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Informal Engineering Education After School: Employing the Studio Model for Motivation and Identification in STEM Domains

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ABSTRACT

Studio STEM adopts a design studio model to provide middle school youth with the opportunity to work with peers and college student facilitators after school in a relaxed, non-threatening, collaborative environment. Two informal learning educators guided overall instruction and pacing, but youth directed their own step-by-step activities by appropriating available resources based on their understanding of presented science and engineering concepts and design problems. We investigated how Studio STEM impacted youth's motivation, beliefs, and identification with engineering, science, and computer science. We documented that the Studio STEM environment supported students' empowerment, highlighted the usefulness of the content, allowed students to feel successful, interested students, and provided the caring needed by students to increase their identification with engineering, science, and computer science. The increases in these beliefs also led to the high *effort* that youth dedicated to Studio STEM, and the claims that youth would *choose* to take a course in these subject areas even if they were not required to do so.

Key Words: Informal education, middle school, design, motivation

INTRODUCTION

Because a mere 10% of U.S. students in K-12 schools receive some type of exposure to engineering in the classroom, informal settings are key to developing engineering skills, understandings, and identity (National Academy of Engineering, 2010). K-12 engineering education is not mandated in the US and only a few states integrate engineering into their standards. Nevertheless, youth are increasingly exposed to engineering education from friends and family members, after-school programs, summer camps, clubs, and other organizations. Recently, the key role of out-of-school learning in science, technology, engineering, and math (STEM) has captured national attention (Bell, Lewenstein, Shouse, & Feder, 2009). Some research exists on how informal science education positively impacts identity and motivation in *science* (see Baum, Hein, & Solvay, 2000; Diamond, St. John, Cleary, & Librero, 1987). Anecdotally, the vast majority of Nobel Prize winners in the sciences have claimed that "their passion for science was first sparked in non-school environments" (Friedman & Quinn, 2006). Nevertheless, research detailing how young people learn *engineering* in informal settings, and how informal engineering education affects youths' beliefs about engineering and identification with engineering is scarce.

Many reports cite anecdotal conclusions and few use valid and reliable measures to determine how informal experiences affect identification with or attitudes toward engineering. In many informal settings, changes in students' perceptions about engineering have been assessed through the Draw an Engineer Test (DAET). Identification with engineering has been inferred from these perceptions (Knight & Cunningham, 2004; Oware, Capobianco, & Diefes-Dux, 2007). As part of the assessment process, students draw an engineer prior to participating in an informal engineering design-based program, and then draw an engineer upon completion of the project. These studies suggest that drawing an engineer that resembles oneself can indicate identification with the field. Other researchers investigating informal engineering design-based projects report that their participants go on to take more engineering-related courses than the general population (Hubelbank et al., 2007), which leads to inferences that the informal engineering experience influenced participants' motivation and identity. Nonetheless, self-selection into an engineering-based intervention may account for stated differences. As another example of informal after-school programming in engineering, Vaughn et al. (2008) used the television show *Design Squad* developed by the Public Broadcasting System television station, WGBH, with students at nine after-school programs. Students watched four episodes of *Design Squad*. Understandings about science and the engineering design process were assessed with pre- and post-tests, as were attitudes toward engineering and interest in an engineering field. It should be noted that this differs from our project in that the intervention was passive, and not actively design based.

In the present study, we used a studio-based learning model to give middle school youth the opportunity to work with peers and college student facilitators after school in a relaxed, non-threatening, collaborative environment. This after-school environment, named Studio STEM, used a design-based, environmentally themed curriculum focusing on engineering design and the science of heat transfer called *Save the Penguins* (Schnittka, 2009; Schnittka, Bell, & Richards, 2010; Schnittka & Bell, 2011). Science, engineering, and computer science educators have been using the design studio as a pedagogical strategy to promote "reflection in action" (Schön, 1984, 1987), to facilitate peer critiques of works-in-progress (Cossentino, 2002), and to help students' understanding of real-world problems (Fortus et al., 2004; Reimer & Douglas, 2003). Studio STEM uses the design studio as a pedagogic tool for engineering education, with energy conservation as a focus area.

Based on a common feature in architectural fields, the "studio" in Studio STEM is a physical and virtual space, which allows youth the opportunity to share their designs (Brocato, 2009; Cennamo et al., 2011; Shaffer, 2003). In a studio, learners justify their proposals in design critiques, incorporate input from peers and facilitators, and co-construct design ideas (Kolodner et al., 1998; Kolodner, Gray, & Fasse, 2003). The mental and physical spaces of the design studio give learners a place for a deeper understanding of content and an ability to generate more coherent and compelling design solutions. Through the integration of cognitive and social elements, the design studio facilitates successful problem solving within groups, which may not be the norm for collaborative learning (Barron, 2003).

In this paper, we first present an overview of the *Save the Penguins* curriculum in the context of an after-school studio established in the library of a middle school building. We follow this introduction by presenting our theoretical framework, which examines the positive motivational factors associated with one's identification with academic domains in formal and informal learning environments. Next, we describe our study that applied a mixed methods approach to examine the ways youth engaged with the design challenge and their subsequent identification with engineering, science, and computer science. Our results, a combination of qualitative and quantitative analyses, highlight the unique combination of an engineering curriculum, information and communication technologies (ICTs), and volunteer educators and facilitators in a studio model. We organize the data gathered from this project into an identification model that allows us to examine how Studio STEM affects students' beliefs toward and identification with engineering, science, computer technologies. We argue that our findings advance the knowledge base and theory in the area of informal STEM programming and point to possibilities for interdisciplinary research in middle school pre-engineering education. Although researchers often claim that students and teachers are interested in and enjoy the use of innovative technologies and engineering-design projects, few studies demonstrate how such projects affect the motivation of youth toward science and engineering (NRC, 2009). This study provides a framework for documenting and analyzing the potential impact of informal learning on the ways that youth identify with science, engineering, and ICTs.

OVERVIEW OF THE CURRICULUM

The curriculum used in this study, titled *Save the Penguins*, was originally developed by members of the Virginia Middle School Engineering Education Initiative (Richards, Laufer, & Humphrey, 2002), but has been revised and re-written by the first author after three years of use in middle school classrooms and after professional development workshops with over 100 teachers (Donohue, Schnittka, & Richards, 2010). As used in the present study, it was modified so that youth would store and exchange proposals and designs through computers networked via the Moodle learning management system (LMS). Moodle (http://www.moodle.org) is an open-source software application for online collaboration among schools or groups in formal and informal learning environments. This online component, which supported blog, chat, storage, and wiki features, complemented the on-site collaborative activities of the youth participants. Although digital and physical collaboration might seem redundant in the small setting of one studio, research has demonstrated that youth and young adults are oftentimes less vocal in face-to-face interactions, and able to more fluently express themselves online (Davidson-Shiver, Muilenburg, & Tanner, 2001; Ravert & Evans, 2007). Moreover, in future implementations of the Studio STEM project, the LMS platform will enable collaboration among youth at geographically separate studio sites when more participants from local middle schools and the Boys and Girls Clubs join the project in spring 2012.

Save the Penguins is about penguins, engineering design, and science. Penguins were chosen as a design focus because they engender empathy and secure interest. Many youth are aware that penguins all over the southern hemisphere are in peril, but they may not understand why, or how their actions at home contribute to the situation. As the Earth warms, the air and oceans warm, and ice melts. Penguins in the cold regions such as Antarctica are losing habitat as ice melts, and losing food sources such as krill (Jenouvrier et al., 2009). Krill are small crustaceans that eat the algae growing underneath the floating pack ice, and as the ice melts the krill population declines (Gross, 2005). Warmer climate South African penguin populations are in decline as well, because as the climate warms, they are abandoning their nests to cool off in the water, placing their eggs at risk to attacks by gulls. Park rangers at Boulders Beach National Park in South Africa have started setting out ventilated fiberglass huts for penguins to nest in, and the intervention appears to be working to keep the nesting penguins cool (Nullis, 2009).

The *Save the Penguins* curriculum is designed to help youth recognize how their behaviors at home may affect penguins in the southern hemisphere. The energy they use to heat and cool their houses comes from power plants, most of which burn fossil fuels. Since the burning of fossil fuels has been linked to increased levels of carbon dioxide in the atmosphere and increases in global temperature, energy use may be having widespread effects on life on Earth, including penguins (Barbraud & Weimerskirch, 2001; Crowley, 2002). If engineers designed better insulating building materials, which reduced energy consumption, and if builders used these materials in our homes, schools, and workplaces, it could have a positive impact on the environment. This is the problem presented to youth who take on the role of engineers to answer: How can one design more energy efficient dwellings for us all, people *and* penguins?

The youth are presented with the design challenge to prevent a penguin-shaped ice cube from melting in a thermal oven. On the one hand, this challenge is analogous to how engineers design shelters for humans. On the other hand, as noted above, tt is also analogous to what is happening in the real world as climate change affects penguin habitats. Prior to the design and testing phase, the particiapants of Studio STEM learn about the thermal properties of various building materials, from paper to polyester. They are led through a series of activities to provide a true sense of how heat transfer happens, and how materials can impede the efficiency of heat transfer. As they are introduced to the science of conduction, convection, and radiation, they participate in hands-on activities that illustrate the three methods of heat transfer. These activities are discrepant events designed to provoke cognitive dissonance, and challenge youth's misconceptions and naïve conceptions of heat transfer. The youth touch silver and plastic trays and infer that one is colder than the other. Later on, they measure the temperatures of these trays and see that the temperatures are the same. They inquire why. The informal educator warms up a model house and youth take the temperature of the air in the attic and first floor. Then, they invert the house and explain what they observe. The youth hold plastic and silver spoons in their hands with ice cubes in the spoon bowls. They are asked to predict which spoon will keep the ice cube colder. Their senses tell them that the metal one will keep the ice colder since the spoon handle itself is cold. However, they see different results and inquire why. The youth observe cold cans of soda wrapped in different materials and predict which one will stay cold the longest. They predict that aluminum foil will work the best and that wool will make the soda warm. They measure the results and inquire about insulators.

Working as if engineers with a problem posed as a design task, youth are given a small budget from which to purchase materials, and are guided to experiment with these materials to determine which ones reduce heat transfer. They put the materials under lamps and measure the temperature beneath the material to determine which materials are better for reducing heat transfer. Materials for "sale" at the Igloo Depot are: bubble wrap, aluminum foil, colored construction paper, colored foam sheets, metallic Mylar film, wooden sticks, cotton balls, and small paper cups. The youth then employ tape and glue to design and create structures to save their ice cube penguin while thinking about how engineers do the same thing on a human scale. A 10 gram penguin-shaped ice cube is placed in each dwelling, and then the dwellings are placed in a thermal oven for 20 minutes. Ideally, the dwelling will preserve at least half the mass of the ice cube. The youth are naturally competitive between groups and try to build a dwelling that preserves the most ice. Repeated trials after discussion, evaluation, and re-design mimic the engineering design process and help keep the competition within each group, with the goal to improve upon one's design, not necessarily to "beat" the opponent. For a more detailed description of the curriculum, see Schnittka (2009).

In the after-school setting of Studio STEM, two informal educators guided the overall instruction, but youth directed step-by-step activities working in small teams with volunteer studio facilitators. These facilitators were undergraduate students from a local, large research university fulfilling service hours to the community required by their degree programs. The facilitators helped the youth test materials, design the dwelling, test the dwelling, create virtual representations of their designs and ideas, and write about their design decisions, the materials they used, and their final design. The facilitators also encouraged the youth to develop storyboards, which provided for a physical space to document the design process from start to finish as it evolved at the work table, and allowed for groups to readily share their progress and thoughts with others. One of the purposes of the volunteer facilitators was to motivate the youth and keep them focused on the design goals.

The curriculum design, studio, use of ICTs, and instruction in Studio STEM are congruent with the cognitive development for youth in middle childhood. Collins (1984) notes that the ages between 10 and 12 mark a distinctive period in which children take on new roles and responsibilities and begin to gain a greater awareness of the adult world. In these biological and cognitive stages of development, youth have greater capacity in terms of spatial reasoning, the ability to complete complex tasks, and self regulate their behavior. Scientific reasoning develops as youth compare their theories to the evidence and reflect on and evaluate their thinking (Kuhn, 2000). Youth in Studio STEM are given the opportunity to design and re-design projects to provide them with the opportunity to develop theories, compare them to the evidence, reflect on outcomes, and modify their theories as needed. Moreover, because their abstract thinking is futher developing, youth can go beyond what is real to what is possible (Berk, 2004). This ability allows youth to imagine the ideal and perfect world. Studio STEM builds on these idealisms by focusing on a curricula that involves saving animals. To many youth, this idea can be appealing because it allows them to create a more ideal world. Finally, similar to Rogoff (2003), we also argue that a child's development must be understood in the context of their cultural environment, and thus, we allowed for ample opportunities and activities that fostered collaborative interactions, social practices, and dialogue in the studio.

RESEARCH QUESTIONS

This mixed methods study (Creswell, 2003), using questionnaire, direct observation, and video data, was designed to understand youth's beliefs about and identification with engineering, science, and computer science. Youth participated in an ICT-supported, engineering design-based, after-school program at a Boys and Girls Club in a rural southwest Virginia community. The Boys and Girls Club was hosted at the middle school where youth attended daytime classes.

The research questions that guidied the investigation were as follows.

1. How does Studio STEM (the curriculum, strategies, and technologies) influence youth's beliefs about and identification with engineering, science, and computer science?
2. How do the facilitators and instructors influence youth's motivation to participate in the Studio STEM design activities?

THEORETICAL FRAMEWORK

Youth's Identification With an Academic Domain

We chose to focus our investigation on factors related to identification because there are many positive motivational outcomes associated with domain identification. Identification with an academic domain (such as engineering, science, and computer science) refers to the extent to which people define themselves through a role or performance in activities related to that domain (Osborne & Jones, 2011). When youth strongly identify with a domain, they are more likely to choose to engage in activities within that domain, put forth more effort, and persist longer in the face of frustration or failure than those who are not identified with the domain (Osborne & Jones, 2011). Youth who are strongly identified with a domain are also more likely to have goals, beliefs, and identities that foster their success in these areas. For the youth in this study, their choices, effort, persistence, goals, beliefs, and self-schemas should lead to desirable engagement behaviors that increase the probability of desirable academic outcomes (e.g., achieving good grades, scoring higher on standardized tests, remaining in school, graduating, and attending college).

Osborne and Jones (2011) presented a model, based on research and theory, which describes how an informal learning environment, such as Studio STEM, can impact youth's beliefs, identification with a domain, and motivation. The model shows that youth's identification with an academic domain is influenced by at least four factors: (1) group membership (race, gender, social class), (2) family, peers, and community environment, (3) school climate, and (4) formal and informal educational experiences. These four factors influence not only youth's identification with the domain, but

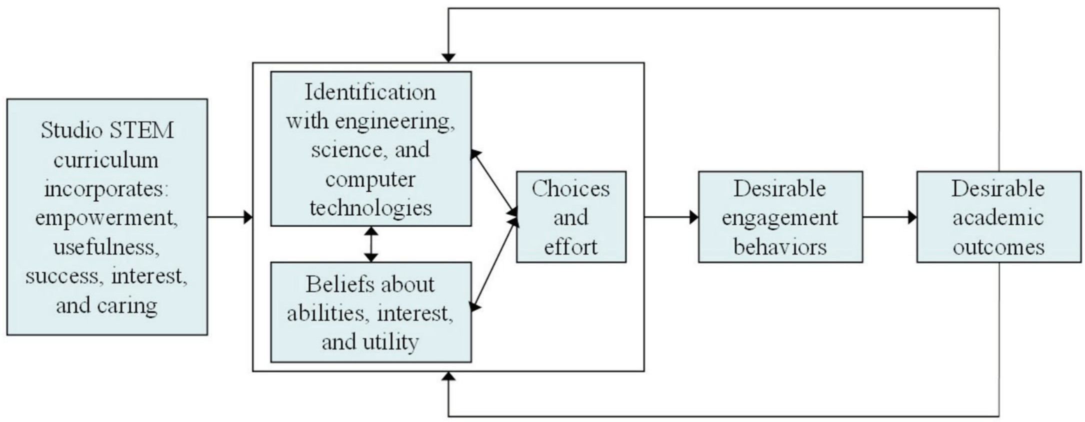

Figure 1. Model of how Studio STEM affects youth's identification with engineering, science, and computer science.

also their goals, beliefs, self-schemas, choices, effort, and persistence in that domain. These factors can lead to desirable engagement behaviors, which can lead to desirable academic outcomes. This model allows us to understand how informal educational experiences, such as Studio STEM, can affect youth's beliefs and identification with domains such as engineering, science, and computer science. Part of the Osborne and Jones (2011) model is shown in Figure 1 with the variables of interest for the present study.

Youth begin to identify with a domain when they (a) believe that they are *empowered* to act independently within it, (b) believe that the domain is *useful* to their goals, (c) believe that they can *succeed* in it, (d) are *interested* in it, and (e) believe that they are *cared* for in a supporting environment that fosters belongingness (see the MUSIC Model of Academic Motivation in Jones, 2009, for a further description of each of these components; see Osborne & Jones, 2011, for a discussion of how these components can affect youth's domain identification). Studio STEM was designed to provide middle school youth with each of these five components; and thus, the design of the studio model is aligned with the framework in Figure 1 by providing the components listed in the left-hand box. The framework represents how our studio model can lead to desired outcomes. As examples, Studio STEM provided youth with a sense of *empowerment* by providing them with many opportunities to make choices, such as choosing how to construct their penguin dwelling and which materials to use to build it. The various projects presented problems that are relevant in today's world; and therefore, can be seen as *useful* to youth. Studio STEM projects challenged learners at a range of ability levels and were completed with the help of the instructors and facilitators who provided feedback to youth as needed. Thus, the instructors and facilitators helped ensure youth's *success* and make sure that that they felt supported. Many of the activities, and digital and networking technologies supported by the Moodle LMS, used in the projects were novel to the youth, which was one way to foster *interest*. Finally, the Studio STEM volunteer facilitators and instructors were trained to provide a *caring* environment and foster a sense of safety in risk-taking and of belonging to the learning community.

Because individuals' identification with a domain is closely related to their beliefs about that domain, we chose to include measures of youth's beliefs in this study. Specifically, we selected measures that assessed constructs within the expectancy-value model developed by Eccles and her colleagues (Eccles, Adler, & Meece, 1984; Eccles et al., 1983; Eccles & Wigfield, 1995) because these constructs have been shown to be important predictors of people's motivation and achievement. People's expectancies for success and values are strongly correlated with their performance on a task and their intentions and choice of activities (Eccles, 1984a, 1984b; Eccles et al., 1983; Meece, Wigfield, & Eccles, 1990). We chose to use "ability perceptions" as a measure of expectancy because it was only possible to ask the youth about their abilities (as opposed to their expectancies) at the end of a project and it has been demonstrated that ability perceptions and expectancies are not empirically distinct (Eccles & Wigfield, 1995). Eccles and Wigfield (1995) used factor analysis techniques to demonstrate that the value of a task can be separated into at least three factors: intrinsic interest value, attainment value, and extrinsic utility value. Thus, in addition to examining participants' ability perceptions, we chose to examine their intrinsic interest value (i.e., the enjoyment one experiences from performing a task, or the personal interest one has in a subject), attainment value (i.e., the importance one places on doing well on a task), and extrinsic utility value (i.e., the perceived usefulness of the task in terms of an individual's future goals) (Eccles & Wigfield, 1995; Wigfield & Eccles, 2000).

Social Constructivism and Sense-Making Activities

The framework of social constructivism is the model, based on research and theory, which describes how Studio STEM was devised to impact youth's construction of scientific and design-related knowledge and skills. The Studio STEM project involved concrete, sense-making activities in social groups with facilitator scaffolding (Driver, Guesne, & Tiberghien, 1985; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Ferguson, 2007; Puntambekar & Kolodner, 2005). When the volunteer facilitators functioned as a "more sophisticated other" (Maloch, 2002), they supported or scaffolded youth's attempts to understand content that they were unable to complete unaided (Pea, 2004). Thus, the facilitators used language as a pedagogical tool (Mercer, 1995) to employ particular linguistic techniques in supporting students as they constructed understanding. The facilitator, therefore, is "guiding the construction of knowledge" (Mercer, 1995, p. 1). Moreover, the conversations during sense making in the design process, allowed youth to play with ideas about science and engineering, as well as practice speaking about their ideas with others.

A social constructivist account of learning examines the explicit and implicit opportunities for youth to self-identify with science and engineering. As youth align themselves with ideas, practices, other people, or groups, they *self identify*, or position themselves in the context of the STEM fields. In much the same way, Emirbayer and Mische (1998) argue that researchers should attend to the ways in which individuals actively "construct" their sense of self in social contexts. As youth talk about their interest in the STEM fields and the ways they act upon those interests, they "position" or align themselves to these domains. Similarly, Davies and Harré (2000) speak about "positioning," or how one positions oneself in their talk and conversation as they self-identify, as being the key to understanding personhood. For example, as girls and boys speak about their abilities to one another, they might begin talk about being a "designer" or an "engineer" in an active role, rather than as a passive observer. They begin to assert their decision-making more forcefully and speak about role in the present task, but also how they see themselves extending this kind of work into their future.

METHOD

Participants

Eight middle school-aged youth enrolled in an afterschool Boys and Girls Club participated in Studio STEM. All 15 club students were invited to participate in the Studio in an introduction activity that involved building bridges out of paper, but the club director only allowed the eight students who returned parental consent forms to participate. The students who participated did not seem to be particularly interested in STEM at the outset; they seemed to be looking for something fun to do in addition to the usual after-school choice of activities. All of the students were White/Caucasian. Five were boys and three were girls. Their ages ranged from 11 to 14, with four 11 year olds (all sixth graders), one 12 year old (a sixth grader), two 13 year olds (a seventh grader and an eighth grader), and one 14 year old (an eighth grader) (see Figure 2).

The studio instructors were two females in their late 20s. One was a Ph.D. student in education with a background in science teaching and over five years experience working in informal science institutions and after school programs. The other was a master's student completing her teacher certification in science education. Both instructors received training, led by the first author, so that they could implement the curriculum with the assistance of six volunteer facilitators who worked directly with small groups of youth throughout the seven weeks. This training consisted of a

Figure 2. Youth, instructors, and facilitators working together.

three-hour workshop where the instructors engaged with the curriculum themselves. Training for the volunteer facilitators took place separately in a two-hour session and focused mainly on basic questioning strategies, ways to provide encouragement, means for keeping the youth on task, and positive mentoring techniques. All facilitators were undergraduate students: three majoring in engineering, one majoring in biology, and two majoring in the humanities. Three facilitators were female and three were male. Two boys were placed with a male mentor, a boy and girl were placed with a female mentor, two girls were placed with a male mentor, and two boys were placed with a female mentor. The final two female mentors floated between groups and assisted the instructors.

Youth met for one hour, once a week for seven weeks during a regularly scheduled after school meeting time for the Boys and Girls Club in fall 2009. Youth met in the middle school library, a location that was not being used during this time after school and provided several networked computers that instructors and investigators could use during project time. The library was arranged with tables that seated four youth in the center and computers arranged on the periphery on tables along the walls.

Studio STEM Video Link

Data Collection

Our research employed a mixed methods approach in which data were collected through questionnaires and video. The purpose of using a mixed methods approach was to increase the internal validity of assertions through triangulation of the data sources. Because all research methods have limitations, multiple approaches complement one another and compensate for potential bias in a particular method. Additionally, the results from each method can be used to confirm or corroborate findings from the other (Creswell, 2003). Data sources included exit surveys and analysis of discourse recorded on video. The study can best be described as mixed methods using the concurrent triangulation strategy (Creswell, 2003).

Mixed methods are also ideal for approaching a motivational model with the level of complexity as proposed by Osborne and Jones (2011). We asked the youth directly about their beliefs, interests, and values through questionnaires, but we also wanted to examine how these beliefs, interests, and values were unconsciously enacted through participation with Studio STEM. The kinds of engagement behaviors Osborne and Jones describe in their model were captured through videotaping and analysis of girls and boys as they participated in the studio and via their interactions with facilitators and instructor.

All youth were administered a questionnaire at the end of Studio STEM. To ensure that youth remained focused on the questionnaire items and answered all of them, one of the researchers read the questionnaire items aloud individually during the administration of the questionnaire (the researcher did not elaborate on the questions). Most of the questionnaire items had been previously administered to middle school students in studies by other researchers, but in reading the items aloud to the youth, we were able to ensure that none of the wordings were confusing to them. We ascertained this by noting that none of the students asked questions about the meaning of the items or acted confused when asked the questions.

To measure participants' interest and effort in the Studio STEM project, we used a modified version of two scales from the *Intrinsic Motivation Inventory* (available at http://www.psych.rochester.edu/SDT/index.php). The original inventory consists of six scales that assess youth's subjective experiences in an activity. This instrument has been used in several studies and has been shown to produce scores of adequate reliability and validity (Deci, Eghrari, Patrick, & Loene, 1994; Ryan, 1982; Ryan, Connell, & Plant, 1990). We replaced the original scale words, "this activity," with the term "Studio STEM" for all of the items. The 7-item *Interest/Enjoyment* scale was used to assess youth's interest and enjoyment in participating in Studio STEM (e.g., "I enjoyed participating in Studio STEM very much."). The 5-item *Effort/Importance* scale was used to measure the amount of effort that youth put into Studio STEM (e.g., "I put a lot of effort into Studio STEM."). All items were scaled using a 5-point Likert-type format with descriptors at 1 (*not at all true*), 3 (*somewhat true*), and 5 (*very true*). To better understand the specific components of Studio STEM that youth enjoyed, we asked them one open-ended item about what they liked most about Studio STEM and another open-ended item about what they liked least about Studio STEM.

To assess the extent to w hich the youth believed that their instructor and peers provided them with academic support (a measure of caring), we used a modified version of two, four-item scales from the *Classroom Life Instrument* (Johnson, Johnson, & Anderson, 1983): the *Teacher Academic Support* scale and the *Student Academic Support* scale. We slightly altered the original items in both scales to include the word "Studio STEM" because we wanted to focus participants on how they felt about the Studio STEM instructors. An example item from the *Teacher Academic Support* scale is: "The Studio STEM teacher cares about how much I learn." An example from the *Student Academic Support* scale is: "Other students in Studio STEM want me to do my best on this project." All items were scaled using a 5-point Likert-type format with descriptors at 1 (*never*), 3 (*sometimes*), and 5 (*always*).

Because usefulness, success, and interest, have been identified as being important to individuals' identification with a domain (Osborne & Jones, 2011), we designed the questionnaire to measure constructs related to these factors. To assess youth's beliefs in engineering, science, and computer science, we created Likert-type items to measure extrinsic utility value (a measure of usefulness), ability perceptions (a measure of success), intrinsic interest value (a measure of interest), and attainment value (a measure of identification) for youth's perceptions in these three domains. We used attainment value as a measure of identification because attainment value is believed to be conceptually similar to identification (Eccles, 2009) and correlates highly with identification with a domain (Jones, Paretti, Hein, & Knott, 2010). We designed these instruments to be similar in format and content to those designed by Eccles and Wigfield (1995), which have been shown to have excellent face, convergent, and discriminant validity, as well as strong psychometric properties (Eccles et al., 1993; Jacobs, Lanza, Osgood, Eccles, & Wigfield, 2002). Similar items were used successfully in a study of a technology project implemented by Alstaedter and Jones (2009). A complete list of the items used in the present study is provided in Table 1.

As a measure of whether the youth would be likely to *choose* to continue to pursue engineering, science, and/or computer science courses, we developed an item that asked them how interested they would be in taking a course in these subjects even if the course was not required. The items are presented in Table 1.

Because of Studio STEM:	M	SD
Ability perceptions		
1. my engineering knowledge and skills are (a lot worse/better)	4.50	0.76
2. my science knowledge and skills are (a lot worse/better)	4.50	0.93
3. my computer and Internet skills are (a lot worse/better)	3.88	0.84
Intrinsic interest value		
4. I now find engineering (a lot less/more interesting)	4.38	0.74
5. I now find science (a lot less/more interesting)	3.63	1.41
6. I now find using a computer and Internet (a lot less/more interesting)	3.75	0.89
Extrinsic utility value		
7. I now believe that knowing about engineering is (much less/more useful than I thought before)	4.50	0.54
8. I now believe that knowing about science is (much less/more useful than I thought before)	4.00	1.07
9. I now believe that knowing about the computer and Internet is (much less/more useful than I thought before)	4.13	0.84
Attainment value		
10. I now believe that learning engineering is (much less/more important than I thought before)	4.50	0.76
11. I now believe that learning science is (much less/more important than I thought before)	4.13	0.99
12. I now believe that learning about the computer and Internet is (much less/more important than I thought before)	3.88	0.84
Choice to take a course		
13. My interest in taking a course in engineering, even if it wasn't required, is (a lot less/a lot more)	4.63	0.52
14. My interest in taking a course in science, even if it wasn't required, is (a lot less/a lot more)	4.00	0.93
15. My interest in taking a course in computer and Internet, even if it wasn't required, is (a lot less/a lot more)	4.13	0.84

Note: All items were rated on a 5-point Likert-type scale with the endpoints as noted in parentheses in the left-hand column of the table and the mid-point value (i.e., 3) labeled in a way that indicated "the same as before the project."

Table 1: Descriptive statistics for youth's beliefs a result of Studio STEM.

All studio sessions were videotaped with four cameras and transcribed for analysis by a graduate student. One camera was stationary and focused on the entire room, while the other camera, controlled by a graduate assistant who moved about the room, focused on close-up actions at worktables where youth were designing and constructing, or where they were working at computers on their Moodle entries. Youth and their facilitators operated two additional compact digital video cameras (Flip™ cameras). To determine whether data from questionnaires matched the actual behaviors of the participants, all videotapes were examined in detail. We focused on three different levels of analysis; by moving back and forth between these levels we tracked meaning making as it occurred in the studio among youth, their facilitators, and the instructors. The videotapes were viewed in full at least two times, with sections of the video watched multiple times in a more detailed analysis of dialogues and action (Derry, 2007). The video granted investigators opportunities to focus on microgenetic details (Roth, 2001) in which youth, their instructors, and volunteer facilitators used questions, analogies, and metaphors as a means for understanding key concepts of energy and design in the studio setting.

Digital representations of youth's ideas and designed artifacts were documented and shared through the online network site, Moodle. This network platform facilitated the exchange of data and information so that youth could collaborate and comment on each other's work. These commentaries, expressed through blogs, chat, and wiki entries, were also collected, but for this study were not main components of the analysis. Transcripts of discourse and interviews/questionnaires were the primary sources of data for analysis.

RESULTS

Questionnaire

To determine youth's beliefs about the programmatic elements of Studio STEM, we examined the results presented in Table 2 and found that youth were highly interested in and enjoyed participating in Studio STEM, put forth a lot of effort into Studio STEM, and felt that the instructors provided

Beliefs about Studio STEM	M	SD
1. Interest and enjoyment in participating in Studio STEM[a]	4.70	0.37
2. Effort put into Studio STEM[a]	4.60	0.48
3. Peer academic support during Studio STEM[b]	3.56	1.08
4. Instructor academic support during Studio STEM[b]	4.66	0.52

[a] rated on a 5-point Likert-type scale labeled at 1 (not at all true), 3 (somewhat true), and 5 (very true)
[b] rated on a 5-point Likert-type scale labeled at 1 (never), 3 (sometimes), and 5 (always)

Table 2: Descriptive statistics for youth's beliefs about Studio STEM.

much academic support. Youth believed that their peers provided *some* academic support, but their ratings on this scale were lower than their ratings on the other scales.

When asked what they enjoyed most and least about Studio STEM, the youth provided comments that were consistent with the closed-ended items, indicating that they enjoyed the project and put forth effort in it. Five youth indicated that they liked working on building the penguin house, four youth said that they liked making their own website, three youth reported that they enjoyed creating the PowerPoint presentation, and two said that they liked helping save the penguins. Two youth said that they did not like writing on the storyboard posters, but these were the only two things that youth said they did not like about Studio STEM. As a measure of their motivation towards participating in the project, two said that they wanted more time to participate each week.

Our examination of the results presented in Table 1 indicate that the Studio STEM project led to increased ability perceptions (i.e., beliefs), intrinsic interest value, extrinsic utility value, and attainment value (i.e., identification) in engineering, science, and computer science. In general, youth's ratings were higher for engineering than science or computer science. We did not conduct a statistical test to determine whether these ratings were statistically different because of the small sample size. Youth also reported that they were interested in taking a course in engineering, science, and computer science even if it was not required.

Video Analysis

Using grounded theory (Strauss & Corbin, 1990) in the analysis of the video, we looked for the ways that youth positioned themselves in dialogue with their facilitators and the instructors. That is, we looked for indications of the ways youth self-identified with science or engineering terms in their conversations with instructors and facilitators, the creative expression of their emerging understanding of energy transfer and conservation in their participation of the program's activities, and how these ideas were shared among their peers, instructors, and facilitators, face-to-face and online. The key themes derived from the detailed analysis of video footage and transcripts were: (1) motivating talk, (2) mentoring through reflective questioning, and (3) sequence and pacing of the design process, as presented in this section.

Motivating Talk

Volunteer facilitators encouraged youth to continue to work on their project when their motivation was flagging. Because Studio STEM was held at the end of the day, youth often came to the studio tired after a day of schoolwork. When youth appeared to lack inspiration, the facilitator initiated the action in the team that was quickly taken up by others. Other times, when youth became distracted and silly, the facilitators were able to gently pull the youth back to the task and infuse their conversation with lighthearted jokes while keeping them working on their projects. Through their encouragement and positive feedback, the facilitators provided forward momentum or redirection on the projects. Phrases such as "awesome," "you got it," and "you're almost there" helped youth gain confidence in their decisions. Other times, the support from the facilitator redirected missteps, as in: "That was a good guess, but…" This support was evidenced through gestures and body language as well. For example, the facilitator Tom used gestures to signal approval and encouragement. Tom would lean back, nod, and smile. Other facilitators would give youth a high-five to symbolize approval. For the most part, youth enjoyed the attention that their facilitators offered and youth looked forward to seeing their facilitators and the instructor each week.

The competition of having the most energy efficient penguin house was also a motivating factor in the design process. Youth expressed excitement as the results of the first test were measured and recorded. Comparing all the designs from the first competition inspired them to redesign so "they could win." Also, youth quickly understood the concept of cost effectiveness and several teams were conservative in how they spent their energy dollars to purchase supplies. They seemed to appreciate the complexity of the problem, to both design an energy-efficient *and* cost-effective dwelling.

Mentoring Through Reflective Questioning

Volunteer facilitators were central to the youth's progress and enjoyment of the studio design process. However, mentoring varied in terms of assisting youth to understand key concepts of energy. Although some of the facilitators were helpful in motivating youth and in keeping them on task, the facilitator's ability to advance thoughtful conversation varied. Questions prefaced with "how" or "what" did not elicit reflective responses from the youth. Instead, youth responded with functional answers and it was apparent that many times they were constructing the penguin houses without a clear reason as to why they were using particular materials.

Below is a transcript from a discussion between Randy, a sixth grader, and Libby, his facilitator, as Randy was speculating on the re-design of their penguin house. Libby was not an engineering or science undergraduate (Flip video interview 17, 11–05–09).

Randy: We…we had lots of aluminum foil. And we used this to put it on top [pointing to illustration on the storyboard], so that the cotton balls would help Penny [their penguin]. And then there was a stick to like, hold it on. And then we used like the foam for like extra layers, and um…our house improved this week.

Libby: Ok, so what do you think we can do next week, because we still didn't win.

Randy: We can have less aluminum foil…just knock it out.

Libby: Do you think less aluminum foil or less foam? Because we had a lot of foam this week that we didn't have last week. Do you think that helped or didn't help? What do you think helped the most?

Randy: It…it really didn't help.

Libby: It didn't help? And what about the tinfoil?

Randy: It was ok, but....

Libby: Maybe, well we said that tinfoil keeps the heat out, so could that have been an issue since the tinfoil wasn't covered on the inside?

Randy: Yeah.

Libby: So, what are we going to do different next week?

Randy: So, we're gonna use less foam.

Libby: Sounds good.

Although this dialogue allowed Randy to reflect on *how* he built his house, his reasoning on *why* he used specific materials was not so clearly articulated. Libby repeated something Randy mentioned earlier, that tinfoil keeps the heat out, but she did not probe his meaning around this statement. Also, she asked, "What do you think helped the most?" a question that does not help Randy make meaning about the ways that the materials interact with heat and energy transfer.

In contrast, several of the facilitators who were engineering undergraduates were able to introduce scientific terms and ask questions that required youth to reflect on their design (see Figure 3). Youth often held naïve conceptions about how heat interacted with different material types. Understanding youth's misconceptions of energy transfer required the facilitators to ask probing questions. Those facilitators who asked, "*Why* are you doing that?" were able to hear youth articulate the reasoning behind their design process. These kinds of questions provided an opportunity for the facilitators to integrate key terms such as convection, conduction, and insulation. Facilitators were also able to challenge youth to test their ideas or to connect their design with the observations of the materials they made before they started the penguin house construction.

Below is a transcript of a conversation between Brian, a seventh grader, and his facilitator, Gary, as they were planning the re-design of their penguin house. In this dialogue, the facilitator Gary has re-introduced terms that Brian found on a website while constructing his blog. Through his questions, Gary realized that Brian did not understand the difference between the terms conduction and convection, and offered some real life examples. (11-05-09, Video 31).

Gary: What about the light bulb?

Brian: The light reflects on every side.

Gary: They do. Isn't that where the heat is coming from?

Brian: The light bulbs…they are reflecting, keeps…keeps…keeps. [Brian uses hand signals to indicate the generation of heat.]

Gary: That's right, so what happens? You've got radiation from those light bulbs. That's like the sun. There's two other things the website talked about, conduction and convection. Do you remember anything about that? What was conduction like?

Figure 3. Engineering student facilitator (left) with a middle school youth.

Brian: Conduction is…an insulation…it's like electricity.

Gary: Conduction is like a pan, a frying pan on a stove. Right? It touches the stove and it gets hot. Right? What is conduction like?

Brian: What's a conduction?

Gary: That website that Robert was talking about. Conduction…where two things touch and they transfer heat.

Brian: Oh, and it's heat…hot.

Gary: Convection must be the opposite right?

Brian: It's insulating?

Gary: Convection is like when heat transfers through the air, when two things aren't touching.

Brian: Oh! Like that [he points to the heat box behind him]. So we need to build it like that, so that it will balance.

Gary: Exactly! Yeah, you want to think about convection and conduction. So, let's talk about the design of the house.

Brian became excited when he understood what was meant by convection, pointing to the box with the heat lamps next to their table. Their re-design proceeded with Brian and his teammate Robert reconsidering their building materials, using these new words together as they debated their revised design (see Figure 4).

Figure 4. Brian and Robert re-constructing their penguin house.

Sequence and Pacing of the Design Process

The instructors' and facilitators' movement back and forth between storyboards, blogging, and building during the design process afforded time for youth to reflect on how to revise their designs. The second round of re-designing the penguin houses offered youth an opportunity to question their understanding of the ways that heat transferred. Rather than launching directly into the redesign and a new construction, the instructors asked the youth to either work on their storyboards or to record their ideas on their Moodle website, which allowed the facilitators and youth more opportunities to talk about their experiences and emerging understandings. This sequence and pacing was an important aspect of enhancing youth's sense of their abilities and success at each step of the design process.

The storyboards were not as effectively used as the Moodle websites, possibly because the storyboard format was new to the youth; and instructors did not give them a template for how to compose the storyboard or what exactly to record on the board. Despite this, with some guidance from their facilitator, one team found the storyboard to be a place where they could record their thoughts about the design process (see Figure 5).

The Moodle site was more familiar to the youth, as their school used this application in its day-to-day activities. Youth enjoyed the freedom of personalizing their Moodle space and choosing to record what they found interesting from each studio session or what they gleaned from other Internet websites through focused searches. The older youth were particularly sophisticated in

Figure 5. Randy's storyboard.

terms of bringing in web content from other locations on the Internet, as well as using PowerPoint to compose a presentation at the end of the project (see Figure 6).

DISCUSSION

The Influence of Studio STEM on Youth's Self Identification

Our first research question asked: How does Studio STEM influence youth's beliefs about and identification with engineering, science, and computer science? We were especially interested in

Figure 6. Facilitator working with two youth on their Moodle sites.

how the facilitators and instructors affected youth's motivation to participate in the Studio STEM design activities. We will discuss the results from the questionnaire and video analysis within the context of the identification model presented by Osborne and Jones (2011). The parts of the model that were most relevant to the present study are presented in Figure 1.

Some of the ways in which Studio STEM was hypothesized to provide youth with empowerment, usefulness, success, interest, and caring were discussed in the Theoretical Framework section. Our findings provided evidence to support some of these ideas. The open-ended items and video analysis confirmed that the youth felt *empowered* through personalizing their Moodle websites and choosing what to record, and designing their penguin house (over which they had complete control). Results from the questionnaire indicate that youth better understood the *usefulness* of engineering, science, and computer science as a result of participating in Studio STEM. The sequencing and pacing of the project, along with the encouragement and positive feedback of the facilitators and instructors, helped the youth to be *successful*. The competition of trying to build the best penguin house gave them feedback to know how successful they had been. Because there was a second round of re-designing, youth were motivated to improve on their success the second time around. Participants cited several activities in which they were *interested*, such as building the penguin house, making their own website, and creating the PowerPoint presentation. In fact, writing on the storyboards was the only part of the project some participants reported that they did not enjoy, which leads us to believe that they found most of the Studio STEM activities interesting and enjoyable. The results shown in Table 2 also provide evidence that the youth were very interested in and enjoyed Studio STEM. The *caring* shown by the instructors and facilitators motivated the youth. They enjoyed the attention received from the instructors and facilitators, and the facilitators were effective at keeping the youth on task and motivated to continue working on their project. These findings are verified by the quantitative data in Table 2, which show that youth felt supported by their instructors, as well as by their peers (although to a lesser extent).

As predicted by the MUSIC model (Jones, 2009) and the model in Figure 1 from Osborne and Jones (2011), we contend that the empowerment, usefulness, success, interest, and caring provided by Studio STEM led to the increases we documented in youth's ability perceptions, intrinsic interest value, and extrinsic utility value. Further, we propose that the increases in these beliefs led to the increase reported in their identification with engineering, science, and computer science (as measured by attainment value). The increases in these beliefs then led to the high *effort* that youth reported putting into Studio STEM and the fact that they reported that they would *choose* to take a course in these subject areas even if they were not required to do so.

We did not investigate the outcomes of participants' increased identification with engineering, science, and computer science, but the model predicts that higher levels of identification will lead to more engagement with these domains in the future (possibly by taking more courses in these areas or seeking more informal educational opportunities), which will lead to positive academic outcomes (such as higher grades in courses related to these domains). Ultimately, we hypothesize that youth who are highly identified with engineering, science, and computer science will seek careers in these fields. Although the results of this particular study are tentative given the small sample size, we believe that our findings show how data can be collected and used within motivation frameworks to understand how informal learning experiences affect students' identification in STEM domains.

Overall, Studio STEM had a greater influence on participants' identification with engineering than on their identification with science or computer technologies. This might be due to the fact that youth had insufficient knowledge about what engineering was at the beginning of Studio STEM. Therefore, they had the most to learn about it. Or, it might be that the design activities were focused more on engineering than science or computer technologies and this had a bigger impact on their identification with engineering. Either way, we were encouraged that Studio STEM helped youth to become more identified with engineering, science, and computer science.

The Influence of Facilitators and Instructors

Our second research question asked: How do the facilitators and instructors influence youth's motivation to participate in the Studio STEM design activities? Youth felt supported by their Studio

STEM instructors and facilitators. They also felt supported by their peers, but to a lesser extent. Given the importance of caring interpersonal relationships in academic settings (Deci & Ryan, 2000; Jones, 2009) and our attempt to design Studio STEM with that component in mind, the results support the fact that youth felt cared for by their instructors. The facilitators played a key role in helping the youth by providing support, coaching, and reflective questioning. Engineering student facilitators were especially skilled at providing science and engineering content support by asking questions that elicited evidence of youth's scientific reasoning. Another key element that the instructors and facilitators offered was in providing the youth with time to reflect on their ideas through storyboarding and the Moodle online platform. Reflection was facilitated by storyboarding, but more effectively through the Moodle online platform.

IMPLICATIONS, LIMITATIONS, AND FUTURE RESEARCH

The design of Studio STEM, including the curriculum, strategies, and technologies, worked to engage youth in engineering, science, and computer science in a way that can motivate and foster identification with these domains. Our findings provide evidence that designing informal learning environments that support empowerment, usefulness, success, interest, and caring can motivate youth (Jones, 2009). Future research could identify whether some Studio STEM experiences and design attributes were more important than others in affecting youth's motivation and identification within these STEM domains.

This study also demonstrates how motivation models can be used to examine the motivation of youth in informal learning environments. Examining the components of the MUSIC Model of Academic Motivation (Jones, 2009) within the larger domain identification model proposed by Osborne and Jones (2011) shows how informal educational experiences can affect youth's beliefs, effort, choices, and possibly future behaviors and outcomes. One limitation of our study is that it is difficult to document exactly how the processes in the Osborne and Jones (2011; see Figure 1) model occured. Although we documented that Studio STEM provided students with empowerment, usefulness, success, interest, and caring, we inferred that these conditions led to students' increased identification with engineering, science, and computer science based on these motivation models. It is possible that there were other factors that influenced students' identification beliefs. Using the MUSIC model and the domain identification model to interpret much of the data could have been limiting to our analysis and might have biased us against identifying other factors that influenced students' motivation. Future research could examine other possible factors and how they might influence students' beliefs about and identification with STEM domains.

The major limitation of this study is its scale. Generalization cannot be made from such a small sample size. Future plans are in place, and external funding has been obtained, to offer this program to youth in three communities in rural southwest Virginia. Different engineering design-based curricula will be used throughout the year to interest and engage youth in fundamental concepts in alternative energy resources, energy transfer, and energy sustainability through solving problems related to saving animals. This will allow us to examine how different curricula affect youth's motivation and domain identification over time.

CONCLUSION

Engineering education is slowly making its way into formal school classrooms, but informal engineering education remains an important source of exposure, practice, and motivation for young adolescents. Without a nationwide emphasis on formal engineering education at the middle school level, informal experiences may be the only ones some youth receive. Informal engineering education opportunities are usually more accessible for all youth, and many universities, companies, and engineering organizations sponsor them (Jeffers, Safferman, & Safferman, 2004). Sometimes those experiences promote authentic experiences and information, help youth form identification with engineering, and promote positive beliefs about engineering. However, those experiences can also reinforce misconceptions about who engineers are and what they do. Due to the inherent difficulties in performing research in informal settings, research is limited into how these informal engineering education outreach efforts impact youth's interest in and capacity to do engineering (NRC, 2009).

This research study provides guidance for those involved with informal engineering-based programs for young adolescents. The combination of blogging and storyboarding for personal expression, low-key pacing for time to explore engineering and building relationships with the undergraduate facilitators, and the opportunity to re-design multiple times made for a successful intervention that promoted beliefs about and identification with engineering.

The model for Studio STEM and our resulting research were the product of an interdisciplinary effort: our research team includes members from engineering education, educational psychology, educational anthropology, and instructional design and technology. As an after school program, Studio STEM was intentionally designed as a place where youth could freely explore the media, concepts, and language surrounding engineering, science, and computer science. The studio is offered as a space for tinkering and experimenting with engineering design concepts and science ideas in a supportive environment enhanced with online support and channels for communication.

Moreover, youth are encouraged to talk, discuss, and play with the materials. They are encouraged to engage with the problems posed and the materials provided in ways that we hope will positively influence their future relationships with learning in engineering. Results from this study provide a holistic approach to developing a nuanced understanding of ways to integrate science and engineering into informal STEM education that takes into account youth's identities, practices, and the social context in which they participate.

Through their participation in Studio STEM, underserved youth from a rural southwest Virginia community realized, to an identifiable degree, that science and engineering could have a positive effect on their lives and, quite possibly, the lives of all living creatures of the world. While learning the domain and practice of the science of heat transfer and thermal energy, youth also learned identifiable technical and collaborative skills. Implementing the *Save the Penguins* curriculum in an informal setting with underserved youth in a rural community was a success in that youth experienced engineering in the form of play and exploration. Facilitators provided motivation through discourse, mentoring through reflective questioning, and promoted sequencing and pacing to allow for sufficient reflection time. Through the caring influence of undergraduate facilitators to help guide them and social networking software to help motivate them, Studio STEM encouraged youth to identify with engineering, science, and computer science. Youth felt empowered, useful, successful, interested, cared for, and put forth great effort. At the end of the seven weeks, which illustrates our point, youth asked the volunteer facilitators: "When can we save more animals?"

For more information about Studio STEM, visit our website at www.studiostem.org

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