencies in math are barriers to STEM success, particularly in introductory courses. Dr. Shears (Allied Health Sciences) summarized the perceptions of the faculty when she said that, "students in the undergraduate class, generally, are not prepared for my class. They're lacking quantitative mathematics skills." Dr. Hart (Life Sciences) concurred: "The vast majority of students that come to any university in the country are under-prepared in math—and especially in the sciences. I think that we need to work on math skills early and often."

Lack of mathematical knowledge and skill was seen as particularly problematic because, as Dr. McGuire (Engineering) noted, students "need the math skills […] to be able to understand the coursework that they're going to embark on." Dr. Rogers (Physics) concurred: "The biggest problem with students in the introductory courses is that they just don't have the mathematical sophistication that they need. Math is our language, so the biggest challenge is getting them to overcome their fear of math." The faculty perceived that when students do not enter tertiary STEM courses and programs with sufficient mathematical knowledge, a lot of class time that should have been dedicated to discipline-specific content was focused, instead on "how to solve math problems." Dr. Parikh (Physics) described this phenomenon:

> What happens is we'll start talking about physics, and people will get lost in the math; and then I have to stop and say, "Let's back up, and let me explain this in a way that we don't need to worry too much about the math, or we don't have to do all the algebra to rearrange equations." And that's where things get held up in the class.

Mathematics faculty also agreed that students enter college with insufficient math skills—or with a fear of math—that keeps them from succeeding in tertiary math coursework and programs specifically. Dr. Mico (Mathematics) stated that he has seen a decrease in the mathematical skills of incoming students since he joined the faculty 25 years ago. When we asked him if he felt like students were prepared for his classes, he said no, claiming that "what is killing them is the [lack of] algebra background." Additionally, he said that "the kids, they cannot tackle word problems. The minute they see a word problem, they get chickened out, and the same thing with the algebra." Dr. Palmer, another mathematics professor, claimed that, although students might have previously learned some desirable mathematical skills before entering college, they do not seem aware of when and where it is appropriate to apply those skills.

> They're lacking connections. They don't know what to use and when. They misuse a skill in a place where they shouldn't be using it, and then they neglect to use it in places they should. That probably comes from a lack of depth, I guess.

It is clear that, to the faculty interviewed in this study, lack of mathematical knowledge and skills was seen as the major obstacle to success in tertiary STEM courses. But what type and level of mathematical knowledge and skills do faculty perceive to be desirable in an incoming tertiary STEM student? The answers to this question differed by individual faculty members and, in some cases, by discipline; however, there were some common themes in the faculty responses. In the sections that follow, we discuss those general themes.

Math skills tertiary STEM students should have to be successful. During their interviews, faculty discussed both the minimum level of mathematical prowess that they expected in their incoming undergraduates as well as mathematical skills that they perceived to be vital but currently lacking in undergraduate students.

Although faculty in engineering and physics declared that it would be useful for students to have some calculus—or at least pre-calculus—knowledge before entering tertiary STEM programs and courses, all of the faculty members we interviewed agreed that, at a *minimum*, entering students should have strong algebraic skills. Algebra is a common prerequisite to many undergraduate STEM courses and an area in which students in STEM-related programs are expected to be proficient. When asked which mathematical skills he expects in his incoming students, Dr. Clark (Mathematics) stated:

> The skills would be fluency in the algebra. If I do something on the board, some calculus stuff, and then quickly do the algebra, that quickly doing the algebra shouldn't lose them. If I skip some algebra, they should be comfortable doing that.

The key feature of Dr. Clark's statement, which was expressed by many faculty, was that students not only need to have received basic training in algebraic skills, but that they must be "fluent" in those skills. We will discuss this topic further in a section that follows; but, essentially—and according to the faculty we interviewed—being "fluent" in mathematical skills means being comfortable with using those skills, being able to quickly apply those skills, and knowing when it is appropriate to apply those skills.

A particular application of algebra that two faculty participants perceived as lacking in their current undergraduate students is the ability to interpret word problems and convert them into mathematical language and equations. Dr. Rios (Chemistry), for example, commented that many students who are capable of manipulating algebraic equations find converting word problems into mathematical equations challenging:

> [The problem] isn't so much the math that's covered, which is pretty basic algebra, but it's being able to look at a description of some sort of a chemical problem and convert that into a math equation that they can solve. That's the biggest place where they struggle. I think that if I were to simply give them the math problem that you have to solve to be able to solve this chemistry problem, most of them could probably do it, but once you have a sentence you need to convert into an equation, that's probably the biggest roadblock for them.

Mathematics coursework and background tertiary STEM students should have to be successful. In order to develop a comfort level and fluency with algebraic skills, faculty participants said that students should take as many math courses as possible before entering college. A major point of consensus among faculty was that all incoming students should complete math coursework that would allow them to take calculus courses during their first semester in college. "At the very minimum I would expect that the students entering here would've had a solid foundation in pre-calculus, so that they would be ready for calculus" (Dr. Rogers, Physics).

The underlying implication that faculty conveyed is that taking more math courses before entering college gives aspiring STEM students exposure and practice with mathematical skills, which then—at least ideally—leads to the development of the comfort level and "fluency" that they see as desirable and essential for their successful tertiary STEM students. Although simply taking math courses does not guarantee that students will develop the desired fluency in mathematical skills, faculty did note that those who tend to do better in their university STEM courses are those who have taken a lot of math courses during their secondary education. For example, Dr. Rios (Chemistry) agreed with other faculty that students should take at least a pre-calculus course before entering college. However, he expected that students who had taken calculus courses during high school would be more likely to succeed in his courses than students who had only taken pre-calculus courses:

> I would say that they should have taken at least pre-calculus, but I think that students that have enrolled in a calculus course are probably likely to do better [in my courses]. I'm not sure if that's because students that are further along in math will have an easier time with chemistry in general or if it's because the additional math experience has helped them more.

While faculty did not know if additional mathematics coursework would increase students' mathematical knowledge or their fluency with mathematics, they all agreed that prospective students should take as many math courses as they could before entering a STEM major or course of study. Dr. Rogers (Physics) said that this is a viewpoint he promotes to prospective tertiary STEM students whenever he visits secondary classrooms:

> When I visit high schools and middle schools, […] they'll ask me, "What does it take to become a physicist, or scientist?" And the first thing I'll say is, "you've got to stick with the math. You've got to be comfortable with the math. You've got to work with it. It's a language; it's how we communicate. You can't do science without the math, and that's any science, even biology."

Beyond skills and coursework: The mathematical "fluency" of successful tertiary STEM students. As previously noted, although all faculty believed that students should take as many math courses as they can before they enter college, faculty did not believe that simply attending courses was sufficient to prepare students for university STEM majors and courses. It was more important that students develop a sort of comfort level and fluency with mathematical concepts and skills. Three faculty members mentioned that students who had taken fewer mathematics courses in high school but who happened to be very comfortable with approaching math problems were able to learn STEM content better than students who had taken extensive coursework, a point made by Dr. Palmer (Mathematics): “I honestly can tell you it’s not the coursework [that makes a student successful]. It’s the level of attention paid to the details of that coursework.” He continued by saying that successful students are “more practiced [in their mathematical skills]; they’re more at ease. They know what to apply when, usually quicker, without a reminder, context cue.”

Several faculty participants (5 out of 27) expressed a concern that students are not able to develop a comfort level or fluency with math because they have a fear of math. They also stated a belief that students have been told that math is difficult, which may deter them from finding math approachable. They perceived that many students develop an aversion to math at an early age, which then impedes their ability to positively approach math and the STEM topics that depend on mathematical knowledge and skill.

Faculty discussed how the fear of math has become a major obstacle to STEM students’ success. Dr. Rogers (Physics) discussed how fear of mathematics can become a roadblock for students, particularly in the introductory courses:

> The biggest problem with students in the introductory courses is that they just don’t have the mathematical sophistication that they need. Math is our language, so the biggest challenge is getting them to overcome their fear of math. The physics, per se, is not that challenging, once they can see it on a conceptual basis, because, I always tell them, “you’re doing physics every morning of your existence. I’m just trying to make you aware of it.” Whether it’s using your auditory ears to detect sound waves or light waves, it’s all physics. Math, the fear of math, I think is the biggest problem for me.

Dr. Parikh (Allied Health Sciences) shared similar sentiments about students in his program who do not understand why they need math to understand the concepts in their field of study:

> Math is the root of a lot of what we do; and, unfortunately, a lot of people have this math phobia. Students have a hard time making a connection between why they need to understand trigonometry [in a kinesiology course]. […] It does make teaching biomechanics a little bit more challenging when they don’t have the math and the physics background.

Students’ fear of math has been discussed as one of the major obstacles for recruiting students into STEM-related fields (Krantz, 1999; Perry, 2004). Many students prefer to avoid math classes and even majors that require quantitative skills (Bisk, 2013). Dr. Peyton (Geoscience) said that, in order for students to succeed in his courses, they should not be afraid of math. However, he also noted that his students tend to lose interest as soon as he connects course content to math, even if that math is fairly simple.

> Not being afraid of math is pretty important. Not that we do crazy math on any sort of regular basis; but to not be afraid of putting together a pretty serious calculation, that seems to be a key. Usually I have five students who are interested in what I’m doing, and then they see that you have to use computers and a little bit of math. That usually turns them off. Then they usually don’t continue [in the program].

Overall, it is clear that faculty believe that lack of fluency with mathematical skills is the major obstacle that students must overcome to be successful in tertiary STEM courses and programs. Given this finding, it is important that future research examine in more detail what it means to be "fluent" in mathematical—and particularly in algebraic—skills and how such fluency can be developed.

Discussion

Faculty provide an important perspective into issues related to tertiary STEM recruitment and retention because they are experts who have successfully navigated the STEM educational pipeline. As such, they understand some of the characteristics of people who have been successful in STEM educational pathways and fields. Additionally, as instructors, they are in a position of positively impacting the recruitment and retention of tertiary STEM students.

The results described here provide key insights into faculty perceptions of (1) the characteristics of successful STEM students and (2) the major barrier to students' success in STEM courses and programs of study. Faculty members' perceptions of student characteristics related to success in STEM fields fall into two categories. First are skills that they perceive as malleable, that may be fostered, promoted, and developed—skills like problem-solving ability, mathematics ability, and the ability to communicate effectively via written and oral means. A second group of characteristics are those that faculty perceive to be innate to the student, over which faculty members perceive they have limited influence—characteristics like curiosity, inquisitiveness, work ethic, positive attitude, and a sense of engagement. Given the influence faculty beliefs have on their classroom practices and the influence of classroom practices on STEM recruitment and retention, it is important to individually consider the potential implications of both categories of perceived characteristics of successful tertiary STEM students.

First, faculty identified characteristics that they perceive can be developed in STEM students. These characteristics generally aligned with the research literature (e.g., mathematics ability is related to success in STEM fields; see Astin & Astin, 1992); however, when we asked faculty how they thought students should develop these characteristics, the faculty mentioned that students should take particular classes in high school or participate in clubs like the chess club (to develop problem-solving abilities) or a toastmasters club (to develop oral communications skills). What we found interesting is that faculty did not mention ways that they could structure their classroom experiences in order to help students develop these desirable characteristics. Instead, faculty stated that students should develop these characteristics outside of the classroom. Faculty often have very little training in pedagogy or learning theories (Brown *et al.*, 2006; Mansour, 2009; Sunal *et al.*, 2001). As a result, although they may wish to help their students develop these desirable characteristics, they may not know which instructional strategies they can use to do so (e.g., the use of ill-structured problems in classes can help students develop problem-solving abilities; see King & Kitchener, 1994). They may also have misconceptions that would prevent them from implementing such effective strategies in their classrooms. For example, faculty might not believe their students are capable of using active learning strategies or effectively participating in group work (Johnson & Hall, 2007). Alternatively, they might believe that they cannot use active learning strategies in large classrooms or that they cannot cover the required course material if they devote class time to the types of active learning strategies that are known to promote desirable characteristics (Brown *et al.*, 2006; Fang, 1996; Mansour, 2009).

Second, faculty identified what they perceive to be "innate" characteristics of successful tertiary STEM students. These characteristics also generally correlate with the research literature. For example, research indicates that students who are interested in and curious about STEM concepts are more likely to be successful in STEM fields (see Astin & Astin, 1992; Sullins *et al.*, 1995). Faculty perceptions of the origins of these characteristics will impact their classroom practices. If faculty believe they cannot influence a student's sense of engagement in the classroom or their level of persistence because these characteristics are "innate", they will be less likely to change their classroom practices in ways that will support the development of these desirable characteristics, even though research indicates that certain classroom practices—like contextualizing course material in real-world events—can positively influence students' level of persistence in STEM fields (Maltese & Tai, 2011).

It should be reiterated that, while faculty perceptions of the characteristics of successful STEM students generally align with the research literature, faculty did not mention experiences or instructional strategies they could implement in their classrooms to help students develop these characteristics. A future study could examine faculty members' perceptions of the experiences and strategies that can be used to develop desirable characteristics in their tertiary STEM students. A comparison of the faculty members' perceptions with the factors that have been shown in the research literature to support STEM recruitment and retention could then inform the design of professional development opportunities to help faculty (1) align their understanding with the current research on what makes students successful in STEM disciplines, (2) implement instructional strategies that will develop desirable characteristics in their tertiary STEM students, and (3) identify and address ways to overcome potential barriers to the implementation these instructional strategies.

Limitations of the Current Study

There are two main characteristics of the participant population for the current study that may limit the study's results. First, all of the university STEM faculty interviewed for the current project are employed at the same university. It is reasonable to assume that these faculty work with similar students and, thus, have similar experiences with and perceptions of the students. Those perceptions, however, may be different than the perceptions of faculty at other—or different types of—institutions. Future studies could build on the results of the current study by examining the perceptions of university STEM faculty at multiple institutions and at multiple institution types (i.e., research-intensive, primarily undergraduate, 2-year college, etc.). Second, although all STEM faculty at the university were invited to participate in the current study, participation was voluntary. As such, the study population (1) is not representative of the numbers of faculty in different STEM disciplines on campus and (2) does not include many faculty from particular STEM disciplines. For example, only 2 biology faculty members agreed to participate in the current study even though the biology department is one of the largest STEM departments at this particular university. It may be that faculty perceptions of the characteristics of successful tertiary STEM students differ by discipline. The small numbers of participants from particular disciplinary backgrounds did not allow us to examine this possibility in the current study; however, an expanded future study could compare the perceptions of university STEM faculty from different disciplines (for example, physics faculty perceptions of successful tertiary STEM students could be compared with the perceptions of health sciences faculty). Despite these limitations, the current study is useful in that it provides initial insight into the perceptions of university STEM faculty about the characteristics of their successful students, insight which can be used as the foundation for future studies.

Conclusions

Although much of what has been mentioned may require future study and exploration, it is clear that STEM faculty members are in a unique position to influence whether or not students persevere in STEM disciplines. As experts, faculty have successfully navigated the STEM educational pipeline and understand some of the characteristics of people who have been successful in STEM educational pathways and fields. As instructors, they are in a position to positively impact the recruitment and retention of tertiary STEM students. As mentors, faculty model STEM related skills and behaviors and provide valuable points of entry into the fields. Ultimately, steps must be taken to ensure that faculty is aware of ways to facilitate positive experiences for students in their courses, as well as understand what factors have positive impacts on student success in STEM courses and programs of study. The current study provides initial steps in that direction.

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RESEARCH REPORT

How STEM Academy Teachers Conceptualize and Implement STEM Education

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Abstract: *STEM (science, technology, engineering and mathematics) education has been gaining increasing nationwide attention. While the STEM movement has ambitious goals for k-12 education, a lack of shared understanding exists of what STEM is as well as how to implement STEM in the elementary classroom. This study investigates how seven elementary teachers in three STEM academy schools conceptualize and implement STEM in their classrooms. Teacher interviews were conducted. The findings reveal that the majority of teachers believe that STEM education involves integrating STEM subject areas. STEM activities consisted of student-led research and reading activities on STEM topics. Two teachers described STEM as involving "hands-on" science activities. Teachers at each STEM academy school conceptualized and implemented STEM differently. How STEM was implemented at each school was based on how teachers interpreted STEM and the resources they had access to. The STEM coaches played a central role in supporting the elementary teachers to plan and implement lessons. Teachers relied on them for ideas to plan and teach STEM lessons. The results of this study indicate that as more schools embrace the STEM movement, a unified understanding and resources are needed to support teachers.*

Keywords: *STEM Schools; Lesson Planning; Learning*

This study investigates how STEM academy schools in a western state interpret and implement STEM education. Across the country, there are various elementary schools which have transformed into STEM academies. The goal of these STEM academies is largely consistent—to "prepare students to communicate and compete as global thinkers within the community using Science, Technology, Engineering, and Mathematics" (Bluford STEM Academy website, 2013, "STEM (2)", para.1) through "STEM learning environments [that] are fully integrated verses the typical instructional structure of subjects being taught in isolation." (West Hills STEM Academy website, 2013, "How is STEM learning environment different from your average elementary and middle level classroom?" para.1). This study specifically seeks to understand how teachers in STEM schools interpret what the word "STEM" represents and how they implement STEM in the classroom.

Review of Relevant Literature

As the United States economy is becoming more diversified and reliant on innovation, Science, Technology, Engineering, and Math (STEM) skills and proficiency are increasingly needed for competition and advancement. American students are less competitive with other countries in STEM fields, placing 17th in science achievement and 25th in math (Hanushek, Peterson, & Woessmann, 2011). There is a persistent dialogue on emphasizing the teaching of STEM in schools due to a growing supply of high-skill STEM jobs expected to outpace non-STEM jobs in the next decade (National Math and Science Initiative, 2012). Ultimately, a broader goal underlying the STEM movement is to increase STEM literacy. STEM literacy is defined as "the knowledge

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and understanding of scientific and mathematical concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity for all students" (National Research Council of the National Academies of Science, 2011). With the rapid changes in society and the 21st century affecting everything from health to technology, STEM skills help individuals make more informed decisions.

With this new movement in education to focus more on STEM, educators are questioning what is STEM and how exactly to teach STEM. Jonathan Gerlach, *an Albert Einstein Distinguished Educator who works on federal education policy in Washington, D.C., asked several questions pertinent to the focus of this study in a report for the National Science Teachers Association news digest in* 2012. Gerlach asked whether science alone or mathematics by itself can be considered STEM education; whether using technology is sufficient in covering the 'T' in STEM (2012). He also pointed out that asking a number of teachers to define STEM will likely bring about many different answers.

Conceptualizing and Defining STEM Education

Many educators approach STEM education with uncertainty because no single definition of STEM education exists, and many "do not have an interdisciplinary understanding of STEM" (Breiner, Harkness, Johnson, & Koehler, 2012, p. 6). The confusion does not solely lie with general elementary school teachers, but also with some STEM teachers. These teachers do not share a unified understanding or definition of STEM (Breiner et al., 2012).

Brown, Brown, Reardon, and Merrill (2011) wrote about the lack of understanding of STEM education in schools. They define STEM education using a 2009 formal definition outlined by one of the authors, Dr. Merrill. Merrill is a Professor of Technology at Illinois State University and has previously written extensively on STEM and specifically technology. He defines STEM education as:

> [A] standards-based, meta-discipline reading at the school level where all teachers, especially science, technology, engineering, and mathematics (STEM) teachers, teach an integrated approach to teaching and learning, where discipline-specific content is not divided, but address and treated as one dynamic, fluid study (Brown et al., 2011, p. 6).

This definition mentions the use of an integrated approach, which refers to combining subjects rather than teaching them separately. The National Science Teachers Association defines STEM education as:

> [The] preparation of students in competencies and skills in the four disciplines (science, technology, engineering, and math). A successful STEM education provides students with science, math, and engineering/technology in sequences that build upon each other and can be used with real-world applications (Eberle, 2010, "Why STEM is important" para. 3).

This definition does not outline an approach or design for implementation of STEM education as Dr. Merrill's definition does, but emphasizes the use of "real-world applications".

The National Education Association (NEA) is the largest professional organization and labor union in the United States. But the NEA does not seem to have its own definition of STEM education. Rather, the NEA has resources for teachers to teach STEM and refers to STEM education in general terms as it is referred to by other organizations. The lack of a clear definition for STEM is likely one reason why teachers have different conceptualizations and approaches for teaching STEM.

The Committee on Science, Technology, Engineering, and Math Education (CoSTEM) of the National Science and Technology Council crafted a formal definition of STEM education to establish federal guidelines and to aid in the federal grants process. In 2011, the committee published a report indicating that agencies use different criteria for describing a "STEM education program." STEM education is defined by CoSTEM as "education that is primarily focused on physical and natural sciences, technology, engineering, and mathematics disciplines, topics, or issues (including environmental science education or environmental stewardship)" (2011, p. 5). CoSTEM further identifies eight possible primary objectives of STEM education in the form of learning, engagement, pre- and in-service education/education leader performance, postsecondary STEM degrees, STEM careers, STEM system reform, institutional capacity, and education research and development (2011). Again, no approach or teaching methods are outlined by CoSTEM's definition, but those elements would likely be irrelevant to the committee's purpose for crafting a definition of STEM education.

STEM Programs in the United States

The *Conceptual Framework for New Science Education Standards* by the National Research Council of the National Academies of Science (2011) cites research studies which suggest that effective STEM-based instruction depends on teachers who understand their students' strengths and weaknesses and are able to actively engage students in the STEM subjects with concepts requiring problem-solving thinking. Most of the STEM-focused schools have curricula which are inquiry-based and problem-centered; assessments are thus aligned to reflect students' knowledge, and can be informal, such as classroom observations by trained staff or external reviewers (National Research Council et al., 2011).

The Committee on Highly Successful Schools or Programs in k-12 STEM Education (2011) identified three types of STEM-focused schools which can serve as models for schools attempting to implement STEM education: selective STEM schools, inclusive STEM schools, and schools with STEM-focused career and technical education (CTE). These schools were identified as successful by the Committee and the National Research Council based on varying factors since each school has its own data on student outcomes and returns on investment. However, the schools' overall impacts on student achievement and motivation were largely taken into consideration. The Committee also notes that these schools' programs can be modified for any k-12 school (2011).

Selective STEM schools "organize around one or more of the STEM disciplines and have selective admissions criteria," enrolling a small number of students who have demonstrated talent and initiative in the STEM subjects (National Research Council et al., 2011, p. 8). Selective STEM schools tend to be high schools and they prepare students to earn STEM degrees or careers in STEM fields. These schools share the following qualities: teachers with degrees in one or more STEM subjects, advanced curricula, laboratory equipment for the regular use by students, offer students apprenticeships with scientists, and provide staff with professional development (U.S. Department of Labor, 2007). There are 90 selective STEM schools in the country. Studies show that students who are involved in programs such as those offered by selective STEM schools are more likely to complete a STEM major (Stone, Alfeld & Pearson, 2008).

The second type of STEM-focused school is an inclusive STEM school. These also organize around one or more of the STEM subjects, but do not have selective criteria so they serve a wider population (Young, House, Wang, Sindleton, & Klopfenstein, 2011). Inclusive STEM schools offer experiences in line with the understanding that "math and science competencies can be developed, and that students from traditionally underrepresented subpopulations need access to opportunities to develop these competences to become full participants in areas of economic growth and prosperity" (National Research Council et al., 2011, p. 11). Records of student involvement and success, particularly those from the state of Texas, indicate that students in inclusive STEM schools score higher on standardized science and mathematics exams, attend school more frequently and regularly, and take more advanced courses than students in other schools (Young et al., 2011).

The third type is a school with a STEM-based CTE. These enroll high school students and prepare them for STEM-related careers with a larger goal of dropout prevention (Stone et.al. 2008). STEM-based CTE typically has programs which allow students to engage in practical applications of STEM subjects in order to grasp an understanding of different types of STEM jobs.

The National Research Council and the Committee on Highly Successful Schools or Programs in k-12 STEM Education (2011) note that STEM instruction, as seen in the three types of STEM-focused schools, remain in the minority. Heavy focus on STEM education is still not the norm in today's schools. Teachers have little understanding of how to overcome the challenges in implementing a successful STEM curriculum that both aligns with standards and is feasible given economic and time restraints, and the teacher's level of knowledge. These STEM schools are typically high schools, not elementary schools. There are far fewer elementary STEM academies across the country to be able to describe the organization of their schools and STEM curricula in detail. Therefore, there is a need to understand what it means to prepare students for STEM education at the elementary school level.

Theoretical Framework Guiding the Study

Across the country, there are various elementary schools, which have transformed into STEM academies. The goal of these STEM academies is largely consistent—to "prepare students to communicate and compete as global thinkers within the community using Science, Technology, Engineering, and Mathematics" (Bluford STEM Academy website, 2013, "STEM (2)", para.1) through "STEM learning environments [that] are fully integrated verses the typical instructional structure of subjects being taught in isolation." (West Hills STEM Academy website, 2013, "How is STEM learning environment different from your average elementary and middle level classroom?" para.1).

Very little research exists on how schools interpret and implement STEM education. This may be due to the overall lack of a coherent definition of STEM education by major education organizations. Therefore, there is a need to understand how schools interpret and implement STEM. This study attempts to understand how STEM academy schools in a western state interpret and implement STEM education. The following questions are investigated: How do STEM academy teachers define and implement STEM education? What resources do STEM teachers use to aid in the implementation of STEM education?

Methodology

Context, Participants and Intervention

A large district in a western state received Title 1 funding to create STEM academies to improve learning and academic performance. The district has over 30,000 elementary school students who are racially and economically diverse. It has 63 elementary schools and three of which are STEM academies. The three STEM academies in this district received a School Improvement Grant (SIG) to aid in the transformation of their curricula and infrastructure through the ability purchase new resources in order to support STEM education. As per the grant fulfillments, the new curriculum must have an "emphasis on problem solving, technology integration, common core standards, and science and engineering emphasis to promote a rigorous, challenging academic program for all students" (School One, 2012).

These STEM academies can be considered inclusive STEM schools as defined by the National Research Council (2011) because they attempt to serve all their students at these schools. Two of the three STEM academies have a definition of STEM education on their websites, which offers some insight into these schools' perception of STEM education. School One defines STEM as:

> Science - a way of learning and discovering about our natural world; Technology - the making and use of tools, machines, techniques, etc. to achieve a goal or function; Engineering – don't let the 'E' scare you - science and math to benefit humans; Math - study of quantity, structure, space, and change (School One website, 2013).

School Two uses its school purpose to outline STEM education:

STEM is the use of integrative and thematic units of instruction to logistically tie-in the often neglected science and technology components of sound teaching" (School Two website, 2012).

Data, Data Sources and Data Collection

This study investigated how teachers interpret and implement STEM in three STEM elementary schools in the western U.S. Therefore, seven teachers from these three STEM schools were interviewed after school. An e-mail was sent to all teachers in the STEM schools requesting interviews. Seven teachers volunteered to be interviewed. Teachers were individually interviewed after school. The interview questions were based on the following categories: STEM – Teacher Perception, STEM Activities, STEM – Student Perspective, STEM Planning, STEM Resources, and STEM Support. The data was further coded into categories as represented in table one for further analysis. (see Appendix B for Interview Questions.)

Data Analyses

The data was systematically analyzed and coded for themes using Strauss and Corbin Grounded Theory approach (1998). Open coding was used to identify key words or phrases that embodied each teacher's definition and implementation of STEM education. Key words and phrases were underlined or highlighted, and subsequently categorized more broadly to then identify patterns or differences in teacher responses. The underlined phrases represent repetition of codes across the data. And because the main research question dealt with the definition and implementation of STEM education by STEM academy teachers, the researcher compared the codes within each interview question category for each individual teacher to identify any relationships or influences on such things as STEM activities or STEM planning. The similarities found across the data and the analysis of codes within categories allowed for the emergence of theories to answer the research questions (see Appendix A for sample coding example).

Results

STEM: Teacher perception

The STEM academy teachers were first asked to define STEM education. They used several common key words and gave broad definitions of STEM education. All seven teachers said the word 'integration' many times throughout their individual interviews. Six out of the seven teachers specifically indicated "reading about STEM or STEM topics" as an integral part of their STEM curricula, exemplified in this response by a teacher from School One:

> We separate our subjects throughout the day, but as I said before you can find all aspects of STEM throughout the day, so it's more broad fields. And while we say it is Reading time between 9:00-10:30, you could find a lot of STEM going on as well as we read about science, technology. (Teacher B, School One, Interview, Jan. 17, 2013)

Further clarification from other teachers also indicated that students read about STEM during reading blocks, and even during designated science times, and that the teachers indicate this qualifies as STEM education. This theme, "integration of STEM content areas through reading," explains teacher perceptions of STEM education more broadly. It also aligns with most modern conceptions of STEM education that include integration or the teaching of the "integrated disciplines as one cohesive entity" (Breiner et al., 2012, p. 5).

When asked to define STEM education, most of the teachers defined the acronym "STEM," but gave little insight into what STEM education is and how it is implemented, aside from mentioning integration of the subjects into the everyday curriculum. This is not entirely surprising because "there is no common understanding or agreement on the nature of STEM education as an integrated or multidisciplinary endeavor…Few guidelines and models exist for teachers to follow regarding how to teach using STEM integration approaches" (Roehrig, Moore, Wang, & Park, 2012, p. 32). The response below is very similar to those of the other teachers' responses: STEM stands for Science, Technology, Engineering, and Math. STEM education is a way to include all four areas into what our students are learning. (Teacher A, School One, Interview, Jan. 17, 2013)

This teacher, along with the others who defined STEM education simply by defining the acronym, did not describe the teaching methods employed or types of lessons used to implement STEM education in the classroom.

STEM Activities

The STEM activities that the teachers did with their students further illustrate the teachers' definitions of STEM education. Again, "integration of STEM content areas through reading" appeared in five out of the seven interviews; the two teachers from *School Three* did not indicate reading about STEM as a STEM activity. Some teachers, however, gave examples of "hands-on science activities." Three out of the four teachers from School One indicated the use of FOSS kits for some science lessons. Similarly, three teachers also mentioned interactive websites and/or interactive computer programs in which students learn about a STEM topic through a game-like setup. Three teachers gave examples of their students creating, engineering, and/or experimenting. Below are examples of hands-on activities:

> We did the Eco-Bot challenge…Students created an eco-bot robot out of a toothbrush, battery, wires, double sided tape, and they had to contain a toxic spill (bird seeds) without touching their robot. Then, calculate their robot's efficiency. Now, we are engineering egg vehicles that need to survive a crash test, so we're learning about Newton's Laws. (Teacher G, School Three, Interview, Jan. 15, 2013).

> My class and the other fourth graders got to develop podcasts during their unit on erosion. Lots of research on their part, we went outside and did experiments with water and dirt, watched interactive videos on iPads, and the students each had to play the role of "scientist" for their podcast [recorded each other explaining a different part they each specialized in]. (Teacher E, School Two, Interview, Jan. 22, 2013)

These activities were coded as "hands-on activities" because the students played active roles in the learning process by creating, experimenting, calculating, and using various tools and resources in order to understand a concept. The teachers believed these activities were STEM activities because of the subject matter (science and/or engineering, and math), the use of tools and materials, and the active engagement of students. It should also be noted that while Teacher A described a seemingly successful STEM activity, she mentioned that her STEM academy performed poorly in math on the Adequate Yearly Progress (AYP) assessments; therefore, her school's main focus is mathematics. STEM is taught as a single lesson once a week.

Another theme that emerged based on the repetition of its occurrence in the responses of five out of seven teachers was "student-led research on STEM topics." One teacher from School Two and a teacher from School Three did not mention students researching STEM topics as a STEM activity. Below are examples of responses from teachers who did mention student-led research.

> We recently covered a STEM lesson based on scientific inventions [read about and viewed "virtual models" through a website] and how each has improved our lives today. Students had to research a particular invention and create a "virtual museum" on their laptops, in which all the rooms are like different slides in a Power Point. They were to find info for each area of STEM for their topic. (Teacher A, School One, Interview, Jan. 17, 2013).

> We just finished a Reading/Science unit on space. The students did research reports on a planet and a constellation (Teacher D, School One, Interview, Jan. 15, 2013)

These responses illustrate a lack of a unified interpretation of STEM education. Both teachers quoted indicated that the above were STEM lessons. The teachers assert these are STEM lessons because students read about and research science-related topics, thus covering the science, technology, engineering, and possibly mathematical topics, while creating a Power Point-type presentation on laptops—using technology.

Another emerging theme in the category of STEM activities includes "use of technology in any form." All three schools have laptops for students, including iPads and iPods, and Smart Boards in the classrooms. The teachers indicated the use of technology as a way to integrate STEM into the daily curriculum by allowing students to research, read, and/or write about STEM using the laptops. The teacher from School Three gave an example of a STEM activity in which technology was used in various forms:

> We engineered rubber bank and soda straw rockets at the culmination of a science unit on the solar system and flight. We used our iPads and active board to research, and after flying the rockets, we measured the distances they traveled and graphed the distances. (Teacher F, School Three, Interview, Jan. 15, 2013)

This example shows that students had the opportunity to engineer and create, and to also explore and research using the newest technology available at their school. However, this demonstrates the need for more information to explore whether learning about technology qualifies as STEM education, or is using technology is STEM education. This again depends on the teachers' definitions of STEM education.

STEM: Teachers' perspective of student reactions

All seven teachers reported that students positively responded to STEM education. Each teacher indicated students are always engaged and interested in learning. Three teachers indicated the students like to work in groups, and two indicated enhanced memory and comprehension. Below is a response given by a teacher from School Three describing the students' response to the Eco-Bot Challenge:

> It was amazing. There was full engagement, zero behavior problems, and really not much differentiating needed. It was nice that I could also take a step back from just standing there teaching, and have the students explore and do hands-on work that really got them understanding every aspect of the project. (Teacher G, School Three, Interview, Jan. 15, 2013)

Most teachers also indicated as the teacher above that hands-on activities in particular have the most positive effects on their students, from full engagement to a better grasp of the subject matter.

STEM Planning

In the category of STEM planning—or how the teachers plan STEM lessons—three themes emerged. The first theme was "STEM unit team planning." Five of the seven teachers explained that they typically collaborate with teachers who teach their respective grades in planning and creating unit lesson plans. A teacher from School Three explains the STEM unit planning process below:

> We, so the other 4th grade teachers, create Project Based lessons (PBL) units and plan together as a grade level. We have a graphic organizer that allows us to document how each STEM component will be a part of the unit, and most of the time we take the lead on separate parts of STEM if we find we're more knowledgeable or comfortable in that aspect of it. (Teacher F, School Three, Interview, Jan. 15, 2013)

Many teachers specified that while they work together to plan a STEM unit, each teacher may feel more comfortable taking the lead on a specific STEM content area because of his/her background, schooling, or experience. This emerged as another theme coded as "specific STEM area expertise."

The teachers also specified that they use the project-based learning (PBL) units, as well as taking Common Core State Standards (CCSS) and their schools' various kits (FOSS kits for science, Lead 21 for reading) into consideration when planning a STEM unit. Some teachers also referred to various subjects separately such as math and reading:

> Usually math is correlated although it should be incorporated into daily curriculum. I will incorporate it where and if it fits in…Language Arts, Science, and Social Studies are usually broad fields. Our reading program is set up by units. One unit is Science; the next is Social Studies which usually correlate with CCSS 4th grade. (Teacher D, School One, Interview, Jan. 15, 2013)

Some teachers indicated the use of their school's curriculum to use as a guide for the planning of STEM lessons. Below is another response on the planning process:

> We plan for STEM lessons by looking at our Math, Reading, Science, and Social Studies curriculum. So that means using Lead 21 (our reading program) and FOSS kits. We also look at our unit of study that we created. When looking at everything that we are working on, we can combine concepts and incorporate into our Reading or Math block. (Teacher B, School One, Interview, Jan. 17, 2013)

This is coded as "identify common concepts within curriculum." The teachers use a number of tools at their disposal to aid in their STEM lesson planning, as specified. While only three teachers indicated they turn to their school's STEM coordinators for help in planning and for lesson demonstrations, in the next category—STEM Resources—this theme will be more prominent.

STEM Resources

When asked what or where they turn to for extra help in teaching STEM, the teachers listed many similar resources. Five out of the seven teachers said that if they need further STEM-related information, they first do research on their own by searching the Internet. This theme is coded as "Internet for STEM-related news and lesson ideas." While they did not go into detail about the websites they preferred, one teacher from School Three said the following:

> I pay attention to the news and turn to either science, engineering associations or organizations as well as their websites. For example, the American Civil Engineers, or NSTA. Our school also has community partners, like Women in Engineering, and I've had a 4-H club come in to present the Eco-Bot project, which helped me in planning lessons around the entire project. But there really aren't a lot of resources out there on STEM. (Teacher G, School Three, Interview, Jan. 15, 2013)

Aside from the Internet, this teacher also generates ideas for STEM lessons from organizations which specialize in the STEM fields. When the teachers need immediate help with a STEM lesson or do not find what they need on the Internet—which is common, as mentioned by the previous teacher that there are limited resources available on STEM education—they turn to their STEM coordinators. All seven teachers indicated they utilize the expertise of the STEM coordinators at their schools. This theme is coded as "STEM coordinators for planning and lesson demonstrations." Two teachers said the following about their school's STEM coordinators:

> I usually go to one of our STEM coaches, because they are the "experts" and always make themselves available to us and offer great ideas and support. (Teacher D, School One, Interview, Jan. 15, 2013)

> Our STEM coordinator is very useful if we need any help in planning a lesson, gathering materials, or seeking out some help from our partners who many times have great ideas for us and even do demonstrations or presentations for us if we'd like them to. (Teacher E, School Two, Interview, Jan. 22, 2013)

Most notably, the teachers said that STEM coordinators are a base of knowledge in the STEM content areas, offer ideas teachers can utilize, aid in lesson and unit planning, offer guidance on the materials available for activities, and demonstrate lessons teachers may be unsure of approaching.

STEM Support

The question in this category was based on the support the school provided in the teaching of STEM. Again, STEM coordinators were mentioned here by four teachers in relation to the support their school offers teachers in STEM education. This theme was coded as "STEM coordinators for support."

Five of the teachers also said that "technology for student use" is supportive of the implementation of STEM education. School One supplies its students with laptops and iPads. School Three has wireless notebooks, iPads, iPods, and all of the schools have Smart Boards. A teacher from School One was particularly enthusiastic about the support in his school:

> Our school supports STEM teaching by giving us access to 1:1 laptops, active votes, iPads, and any other technology we can get our hands on. This all helps with STEM. Our school supports us with Science kits and other resources in the STEM lab. Our STEM coordinators run the lab. There is a ton of support for STEM at our school! (Teacher B, School One, Interview, Jan. 17, 2013)

The teachers all agreed that the technology is useful for daily activities, specifically pertaining to STEM education. Students use the technology to research STEM topics, read and write about STEM topics, create presentations on their findings, and use interactive websites to learn about STEM. Three of the teachers also indicated that their schools offer professional development opportunities in the form of trainings. Another teacher from School One described the professional development opportunities in the most detail:

> Our school provides us with ample opportunities for professional development and Common Core training — we've had a lot of inquiry and PBL training, which is very useful in teaching STEM. (Teacher A, School One, Interview, Jan. 17, 2013)

"Trainings in teaching methods" includes training in PBL unit planning and instruction, CCSS planning and implementation of standards, inquiry-based learning, and STEM education. These are viewed as useful for teachers in not only the STEM education aspect of teaching, but for teaching in general.

Discussion & Conclusion

The research findings support the conclusions discussed in the literature review (Breiner, Harkness, Johnson, & Kolker, 2012) that teachers, including STEM academy teachers, do not share a common understanding of STEM education. Definitions and perceptions of STEM education are varied, as are teacher perceptions of integration. The teachers interviewed viewed STEM education as involving integration of subjects. This view is consistent with Brown, Brown, Reardon & Merrill (2011) definition of STEM as an integrated approach to teaching and learning. Their descriptions of how STEM integration was implemented varied among the teachers. A majority of the teachers interviewed primarily spoke about activities involving reading about and researching STEM topics as an integral part of their STEM curricula. However, the basic premise of STEM education is described as more inquiry and project-based rather than lecture-based (Breiner et al., 2012). Though, some of these teachers did give examples of hands-on activities that integrated STEM concepts in a project-based fashion, reporting several positive results from these types of activities. The teacher from School Two described an outdoor, exploration STEM unit on erosion that corresponded with her school's definition of STEM education.

Most teachers also believe that the use of technology, such as a laptop, meet the requirements of integrating the 'T' in STEM education. School One's definition of STEM education specifically indicates that the technology component of STEM includes the "making and use of tools, machines, etc." (2012), but the teachers only discussed the use of technology. Furthermore, some proponents of STEM believe that that the technological aspect also includes technology concepts, or learning about technology, rather than simply using technology (Brown et al., 2011).

One teacher pointed out that even though students were engaged in the STEM integrated lessons, their school performed poorly in math and they decided to focus on helping students in mathematics the next year. This raises questions on how does a teacher integrate subjects while insuring rigorous disciplinary content is taught? Furthermore, NSTA (Brown et al, 2011) does emphasize that a successful STEM program helps prepare students in disciplinary competencies and skills in the four disciplines. Their definition of STEM emphasizes carefully designed instructional sequences that build on each other with connections to real world applications.

STEM academy teachers largely favor planning for STEM lessons with other teachers to create a unit. This is regarded as a resourceful way to create STEM lessons using each teacher's strengths and expertise. The joint planning also provides opportunities to carefully sequence lessons. The teachers also indicated a lack of resources for STEM education. This is not surprising considering the push for STEM in schools is a relatively new movement. STEM coordinators are helpful resources for teachers. Aside from STEM coordinators though, most of the teachers indicated that they do research on the Internet to find STEM-related news or lesson plans. The Internet does not always provide high-quality, verifiable information, however, so this can lead to both a misunderstanding of STEM content and the implementation of ineffective lessons.

Lastly, in terms of support, the STEM academy teachers each agreed that updated technology that is readily accessible to students is important in facilitating the goals of STEM education. Most of their lessons center on the use of technology in one form or another. In addition, some teachers mentioned the usefulness of professional development opportunities provided by their school. Trainings in inquiry-based and PBL methods as well as Common Core were viewed as positive learning experiences for the teachers as they attempt to implement STEM education.

Implications

STEM education lacks a clear definition, and most importantly research is lacking on how to implement STEM in elementary schools. A unified understanding of a STEM program will be helpful for developing high quality STEM elementary schools. Elementary teachers are responsible for teaching multiple disciplines. Therefore, teachers need access to high quality materials that provide meaningful learning experiences for students while ensuring rigorous STEM content is taught. Simply integrating STEM subjects is not enough. Ensuring that rigorous content is taught through careful sequencing and efficient use of instructional time is important. Teachers need to have an understanding of how to support students to understand rigorous STEM content and practices as outlined in the documents such as the Next Generation Science Standards (NGSS, 2012), and the Common Core Mathematics Standards (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). Further research is needed to refine and develop models of STEM elementary schools that support high quality learning experiences. Supports for teachers such as materials, and access to high quality professional development is needed.

Limitations

The limitations of this study are the small sample size of 7 teachers from 3 STEM schools. Furthermore, the paper is based on teacher interviews as opposed to observations of actual classroom lessons. We were interested in understanding how teachers perceive and plan STEM lessons. Therefore, further studies involving classroom observations would be helpful to study how these STEM lessons are enacted.

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Appendix A

Table 1

Sample of Coded Teacher Responses

Category	6th grade School one	6th grade school one	5th grade school one	4th grade school one	4th grade school two	4th grade school three	5th grade school three
STEM teacher perception	Inclusion of all 4 areas Integration of STEM topics Integration of STEM content areas into reading	Integration of STEM topics Integration of science into everyday curriculum Everyday use of technology Integration of STEM content areas into reading	Integration of more than one subject Integration of STEM topics Lessons are "STEM focused" Integration of STEM content into areas of reading	Integration of STEM subjects	STEM embedded in culture of school STEM fields not taught in isolation Integrating cognitively demanding standards-based instruction STEM focus throughout the day Integration of STEM Content into reading	Helps students see interconnected-ness of subjects School contexts provides dilemma (need to improve math scores) Student lead hands-on activities (teacher monitors) Integration of STEM content areas into reading	Inquiry-based No discipline should dominate over others Increase student interest in STEM careers (gov goal) Integration of STEM content areas into reading
STEM Activities	Reading about STEM topics Student-led research on STEM topics -presentation Hands-on science activities Use of technology in any form (interactive websites)	Reading about STEM topics Student-led research on STEM topics (writing) Hands on science activities. Use of technology in any form (presentation interactive computer programs)	Reading about STEM topics Student-led research on STEM topics (writing) Hands on science activities Use of technology in any form (presentation) Math to understand engineering careers	Reading about STEM topics Student led research on STEM topics Use of technology in any form Math & science integrated Math taught alone (correlated) ELA, Science, social studies taught together (Broad fields)	Hands on science activities -experiments Use of technology in any form (Developing podcasts, interactive videos on iPads, Active Board) Math explorations of real situations Outdoor activities	Student-led research on STEM topics Hands-on science activities (engineered rockets) Use of technology in any form (iPads, Active Board) Measure distances Plot graphs Measure distances Plot graphs	Science community demonstrations Hands-on activities STEM taught once a week Science community demonstrations Engineering and creating School context provides dilemma (need to improve math scores)

Note: This table represents how data was coded from the teacher interviews. The underlined text represents commonalities among teacher responses.

Appendix B

Interview Questions

Please answer the following questions using your own opinions and experiences.

1. What is STEM education? (Define it in your own words.)

2. How do you teach STEM in your classroom?

3. Has your school outlined criteria for or encouraged teaching STEM? If yes, explain.

4. How does your school support teaching of STEM?

5. What resources do you use for teaching STEM?

6. What kinds of support and resources do you need to teach stem?

7b. What/where do you turn to for extra help, if you seek it?

9. Do you know what started the push for STEM (whether nationally or at your school)?

10. What do you think the future of STEM is in Nevada schools (or your school?)

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RESEARCH REPORT

Stretch, Dream, and Do - A 21st Century Design Thinking & STEM Journey

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Abstract: *This paper describes the journey of d.Loft STEM Learning, a project of The National Science Foundation ITEST program, which supports building knowledge about approaches, models, and interventions involving K-12 education to increase the nation's capacity and innovation in STEM (science, technology, engineering and mathematics) fields. d.Loft STEM Learning used design thinking as an underlying theoretical and pedagogical approach to enhance STEM learning. Design thinking is a human-centered, prototype-driven innovation process and a series of mindsets that provides a robust scaffold for divergent problem-solving. This paper describes how the design thinking provided a frame within which mentorship and STEM learning thrived, and suggests new ways to conceptualize student learning and teacher practice in 21st century learning contexts.*

Keywords: STEM, Teacher Practice, Middle school, Learning, Design Thinking

This paper describes the journey of d.Loft STEM Learning, a project of The National Science Foundation ITEST program, which supports building knowledge about approaches, models, and interventions involving K-12 education to increase the nation's capacity and innovation in STEM (science, technology, engineering and mathematics) fields. d.Loft STEM Learning used design thinking as an underlying theoretical and pedagogical approach to enhance STEM learning. Design thinking is a human-centered, prototype-driven innovation process and a series of mindsets that provides a robust scaffold for divergent problem solving. This paper describes how design thinking was the theoretical and pedagogical foundation for d.loft STEM learning and how it provided a frame within which mentorship and STEM learning thrived.

The inspiration behind d.loft STEM Project was the "Design for the other 90% movement," which consists of engineers, designers, scientists, architects, and mathematicians engaged in designing low-cost innovative solutions for large portion of the world's population who do not have access to basic services. This movement shaped the National Science Foundation proposal and led to crafting the d.loft STEM Project goals.

These goals included the following:

1. to provide middle school students with pathways into STEM careers by introducing the work of engineers, mathematicians, and scientists and the work of the university student mentors engaged in STEM fields
2. to introduce design thinking as a 21st century learning approach
3. to provide university students with opportunities to create and implement STEM curriculum and design thinking activities for middle school students
4. to foster the development of mentoring relationships

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An Introduction to the Design Thinking Process

Design thinking is an orientation toward learning that encompasses active problem solving and believing in one's ability to create impactful change. Embracing design thinking as an approach to human-centered problem solving leads to the development of creative confidence (Kelley & Kelley, 2013). The key components of design thinking process are that it is (1) human-centered (2) action-oriented, and (3) mindful of process (Hasso Plattner Institute of Design, 2007).

Tim Brown, the chief executive and president of global design consultancy IDEO, describes the design thinking process as "an approach that uses the designer's sensibility and methods for problem solving to meet people's needs in a technologically feasible and commercially viable way. In other words, design thinking is human-centered innovation." David Kelley, founder of design consultancy IDEO and Stanford's Hasso Plattner Institute of Design, says, "My contribution is to teach as many people as I can to use both sides of their brain, so that for every problem, every decision in their lives, they consider creative as well as analytical solutions." This approach, which has energized business innovation, is being applied to K-12 education with considerable impact. With its central emphasis on human needs, it refocuses curriculum and assessment and forefronts solving real-world problems.

Design thinking starts with divergence- the deliberate attempt to expand the range of options rather than narrow them. It is a means to go beyond incremental changes and explore opportunities for breakthrough innovations. Design thinking focuses on asking the right questions, challenging assumptions, generating a range of possibilities, and learning through targeted stages of iterative prototyping. Using ethnographic tools and contextual inquiry, design thinkers learn how to observe, interview, and develop empathetic insights that lead to human-centered ways of solving problems. Figure 1 highlights the five key phases of the design thinking process: empathize, define, ideate, prototype and test.

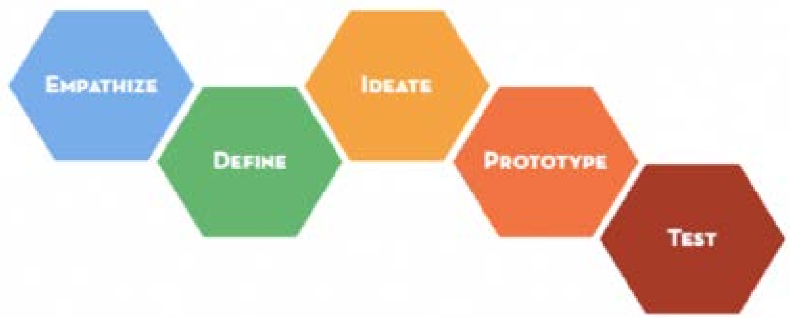

Figure 1. *The Stanford University Hasso Plattner Institute of Design*

Design Thinking Process

Empathy

Empathy is the foundation of the human-centered design thinking process. The following components characterize the empathize mode:

- Observation of user behavior in life contexts
- Engaging, interacting and interviewing users
- Being able to immerse oneself in user's experiences

This sense of empathy provides insights into what people think and feel and is a critical component of the design thinking process.

<u>Define</u>

The second part of the design thinking process is define, which is about analyzing and synthesizing one's empathy findings into compelling needs and insights. Two goals of the define mode are to develop a deep understanding of users and the design space and, based on that understanding, to generate an actionable problem statement. The define mode is critical to the design process because it frames the problem.

<u>Ideate</u>

Ideate is the third step of the design thinking process- it is focused on idea generation. The goal of ideation is to explore a wide solution space – both a large quantity of ideas and diversity among those ideas.

<u>Prototype</u>

The fourth step of the design thinking process is prototyping. A prototype can be anything that takes a physical form that a user can interact with. Prototypes are low-resolution and can be storyboards, role-plays, physical objects or services.

<u>Test</u>

The final step of the design thinking process is testing. Testing is an opportunity to put the prototype into the hands of users so that one can iterate and refine solutions to better meet user's needs.

<u>Design Thinking Mindsets</u>

The design thinking process is supported by a series of mindsets. The mindsets include the following:

- Human-centeredness
- Bias Towards Action
- Radical Collaboration
- Culture of Prototyping
- Show, Don't Tell
- Mindfulness of Process

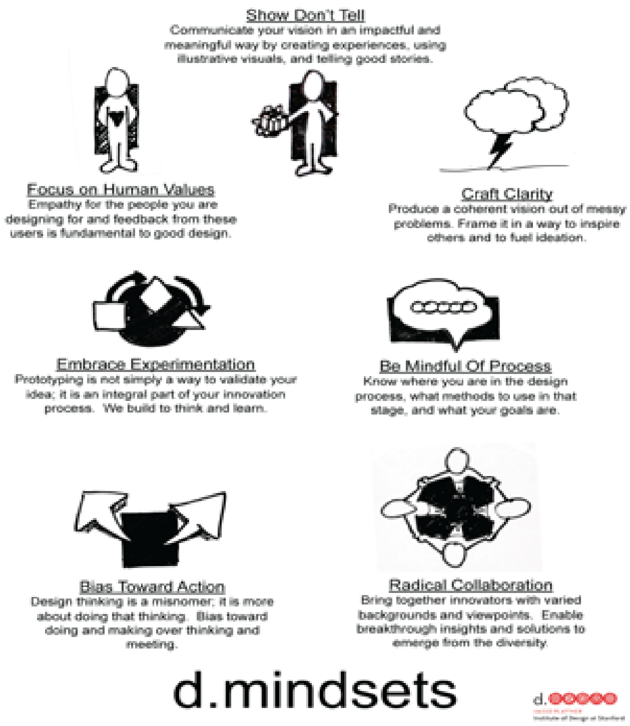

Figure 2. *Design Thinking Mindsets*

Design Thinking in K-12 Education

The need for a design thinking approach is timely. The National Research Council (2009b) states that it takes years or decades to build the capabilities required by societies: "You need to generate the scientists and engineers, starting in elementary school and middle school" (p. 9). Incorporating engineering-based problem solving within students' learning of mathematics, science, and technology is gaining greater attention across many nations, with science, technology, engineering and mathematics (STEM) in K-12 increasingly regarded as an essential component of progressive 21st century education (e.g., Berland, 2013; English & Mousoulides, 2011; National Research Council, 2009a; Zawojewski, Hjalmarson, Bowman, & Lesh, 2008). Today's students will be expected to collectively tackle 21st century problems, yet only 16 percent of teachers reported they are assigning projects that help students develop problem-solving skills (Project Tomorrow, 2009). The Center for Teaching and Learning (2010) report that in California, only 10% of elementary students regularly receive hands-on science lessons and arrive at middle school unprepared for and uninterested in science, In addition, one-third of elementary teachers said they feel prepared to teach science, and 85% said they have not received any training during the last three years. Yet incorporating engineering concepts into middle school curriculum has been found to be an effective way to improve students' problem-solving skills (English, Lyn, Hudson, and Dawes, 2013). Students' engagement in STEM fields can foster innovation, invention, and economic development (Tytler, Osborne, Williams, & Cripps Clark, 2008). It is critical that middle school students engage in challenging learning experiences (Lambert & Stylianou, 2013; Silver, Mesa, Morris, Star & Benken, 2009) as they contribute to building innovative thinking. This is particularly relevant to STEM education, and to the d.loft STEM Learning Project.

According to the Carnegie Foundation Commission on Mathematics and Science (2009), the United States needs an educated young citizenry with the capacity to contribute to and gain from the country's future productivity, understand policy choices, and participate in building a sustainable future. The need for knowledge and skills from science, technology, engineering, and mathematics are crucial to virtually every endeavor of individual and community life. In a comprehensive report on STEM education, it is recommended that there is a need to (1) increase America's talent pool by vastly improving K-12 mathematics and science education; (2) sustain and strengthen the nation's commitment to long-term basic research; (3) develop, recruit, and retain top students, scientists, and engineers from both the U.S. and abroad; and (4) ensure that the U.S. is the premier place in the world for innovation. The role of an engineer requires the integration of knowledge, and its application in constantly changing contexts with the goal of using that knowledge to deliver a successful outcome. Vest (2006) described how students are driven by passion, curiosity, engagement, and dreams and the importance of focusing on the environment, forces, ideas, inspirations, and empowering situations to which they are exposed. Design thinking can provide a frame within which students learn how to be mentors, how to create user-centered learning experiences, and how to share their experiences as developing STEM professionals with middle school students (Author, 2012). Design thinking, with its focus on empowerment and agency is a powerful tool to meet the needs of 21st century learners by providing a human-centered scaffold for problem definition and problem solving. Students need to know how to be empathetic towards others, identify problems, and generate creative solutions.

d.Loft STEM Design Thinking Model for Teaching & Learning

Creative confidence is the foundation of the d.Loft STEM Design Thinking model. It develops as one embraces both the design thinking process and underlying mindsets. The diverse stakeholders who were involved in d.Loft STEM Learning provided a lens that informed the model's creation. This paper focuses on two critical components of the model: human-centeredness and prototyping/testing. Embracing these two elements of design thinking had a critical impact on two areas of the d.loft STEM Learning project: the university course and the after school program. This became evident with respect to the university instructors and university students in different ways. Figure 3 highlights the d.Loft STEM Design Thinking Model.

University Course

Development & Planning & Human-Centeredness

The d.loft STEM Learning university researchers/instructors decided that a university course would be an effective structure to meet the project goals. The course would meet two days a week. On Tuesdays, the course would be held at the university. On Thursdays, the course would be held at a local middle school during its afterschool program. The university students would have the opportunity to act as mentors to the middle school students every Thursday. In designing this course, empathy and a mindset of human-centeredness for the needs of both the university students and the middle schoolers was central. The following questions informed the development of the course and course planning:

- What were the best ways to structure the university course to attain the goals of d.loft STEM Learning?
- What did the university students need in order to best learn about STEM topics, design thinking, mentoring and STEM careers?
- What did the middle school students need in order to best learn about STEM topics, design thinking, and STEM careers?
- What were the best ways to structure the afterschool and intercession camp sessions to support the university student's interactions with the middle school students within the course framework?
- What knowledge did the university students have to have about middle schoolers' cognitive and social development in order to both begin their journey and thrive as mentors?
- What were the best ways for the middle school students to gain exposure to and interaction with STEM pre-professionals and professionals and their work and their pathways into the STEM professions?
- What were the best ways to teach the university students how to be mentors?
- What were the best ways to use university in-class sessions to prepare the students for their work in their afterschool program?

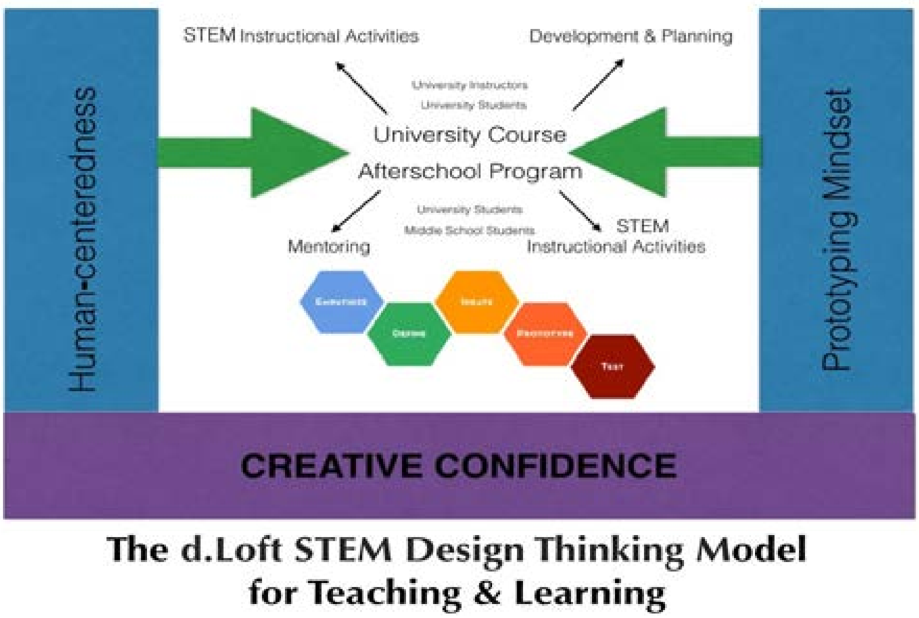

Figure 3. *The d.Loft STEM Design Thinking Model for Teaching & Learning*

Many of these questions might occur in typical course planning, but what distinguished the planning for this course was an explicit emphasis on gaining empathy for the needs and perspectives of the both the university students and the middle school students in the course design. It was a mindset of human-centeredness that drove the development of the university course.

Instructional Activities & Human-Centeredness

With these thoughts in mind, Educating Young STEM Thinkers was created. The ten-week course met twice a week during the university Winter and Spring quarters. For the first two weeks, Tuesdays were spent at the university. In weeks 3-10 the university students traveled to an underserved urban community where they became mentors to middle school youth in an afterschool program. Between the first and second quarter of the course, during their spring break, students had an option to work with a second middle school to deliver a one-week STEM/Design Thinking Camp program.

Students who took the class were undergraduate and graduate students whose majors included Civil Engineering, Environmental Engineering, Mechanical Engineering, Chemical Engineering, Education, Physics, Biology, Learning Design & Technology, Education, as well as those whose majors were undeclared.

The university course gave the students opportunities to deepen their understanding of the role STEM plays in K-12 education. They read literature on STEM pathways issues and the effectiveness that exposure to STEM professional has on K-12students. They also learned about the unique needs of middle school students and read about how to design effective lesson. This background information on middle schoolers helped the university students as they became mentors.

The university students were learning the design thinking process as part of the course, and they were also expected to teach this process to the middle schoolers as they integrated design thinking and STEM-based activities. The university instructors were aware that this would be a difficult task and empathized with the students. One decision that was based on this notion was to invite a small group of middle school students to the university class one week prior to beginning the afterschool program visits. The class session had two components: a hands-on design activity where the middle schoolers were embedded in a team with university students, and an informal interview where the university students asked the middle school students questions about what their lives were like inside and outside of school. After these sessions, many of the university students expressed how much they enjoyed the visit, mentioning how it had been a while since they were middle schoolers themselves, and how they felt they gained more of an understanding of the school they were going to visit and empathy for what the students' lives were like.

Development & Planning & A Prototyping Mindset

The second critical factor for the university researchers/instructors in designing the course was the adoption of a prototyping mindset. Everything was considered a prototype that could be iterated upon and thus improved. The intention was to be metacognitive and mindful and use what did not work as an opportunity to learn what to do the next time. The researchers' goals in year 1 were to prototype the course, and learn from what did and did not work in order to improve the course in year 2 and year 3.

The sense of lingering in ambiguity, which often characterizes the adoption of a prototyping mindset, was a critical part of embracing the design thinking process. This can best be explained by a metaphor of navigating a large ship. A successful course was the destination, but there was an acknowledgment that there would be many course corrections on the journey. The learning was paramount. The university researchers/instructors knew that this first class/afterschool program was the first of a three-year program, and wanted to adopt a prototyping mindset to continually improve the program and meet the needs of the university students and the middle schoolers. More importantly, it was essential that the university students embraced a prototyping mindset as well.

This was explicitly acknowledged by the researchers/instructors with the notion that perfection was not expected, but learning from failure was. Dweck (2007) states that students are often praised for being smart rather than being willing to take chances: "...we tell them that this is the name of the game: Look smart, don't risk making mistakes." She describes a "growth mindset" which purports that intelligence is not fixed, but can be developed. Diener (2007) describes this idea: "Failure is information—we label it failure, but it's more like, 'This didn't work, I'm a problem solver, and I'll try something else.'" The idea of a growth mindset is a perfect complement to the design thinking process of prototyping and testing.

Instructional Activities & A Prototyping Mindset

During the first quarter of the class, the university instructors tried to find a balance between mentorship, design thinking, and STEM. In the subsequent Winter quarter, many instructional changes were made. These included changing the readings based on the class discussions to give students a more nuanced understanding of what middle schoolers were like socially, emotionally and cognitively. In the spring quarter of the first year of the course, the university instructors worked with students in two groups: a curriculum group and a research group. The curriculum group was responsible for planning activities for both groups to implement each week with the middle school students. This was changed in the subsequent quarter, as the instructors realized that it was important for both groups to be able to design activities for their particular middle school students. The curriculum group also shifted to be more inclusive of students' input into the curriculum in the subsequent quarter. In the spirit of a prototyping mindset, giving students more responsibility for the final curriculum proved to be a more rigorous learning experience.

With respect to the learning from students' journals, the university instructors decided to bring the university students to the middle school students one week earlier than had been done in previous quarters. This was done to give the university students additional time to build the mentoring relationship. What was most important with respect to all these changes was the idea that the entire course was a prototype, and how instruction was conceived and developed needed to change in order to continuously improve. This became evident through the focus on empathy, the adoption of a prototyping mind set, and the course content which integrated STEM and design thinking.

Afterschool Program

In order to achieve the program goals the university researchers reached out to a local afterschool program and asked if they would be willing to partner. Both human-centeredness and a prototyping mindset were key in the creation of the Milagra Academy afterschool program. Milagra Academy is a college preparatory secondary school dedicated to preparing all students for acceptance and success at the 4-year college or university of their choice. Their mission is to equip their students with the academic skills, behaviors, habits, and qualities of character necessary to successfully complete college so that they have the opportunity to earn a family-sustaining income and make a positive impact on their community. The school was founded in 2006 in a community where 10% of the residents have a Bachelor's degree and the high school drop out rate is over 70%. There are approximately 300 students in the school, and 97% of the students participate in the federal free/reduced lunch program. 90% of the students speak English as a second language and 97% of the students are first-generation college students. The ethnic background of the students is 86% Latino (a), 11% African American, 3% Asian/Pacific Islander, 1% White/Other.

One of the university researchers/instructors had a long-term relationship with the middle school that was selected for the afterschool program. She had delivered design thinking workshops to the school faculty, and worked with the students on end-of-school extension courses. There was a sense of trust that had developed, and this created a willingness on the part of the school principal to try the new program at the middle school. Two months prior to the beginning of the course, the university researchers met with the Afterschool

Program Coordinator to determine the best days/times for the program. The existing program met each day from the end of the school day at 4 until 6, and she felt the d.loft STEM Project would be a welcome addition. The university students created carpools to drive to the middle school each week.

STEM Activities in the University Course & The Afterschool Program

The content for the university course, which was inspired by the Design for the Other 90% movement, focused on three STEM-based topics. In year 1, the topic was water; in year 2, energy; and in year 3; shelter. The university students were required to design activities for the middle schoolers that integrated STEM concepts from each topic and design thinking.

At the end of each quarter a curriculum was created that contained the university students' activities that were used in the middle school afterschool program. Each year a curriculum was developed:

- Year 1: Dive In! An Integrated Design Thinking/STEM Curriculum
- Year 2: IGNITE! Redesigning Energy Conservation
- Year 3: BUILT TO LEARN! Redesigning Shelter: An Integrated Design Thinking/STEM Curriculum

In Year 1, *Dive In! An Integrated Design Thinking/STEM Curriculum* provided an integrated approach to building science, technology, engineering and math knowledge and skills while engaging students in both identifying and solving problems in their communities and the larger world using a design thinking approach. The activities focused on water conservation, drought, purification, recycling, patterns of use, products that have been designed for those in developing countries and global water usage. All the learning was integrated with a human-centered design thinking approach. The design thinking process activities included conducting interviews, synthesizing data to uncover deep user needs and insights, brainstorming, prototyping and testing. A companion Teacher Guide was created that provided an overview of the project goals, background information on design thinking, teaching tips, a curriculum calendar overview, descriptions of materials, lesson plans, and material lists and resources.

The second year curriculum was entitled *IGNITE! Redesigning Energy Conservation*. Again, the focus was on providing an integrated approach to building science, technology, engineering and math knowledge and skills while engaging students in both identifying and solving problems in their communities and the larger world using a design thinking approach. The activities focused on potential and kinetic energy, exploring concepts of non-renewable energy sources, hydroelectric energy, building water wheels, gaining empathy for someone cooking without electricity or living without lights, building a solar oven, simulating techniques used for extraction of natural resources, investigating and evaluating hydraulic fracking, and learning about technologies used in energy-efficient houses.

The third year curriculum, *BUILT TO LEARN! Redesigning Shelter: An Integrated Design Thinking/STEM Curriculum,* provided an integrated approach to building STEM knowledge and skills while engaging students in both identifying and solving real-world problems using a design thinking approach. Students engaged in integrated STEM and design thinking activities focused on shelter. The foundation of the curriculum was an enduring understanding: *students will develop the creative confidence to fail forward by building successful shelters using both STEM concepts and the empathy-driven design thinking process*. The first module, *The Personal Shelter Design Challenge,* began with an introductory design challenge. This challenge gave students a brief overview of the design thinking process. Subsequent activities provided students with the opportunity to learn and practice the nuances of the design thinking process. In the second module, *The Global Shelter Design Challenge: Redesigning the Shelter Experience for Refugees in the Developing World*, students learned to empathize with children who lived in refugee camps in the developing world. The activities provided an opportunity for the middle schoolers to employ the knowledge and skills they gained from the first module, which included design thinking and STEM concepts. The third module, *The Local Shelter Design Challenge: Redesigning the*

School Shelter Space, gave the middle school students an opportunity to apply their skills to working on a project to benefit their own community and school. They used design thinking and their STEM knowledge and skills gained throughout the curriculum to design a school shelter for a specific user.

In addition to the three design challenge modules, there were seven STEM-based units focused around different shelter topics: building principles, architecture, sustainability, structure and building materials, global shelter, biodiversity, and STEM careers. These units complemented the design challenges by providing the background STEM knowledge and skills needed to create the best design solutions for a variety of users. The seven content areas were chosen because they captured the variety of different considerations that engineers, architects, ecologists, and designers have to consider when thinking about shelter.

Through the creation of STEM-based integrated design thinking curriculum, the university students had the opportunity to not only impact the middle schoolers they worked with, but provided a valuable resource for the larger educational community.

Mentoring & Human-Centeredness

Mentoring and human-centeredness were critical components of the d.loft STEM Design Thinking Model for Teaching & Learning. The expectation was that the university students would learn how to become mentors to the middle school students as they engaged in teaching them about STEM, STEM careers, and design thinking. For many of the students, the notion of what it meant to be a mentor was unclear. Many came from a place of humility and felt that they would learn from the middle schoolers as they were teaching them. The mentors thought deeply about their growing relationships with their students. In their initial visits to the middle school, they were often tentative and tried different approaches to get the middle school students to open up. They planned improvisation warm-ups and unstructured "getting to know you" time so that they could focus on building relationships with the middle schoolers. They realized that they had to get to know those they mentored as people and they realized that they needed to empathize with the middle schoolers. This human-centered mindset permeated their interactions. This awareness was crucial, because adopting a human-centered mindset impacted the development of the mentoring relationships. Fostering empathy was a constant, ongoing topic of conversation among the mentors.

STEM Instructional Activities & Human-Centeredness

Designing and implementing STEM activities for middle school students was challenging, and the university students realized the importance of getting to know the middle schoolers was essential. As part of the course, the university students were required to keep journals reflecting on their weekly work with the middle school students. The mentors used what they learned about connecting with the middle school students as they designed activities. Below are journal excerpts highlighting this understanding.

> "I learned that working with students is all about connecting with them at the level they're at – whether that's their interests or their energy level for that day or whatever else might be influencing their ability to learn. If you can't listen and try to make the activities or mentorship about the relevance of this education to their lives, then it becomes difficult to have the students empower themselves."

> "In terms of mentoring, when talking to the students some of them said they would rather be texting their friends or on Facebook than at our afterschool program. This was an important insight because it helped me understand what types of activities this age group enjoys. I am now wondering how to better incorporate social media into a STEM activity."

> "I learned to be particularly sensitive to middle school students' need to "maintain [their] reputation"! More generally, I became much more aware of the way they handle the social pressures of middle school and tried to be hyper-cognizant of this while developing activities."

The university students paid close attention what engaged and intrigued the middle school students and used this information to design activities. They saw how different approaches, such as hands-on activities, had an impact on students. As the weeks progressed, they adapted their activities as they learned more about the middle schoolers. The role of empathy was central as the university students were able to base their activities on putting themselves in the middle schoolers' shoes.

Mentoring & A Prototyping Mindset

The adoption of a prototyping mindset in design thinking allows one to learn from failure. Ideas are implemented and evaluated, and then changes are made when needed. This was an essential part of the students' journey as mentors for the middle school students. It began with adopting a prototyping mindset themselves. This was not an easy task, because often as a university student, the notion of failing forward was a new concept. Different students had different comfort levels with failure. The emphasis was on learning from failure as a way to improve, and as students began to understand that, their comfort and ability to embrace a prototyping mindset began to permeate their interactions as mentors. This was reflected in excerpts from their journals.

> "I think I managed to strike a balance between guiding and challenging students in their thought process. Being forced to lead students even when I felt uncomfortable or unsure was a pivotal part of this process for me."

> "Though both students and adults respond to failure with varying degrees of fear, I hope that I will be able to develop some activities that will help Milagra students let go of some of the fear associated with failure. Failing forward is one of my favorite design thinking mindsets and I think it is very important for students to be exposed to."

STEM Instructional Activities & A Prototyping Mindset

Once the university students were able to embrace a prototyping mindset, they modeled this in their interactions with the students. When things did not go exactly according to plan in the activities they designed, they explicitly acknowledged that they would move forward and learn from what did not work.

> "I also learned that embracing that inevitability, instead of freaking out about it or getting upset about it, usually makes everything work itself out. For example, when we were working with the students on the boat-building activity and it turned out to be much easier than we expected, we all looked at each other and said "oh well," thought on our feet about how to change it and then tried the change out. The activity worked out fantastically! The students knew that we had misjudged the challenge, but I think that seeing us react to our mistake in a positive way helped them realize that we were human and helped us to make huge steps as mentors. Finally in light of all this, I learned to not be afraid of making mistakes. It's not only part of the design process, but it can actually bring you closer to your students."

Modeling how to learn from what doesn't work is an essential life skill in a 21st century world. In sum, the focus on empathy and the adoption of a prototyping mindset were critical components of the afterschool program design and implementation.

Implications for Practice

Throughout the three years of d.loft STEM Learning much was learned. This section highlights implications for practice. The first implication for practice is that developing a more facilitative stance as an educator/mentor can foster the development of empathy. This happens with a willingness to create a learning climate where questions are important and finding answers is a mutual journey. It is important to embrace this within any forward thinking 21st century community that is looking to be more innovative and more human-centered.

Sharing authority empowers students and helps them become more self-directed learners. Design thinking is often based around challenges where one is designing solutions for another person. When teams of student mentors and middle schoolers collaborated and shared authority this led to a greater sense of agency. This agency is a hallmark of becoming a design thinker.

Personal connections are critical to learning. Design thinking provides that opportunity. Learning flourished through the relationships that were built among educators and students.

Being a life-long learner can be a powerful inspiration for students as they confront the challenges and possibilities of the 21st century. That means being willing to always learn new things, learn from and with each other, stretch the boundaries of creativity, and communicate meaningfully. Empathy and prototyping are inextricably linked. Being able to uncover others' needs demands empathy. Once that happens, there must be a willingness to adopt a culture of prototyping to find solutions. If these mindsets are separated, one is simply conducting interviews and building objects. Explicitly acknowledging mistakes can have both cognitive and social/emotional benefits. Students see that learning happens when one examines and reflects on mistakes. They develop increasing comfort with making mistakes, and begin to embrace a fail-forward, prototyping mindset. This enables them to take risks as learners and to be more metacognitive. Developing a culture that supports risk-taking is essential to creating thriving 21st century learning communities.

Conclusions

Kelley and Kelley (2013) describe creative confidence as the belief in one's ability to create change in the world. Creative confidence is the ability to come up with new ideas and the courage to try them out. It is built upon generating new approaches and solutions. This notion was the theoretical foundation that undergirded the d.loft STEM Learning project, which focused on the integration of design thinking, STEM learning and mentorship.

Embracing the human-centered and prototyping mindsets impacted how the university course was designed, how the university instructors interacted with the university students, how the university students designed activities for the middle schoolers, how the university students interacted with the middle schoolers, and how the university students interacted with the university instructors. Everyone grew in his or her ability to put themselves in another's shoes and there was willingness to both acknowledge, embrace and learn from failure that permeated the program. Most importantly, this enhanced the relationships. The typical notion that the teacher/mentor is the all knowing and immune to failure was reconceptualized. In this more equal learning relationship, relationships thrived amongst the university instructors and the university students and the university students and the middle school students. The most important learning was the importance of caring, engaging, taking risks, and trusting as relationships are built. There must then be a willingness to be vulnerable, to fail, and learn from what doesn't work. This leads to being resilient, optimistic, and ultimately, empowered. The d.loft STEM Learning journey was colored with the optimism, hope and resiliency of 21st century learners.

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RESEARCH BRIEF

Re-engineering an Engineering Course: Exploring the Affordance of Flipped Classrooms for Transformative Teaching, Learning, and Workplace Competency

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Abstract: *This research brief is investigating the extent to which a flipped classroom model enhances student learning of threshold concepts (TCs) in an undergraduate engineering course at a New Zealand university. This project extends the team's previous research confirming the effectiveness of the TC theoretical framework across multiple disciplines including engineering.*

*Keywords**:** flipped classrooms, engineering education.*

Successful engineering graduates not only need to have a flexible understanding of engineering principles and practices but also need to be able to work in teams, to communicate well, to self-assess to improve their abilities and performance, and to work in contexts that can be risky and uncertain (Adamson & Darling-Hammond, 2012; Meier, Williams, & Humphreys, 2000). Current trends in engineering education call for the development of students' "generic engineering competencies" rather than separating generic competencies from engineering competencies (Male, 2010). It is crucial that tertiary educators develop curricula that enable students to develop these capacities during their undergraduate studies to support student capacity to contribute to a country's economic competitiveness and societal well-being and enhance student employability (Crossman, & Clarke, 2010; Hernández-March, Martín del Peso, & Leguey, 2009; Ministry of Education and the Ministry of Business, Innovation and Employment, 2014).

In response to the above, our two-year project (2015-2016), funded by the New Zealand Ministry of Education's Teaching & Learning Research Initiative (TLRI), is investigating the extent to which a flipped classroom model enhances student learning of threshold concepts (TCs) in an undergraduate engineering course at a New Zealand university. This project extends the team's previous research confirming the effectiveness of the TC theoretical framework across multiple disciplines including engineering (Peter, et al., 2013).

The *flipped classroom* is an innovative variant of student-centred learning with the potential to address the issues raised in the international literature. In a flipped classroom lecture materials are usually assigned as take-home tasks, accessible through online modalities. This allows the lecturer-student class contact time to be devoted to addressing student questions and problem solving in teams (Houston & Lin, 2012; Strayer, 2012). Flipping the focus of class time allows students to take increased responsibility for their own learning through active investigation both in and out of class time. This changes the class time focus and dynamics from the transmission of knowledge to one involving collaborative, interactive learning and just-in-time teaching (Bonk & Khoo, 2014). It provides more flexibility for lecturers and students to participate in discussion and collab-

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orative and guided problem solving activities in ways that are known to address student misconceptions and support the mastery of threshold concepts (O'Toole, 2013). These approaches are also known to support the development of the skills needed for 21st century graduates (OECD, 2012).

In our project, TC learning will be a focus for the flipped classroom. Meyer and Land (2003; 2006) introduced the notion of threshold concepts (TCs) as those concepts that students need to master in order to think like a subject specialist. TCs have been linked to ontological shifts (i.e., changes in identity) and shifts in subjectivity that come with the reconfiguration of a learner's prior conceptual framework (Meyer, Land, & Baillie, 2010). These changes are consistent with the goals of tertiary education for engineers (Ministry of Education and the Ministry of Business, Innovation and Employment, 2014). Given the current goals for tertiary education, to better prepare students to apply what they know in new and creative ways in the real world and novel situations (Tertiary Education Commission, 2013), it is imperative that students master TC, competencies and practices in order to reinforce their conceptual development and bolster "threshold actions" within and outside the classroom. Current identification of TC and competencies in engineering has broadened beyond content/technical knowledge to include skills, such as teamwork (i.e., thinking and working together), and communication, both oral and written, that are important to 21st century engineering practice (Male, Bush, & Chapman, 2011; Male & Baillie, 2014). Building on this trend, we postulate that a TC-based flipped class pedagogical approach to teaching and learning can enhance first year students' learning of TC technical competencies and generic skills necessary for engineering graduates in the 21st century. Our research design to address this aim is elaborated next.

Research Design

The three objectives of our research project are: (1) to examine the effects of the flipped classroom on students' learning of hard to grasp TCs (Meyer & Land, 2003), (2) to explore the 'affordances' (defined as the perceivable opportunities for an organism to perform action; Gibson, 2001) of a flipped classroom model of teaching in a first-year compulsory electronic engineering paper, and, (3) to examine the impact beyond the classroom of the flipped class on the development of students' workplace competencies.

Using a design-based research (DBR) process (Collins, Joseph, & Bielaczyc, 2004) involving practitioner-led cyclical processes of planning, design and implementation of a TC-based flipped pedagogical approach, the research team will collaborate with lecturers in an introductory electronic engineering course to develop and trial a flipped class model. This is intended to help students learn TCs and develop the generic competencies needed such as the ability to communicate well, process information effectively, think logically and critically, and adapt to future changes with the overall aim of increasing their workplace competency and future employability.

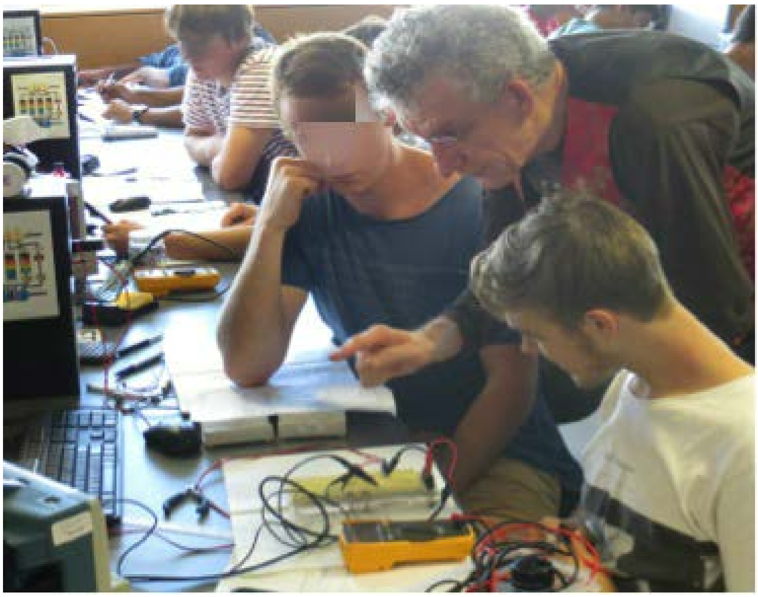

Figure 1. *The lecturer interacting with students in the lab.*

A series of themed "Khan Academy Style" videos (Khan Academy, 2015) is being developed as a replacement for traditional 50-minute lectures. The videos are created with careful reference to recommendations from cognitive principles shown to be effective in multimedia learning (Sorden, 2005). Students will be able to access, view and review the videos from the course Moodle website (Moodle is our university online learning management system) to engage with the new course material outside of class time. They will be reminded to watch the videos prior to attending weekly practical laboratory sessions in which their learning would be put into practice. The weekly three-hour laboratory sessions will be extended to four hours to allow for small group problem solving activities and more personal instructor interaction. In this way, students' role evolves from a passive recipient of knowledge to that of an active knowledge constructor. Concomitantly, the instructor's role also changes from that one of a dispenser of knowledge to guiding and mentoring students to deeper levels of thinking and higher levels of knowledge application.

Data from multiple sources will be collected: (1) lecturer interviews, (2) student focus group interviews, (3) student surveys, (4) observations in the flipped classroom, (5) video analytics of student access strategies to the flipped class videos developed by the team, (6) student access and usage logs in the university learning management system (Moodle), and (7) student achievement data. The analysis will focus on examining the impact of the intervention by tracking changes in lecturer pedagogy and student in-class and workplace learning and development. Statistical analysis will be conducted on the quantitative data to show differences and trends in student achievement and perspectives. Qualitative data will be analysed using thematic analysis to develop themes through inductive reasoning (Mutch, 2005). New videos will be developed and the research activities will be refined and revised in the second year of the study.

Figure 2. *Students working on a collaborative problem-solving task.*

Expected Outcomes of the Project

No other studies that we are aware of have attempted to integrate a TC-focused teaching with a flipped class approach in engineering education. We expect the outcomes will contribute to enhancing our understanding of the ways and extent a flipped class model can foster deep learning of TCs and support learning and transfer of relevant skills into workplace practice. The findings will further help refine guidelines for student workplace competencies and assessment against a robust competency-based criteria for engineering graduates. Such evidence can be used to inform policymakers and practitioners about future implementation and funding opportunities intended to enhance tertiary teaching and learning.

For more information about the project, contact the principal investigators, Dr Mira Peter (mpeter@waikato.ac.nz) and Dr Elaine Khoo (ekhoo@waikato.ac.nz). The project website can be found at:

http://www.waikato.ac.nz/wmier/research/projects/how-flipped-classrooms-afford-transformative-teaching,-learning,-and-workplace-competency

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