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Informal Pathways to Engineering

Dr. Monica E Cardella, Purdue University, West Lafayette

Dr. Monica Cardella is an assistant professor of engineering education at Purdue University. She is also the director of Informal Learning Environments Research for the Institute for P-12 Engineering Learning and Research (INSPIRE). She conducts research on undergraduate engineering students' design and mathematical thinking in formal and informal contexts in addition to research on how children develop engineering thinking in informal learning environments.

Marisa Wolsky, WGBH Educational Foundation

Marisa Wolsky is an executive producer at WGBH Educational Foundation with over 20 years of experience turning STEM content into entertaining and educational media. Ms. Wolsky is the principal investigator for the NSF-funded series Design Squad, for which she oversees all aspects of the production, translating its engineering content into entertaining across many platforms. She is also senior producer for the NSF-funded preschool science series Peep and the Big Wide World, responsible for managing its production and working closely with the series' advisors to oversee the implementation of Peep's educationally rich science curriculum. Prior to this, she worked on the development and production of many children's series, including Long Ago and Far Away, Where in the World Is Carmen Sandiego?, Where in Time Is Carmen Sandiego?, Arthur, and ZOOM. Ms. Wolsky holds a B.A. in American Studies from Barnard College at Columbia University.

Dr. Christine Andrews Paulsen, Concord Evaluation Group

Dr. Christine Andrews Paulsen is founder of Concord Evaluation Group (CEG) in Massachusetts. Dr. Paulsen holds a Ph.D. in education research, evaluation, and measurement from the University of Pennsylvania. She has been conducting evaluation research since 1990 and, prior to CEG, worked for the Institute for Social Analysis and the American Institutes for Research. Dr. Paulsen routinely directs evaluations of STEM-related projects in informal settings, focusing on learners as well as practitioners. Her main research interest lies in evaluating the use of learning technologies that hold the promise of enhancing the lives of traditionally underprivileged populations (children, parents, and communities).

Tamecia R Jones, Purdue University, West Lafayette

Tamecia Jones received a B.S. in Biomedical Engineering with a concentration in Electrical and Computer Engineering from the Johns Hopkins University, a M.A. in Learning, Design, and Technology from Stanford University, and a M.Div. from Boston University School of Theology. She taught middle school math and science for three years, consulted with pre-college programs, and nonprofits and museums. The focus of her doctoral research is assessment in K-12 engineering education.

Informal Pathways to Engineering

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Abstract

Roughly 81.5% of a child's time (waking hours) is spent in out-of-school settings. Therefore, as we consider increasing pre-college students' awareness of engineering, along with the need to broaden diverse participation in engineering and promote a more engineering-literate populous, it is important to not only consider how children learn about engineering in school environments, but also how they learn about engineering in out-of-school settings.

This project seeks to investigate the effect of informal, out-of-school learning activities on students' interest in engineering and decisions to engage in engineering-related activities (leading to choices to study engineering in college). The study builds on the success of "Design Squad" (an NSF-funded, multimedia program for middle school children that includes television episodes broadcast nationally on PBS, an interactive website, and hands-on engineering activities) to engage children in out-of-school settings. The study uses a longitudinal study design where children, parents and educators (both classroom teachers and informal educators) are interviewed and surveyed to collect data, which will be analyzed using social cognitive career theory.

The broader significance and importance of this project will be to support the informal engineering field's ability to inspire more children to pursue engineering pathways (from initial interest in engineering to choices in college majors and an ultimate career as a professional engineer). The project builds on strong partnerships with many youth organizations, such as the Girl Scouts of the USA, FIRST and the National Engineers Week Foundation. This project includes not only a research program, but also the development of new web resources that can further promote children's interest in and understanding of engineering.

Motivation

Engineers, educators, economists and government agencies cite a multitude of reasons for promoting pre-college engineering education, including a need for a more technologically and engineering-literate society; a need for more equitable access to engineering education (and more diverse participation in engineering); and an economic need for a new engineering workforce. The US Department of Labor expects the demand for engineers to increase 11% over the next decade[1] yet the percentage of students graduating with engineering degrees has been steadily declining for the past twenty years[2] . The lack of engineers is especially pronounced among women and minorities—in 2007, only 12% of bachelor's degrees in engineering were awarded to black and Hispanic students, and 19% to women[3]. In order to maintain its competitive advantage, inspiring and preparing more children to become engineers has become an imperative mandate for the US.

As we consider how to inspire and prepare children to become engineers, many efforts have been undertaken to include or integrate engineering in K-12 classrooms, such as the Museum of Science's Engineering is Elementary curriculum, Project Lead the Way, and EPICS High. However, it is important to consider not only formal settings but also informal settings.

According to the LIFE Center, children only spend approximately 18.5% of their waking time inside classroom environments, leaving the majority of their time available for learning during out-of-school time[4]. Over the past twenty years, a growing number of informal programs have been created to take advantage of this opportunity while addressing the need to increase participation in science and engineering. In addition to large blocks of time, these informal programs have other unique benefits over formal schooling. Informal learning experiences offer low-stakes assessments and a greater variety of topics to explore (school curricula tends to focus narrowly on math and literacy due to testing policies). They have also been shown to more deeply engage participants, better encourage direct interaction with real-world phenomena, and build on prior knowledge and interests[5].

Designed to spark children's interest, raise awareness about careers, and provide opportunities to engage in hands-on activities, informal engineering experiences range from single-exposure activities like museum visits to more sustained programs like FIRST and the Future City Competition. These experiences occur at one of three major informal learning environments: everyday settings (such as the home), designed settings (such as science museums), and programs (such as FIRST)[5].

While individual evaluation studies have offered insight into the successes and failures of these discrete informal engineering programs—and occasionally pinpointed correlations between participation and studying STEM subjects in college—more research is needed to look across programs to determine how children move from one experience to another and what motivates them to keep progressing along an engineering-related pathway. Researchers need to recognize that children's informal learning experiences should be studied as part of a larger system—an informal engineering education system, which encompasses children's afterschool activities, media use, interactions with parents at home, summer camp stays, as well as their formal schooling.

Background

Other engineering pathway studies

Other studies have been conducted to understand the different "pathways" that students pursue in college. Through a longitudinal study conducted at four different universities, the Academic Pathways Study (part of the Center for the Advancement of Engineering Education) explored the reasons students choose to study engineering and persist in engineering, and why they choose to "leave" engineering within the context of a four-year undergraduate education[6,7] . The researchers utilized a variety of methodologies to understand students' experiences and decisions, including surveys (40 students per university), structured interviews (32 students per university), and ethnographic interviews and observations (8 students per university). The "Engineering Pathways Study" (NSF #1022644) is currently building on this work, by researching the experiences of early career professionals in order to better understand what educational institutions and employers can do to facilitate the transition from engineering student to practicing engineering professional. Complementing this study [8], Patterson and Swan have begun to follow the professional trajectories of about 500 engineering students to measure changes over time in students' beliefs, knowledge, skills and attitudes towards engineering and their own engineering education.

The Informal Pathways to Engineering study also builds on this research, but is unique in several ways. In contrast to the previous research on pathways to engineering, this study focuses on pre-college students' experiences. Additionally, while some of the other pathways to/through engineering studies included informal, out-of-school time experiences, the main focus of these studies was on students' curricular experiences. The Informal Pathways to Engineering study primarily focuses on students' out-of-school time experiences (with some exploration of the impact of these out-of-school time experiences on students' experiences in school).

Studies of learning in informal environments

While little research currently exists on the nature of *engineering* learning in informal environments (with some notable exceptions [9, 10, 11]), prior research has been conducted to understand how students learn and develop interest in mathematics, technology and science. For example, Bell and colleagues conducted a longitudinal study of 16 middle school children's learning of (and developing interest in) science through everyday experiences[12] . The researchers regularly spent time observing and interviewing middle school students and their families to learn how students encountered and engaged in science in an array of out-of-school experiences, including family discussions, play at home, and trips to the science museum. The researchers captured information about how the science exploration was initiated (particularly when activities were initiated by children vs. parents) and how parents supported their children's interest in and understanding of science. As the study was qualitative and longitudinal, researchers were able to capture longer-term "stories" of how students' interest changed over time. In some cases interest grew; in other cases interest grew, then waned, then grew again[12].

Barron and her colleagues conducted a similar study to understand how children develop technological fluency in out-of-school settings. Through interviews with eight middle-school students and their parents, Barron and colleagues[13] discovered seven distinct roles that parents tend to play as their children develop technological fluency: teacher, collaborator, learning broker, resource provider, nontechnical consultant, employer, and learner. As the parents adopt these different roles, they can provide their children access to additional resources and activities that enable them to develop their interest and understanding in technology, including robotics clubs, opportunities to develop websites (for family members; for nonprofit educational organizations; as a job) and summer camps focusing on robotics, programming and engineering design. Through the interviews, Barron and her colleagues captured rich retrospective accounts of the middle-school students' pathways to technological fluency[13].

The limited research that has been conducted on engineering learning in informal environments provides evidence that participation in engineering programs in secondary school can lead to enrollment or interest in studying engineering in college. In a recent review of the 18 STEM programs targeting girls, the Harvard Family Research Project's Out-of-School Time Database[9] found that most of the programs increased participant's confidence in their math skills, improved attitudes toward and engagement in math, and increased plans to attend or enroll in college. In their evaluation of FIRST (a robotics club), Melchior and colleagues [10] reported that the program's alumni were significantly more likely to attend college and three times as likely to major in engineering than compared to a group of students with similar background and achievement in science and math. A similar study was conducted in order to evaluate Project Lead the Way (PLTW), a non-profit organization that promotes pre-engineering courses in middle and high schools. This study found that PLTW graduates were five times more likely to select engineering courses compared to first-time freshmen at four-year institutions, and their average freshman GPA was higher than their peers[11].

Design Squad

To investigate the effects of informal *engineering* programs on children, the Informal Pathways to Engineering study uses Design Squad as the vehicle for the research. Design Squad is an NSF-funded, multi-media program for tweens and teens that includes television episodes broadcast nationally on PBS, an interactive website, and hands-on engineering activities. Designed to increase children's awareness and understanding of engineering, the Emmy and Peabody Award-winning television series follows two teams of teens who design and build projects for real world clients—from constructing cardboard furniture for IKEA to designing peanut butter makers for a women's collective in Haiti. Its spin-off television series, Design Squad Nation, showcases engineer co-hosts Judy and Adam as they travel across the country, working side by side with children to turn their dreams into reality through engineering. Online, Design Squad provides children with a forum to brainstorm, submit project ideas, and respond to the ideas of others through sketches and real world prototypes. And offline, Design Squad's 40 hands-on engineering activities enable children to exercise their own design skills at home, tapping into their ingenuity and teaching them how to think like engineers.

In addition to being an accessible informal engineering program, providing a way for children who might not sign up for an extended afterschool club to pursue a potential interest in engineering, there are several other reasons why Design Squad is ideally situated as a vehicle for accomplishing the IPE (Informal Pathways to Engineering) study.

Firstly, it's a robust, multiplatform resource that has greatly magnified the number children exposed to engineering. Since its premiere in 2007, Design Squad has shot 46 half-hour episodes, produced 24 short career profiles of engineers, and launched an interactive website—with streaming video, WGBH's first multiplayer game (FIDGIT), and an online community of innovators. The project has conducted 720 trainings, workshops and events for more than 228,000 engineers, educators, kids and families. Over 100 engineering and education organizations have become formal partners, and 8,000 programs have used Design Squad's educational materials, which include six educators' guides (containing step-by-step directions and leaders' notes for 40 activities).

Secondly, the audiences Design Squad is reaching are traditionally underserved in engineering education. About half of Design Squad's television audience is female and a full 40% is African American or Hispanic, compared with only 29% of the general population[14]. Online, 64% of website visitors are girls and 43% are non-white ethnic minorities. Approximately 42% of children served by Design Squad's outreach partners were Hispanic and African-American, and more than one third of families served were from low-income families. Roughly 13% of individuals in the U.S. were classified as below "poverty-level" in 2008[14].

Thirdly, evaluation has shown that Design Squad has a significant impact on children's understanding of engineering and attitudes towards engineering. A summative evaluation conducted by Goodman Research Group, Inc. (GRG) found that, after watching just four Design Squad episodes, children's attitudes towards engineering changed significantly. Children were significantly more likely to agree with three statements about the work engineers do: **(1)** *engineers help make people's lives better*, **(2)** *engineers solve problems that affect real people,* and **(3)** *engineers sometimes have to test their work and start over again.* In addition, children's negative stereotypes decreased significantly from pre to post. After viewing, fewer children agreed that *engineering is boring* or that *men are better than women at engineering*. GRG also showed that, as a result of Design Squad, kids increased their design process skills and demonstrated a strong understanding of the science and engineering concepts presented. In a subsequent study, conducted by Veridian Insight, students who were exposed to Design Squad's hands-on engineering activities in afterschool environments were also positively affected: they showed significant improvement in their understanding of the engineering design process from pre to post, as did their leaders. Finally, Design Squad was found to be effective in formal school environments. Children exposed to Design Squad demonstrated significant gains in their understanding of key science concepts and showed improvement in their attitudes about engineering stereotypes as compared to a control group.

Theoretical Framework: Social Cognitive Career Theory

To build on recent research examining students' interest in engineering, including the Academic Pathways Study, the Informal Pathways to Engineering Study uses Social Cognitive Career Theory (SCCT) as the guiding theoretical framework. Social Cognitive Career Theory (SCCT)[15] has its roots in Bandura's Social Cognitive Theory, which posits that personal characteristics, behaviors, and environment all play important roles in an individual's academic and career choices[16]. SCCT expands on SCT by providing a model for understanding the choices that individuals make with respect to academic and career pathways. The SCCT framework argues that these choices are influenced by three main factors: **self-efficacy** (the degree to which one believes that one can succeed at a given activity), **outcome expectations** (one's beliefs about the outcomes of certain behaviors), and **personal interest** (i.e., intentions). Brown and Lent[17] found that people choose not to follow certain career paths because of faulty beliefs they may hold about their own self-efficacy or faulty outcomes expectations. They found that modifying self-efficacy and outcome expectations can help people reconsider previously disregarded career pathways.

Researchers have used SCCT to demonstrate that self-efficacy plays a crucial role in recruiting women into college-level STEM program[18-20]. Other studies have explored hands-on STEM activities within the framework of SCCT and have found that it provides an efficient model for studying such activities[21, 22]. According to Zimmerman[23], self-efficacy and outcome expectations help learners to consider future consequences, which, in turn, enable them to set goals for themselves. As learners reach specific goals, as a result, their self-efficacy changes. They begin to see themselves as being capable of achieving goals, which then motivates them to continue learning.

Researchers have also found that self-efficacy and positive outcome expectations lead to enrollment in science and engineering programs. Using data from over 3,300 student surveys from the National Education Longitudinal Study of 1988, Tai and his colleagues [24] looked at 8th grade students' expectations for what career they thought they would be in at age 30 and then correlated responses to which degrees children had earned 12 years later. Students who *expected* to have a science-related career were 3.4 times more likely to earn physical science and engineering degrees than students without similar expectations. The study also found that about half of eighth graders who *expected* to have a science career followed through on their eighth-grade career choices, while only a third of students who expected non-science careers switched into science.

Research Design

Our goal with the IPE study is to answer the following research question:
How do informal engineering programs (such as Design Squad) support engineering-related learning over time (i.e., engineering pathways)?

To get at this larger question, we are also exploring five related, secondary questions:

- What types of children benefit the most (i.e., develop positive outcome expectations about engineering, greater engineering-related self-efficacy, and an increased interest in engineering) after exposure to programs like Design Squad?
- How much exposure and what type of exposure to programs like Design Squad is sufficient to support these positive outcomes?
- When is the most critical time to capture the attention of kids (when are they most "ripe" for programs like this)?
- What are the elements of programs like DESIGN SQUAD that support positive outcomes?
- What engineering pathways do children pursue, if any, after using programs like Design Squad?

Study Design

To answer our research questions, we are conducting a qualitative interrupted time series study in which we follow a sample of 60 middle school children before, during, and after they use the Design Squad website and related resources. Conducting a qualitative study enables us to gather rich, descriptive data about the factors that contribute to children's decision processes over time as they relate to engineering activities. Participants (middle school aged children) have been recruited during their 6th grade academic year, and study participation lasts through the students' 8th grade academic year.

Participants

To date, we have recruited 30 middle school children from Massachusetts and 21 middle school aged children from the state of Indiana. The students are recruited to maximize diversity in terms of socio-economic status, ethnicity, and geography (e.g., urban, rural, suburban). Additionally, the Massachusetts sample consists of 30 traditionally schooled children, while the Indiana sample currently consists of 11 traditionally schooled children and 10 homeschooled children. The homeschool children were recruited based on their age rather than their grade level, such that they are approximately the same age as the traditionally-schooled children. Participants have been recruited through the use of flyers, emails, word-of-mouth, and the use of a previously established research panel of over 4,000 individuals, which includes a national sample of parents of middle school children. Through these recruitment mechanisms, parents whose children might be interested in participating in the study are asked to contact the research team or complete an online survey for screening to determine their child's eligibility for the study. Children are eligible for inclusion if they have access to the Internet from home and they can communicate in English, and if they have some interest in engineering and/or design. As an incentive, each family is given $100 per year for participation in the study.

Procedures

Upon enrollment in the study, we schedule one-on-one interviews (primarily in person, but some have been conducted using FaceTime or Skype) with each of the participants and at least one of his or her parents. During the initial interview, students are asked to complete a survey and parents are asked to complete an abbreviated version of the Parent Engineering Awareness Survey[25]. Children and their parents are later interviewed by phone at the halfway point (15 months), and in-person again at the end of the study (~31 months). Quarterly (once per three months), children are also asked to complete a short Web-based survey in order to capture information about their interest in engineering and design, their use of Design Squad resources, and their engagement in other informal engineering activities. In addition to interviews with the children and their parents, we are also interviewing the children's teachers (for traditionally-schooled students) and informal educators at the beginning and the end of the study in order to gain a fuller understanding of potential influencing factors in the children's' lives (e.g., what engineering-related content is being covered in the children's classrooms and what engineering-related activities are offered at schools).

Study Instruments

We have developed interview scripts for three different audiences: (1) children, (2) parents, and (3) teachers and informal educators. The objective of the interviews is to gather qualitative data that enables us to assess the factors that influence children's engineering-related interests, intentions and behaviors. The development of interview protocols was informed by the those developed for the Academic Pathways Study[6] and evaluations of FIRST[10]; however, most of the questions are also unique to this study. Additionally, we have created a modified version of the Parent Engineering Awareness Survey[25] to capture information about the parents' knowledge of and attitudes towards engineering as well as behaviors they engage in to promote their child's engineering learning. Finally, we have created a series of surveys to further capture the children's engineering-related interests, intentions, and behaviors. These surveys consist of items from existing, validated instruments from repositories, including the "Assessing Women and Men in Engineering" resources (developed by Penn State and University of Missouri with NSF funding)[19] and the Academic Pathways Study[6]. They also contain items created specifically for this study (e.g. questions specifically related to the child's use of Design Squad resources). To validate the instruments, we shared them with an expert panel consisting of representatives from other informal education programs, including the Girl Scouts of the USA, FIRST and the National Engineers Week Foundation, as well as the project's external evaluators. The instruments were revised based on the feedback received from our expert panel and external evaluators, and then pilot tested with a sample of 6 children, 6 parents and 14 educators (8 formal educators and 6 informal educators) who represent the study populations.

Analysis

Following transcription of the interviews, rather than approaching the data analysis with a pre-conceived set of themes and data classifications into which one could fit the data ("emic" approach), we will instead use an "etic" approach, in which we will look for the themes and narratives that naturally emerge from the data. Qualitative data collected from the surveys will also be analyzed in a similar manner. Any quantitative data collected during the surveys (i.e., responses to Likert scales) will be analyzed with descriptive statistical analysis (e.g., measures of central tendency).

Preliminary Findings

We have only just recently begun data collection for the Informal Pathways to Engineering Study. We have collected many rich stories of students' interest and engagement in engineering and design, and are beginning to collect additional information about how the families have benefitted from the introduction to the Design Squad materials. For example, a month after the initial interview, one parent reported that their child had used up every possible spare material (e.g. paper towel tubes, toilet paper tubes, egg cartons, cardboard) they could find at home in order to engage in the design challenges they encountered through the Design Squad web resources. Her child's passion for engineering and design had been fueled by the access to the web resources in only a month's time.

As the initial interviews are completed, and analysis begins, we will report additional preliminary findings in the final version of the paper.

Broader Impacts

While the research activities are still in the early stages, this study already offers two significant contributions. First, the instruments that have been developed and tested for this study represent a valuable contribution to the STEM education community. As the project continues, we will share these instruments with other researchers, while also pursuing opportunities to disseminate them more broadly. .

Second, the project accomplishes several goals through the development of the Design Squad resources, which include: providing additional opportunities for sustained exploration of engineering; encouraging more collaboration among website visitors; take advantage of social media to reach parents; and building stronger bridges to strategic partners (e.g. the Girl Scouts of the USA, FIRST and the National Engineers Week Foundation) to facilitate students' progression along engineering pathways. The following resources are currently being produced:

- series of highly accessible video shorts, all between one and five minutes long, featuring Design Squad hosts Deysi Melgar and Nate Ball, along with a rotating cast of kids, taking on engineering projects, answering questions, and profiling young inventors; ;

- a redesigned website featuring a thematic structure that offers kids an entry point into engineering through a topic that they already enjoy or appreciate, such as fashion, sports, and music; 16 new hands-on, engineering activities (with accompanying how-to videos presented by Design Squad hosts, optimized for kids to play on their cell phone or other mobile device);
- mini-design contests that ask kids ask for quick creative solutions to small-scale projects;
- a "Sketch on Sketch" website feature that enables kids to contribute their own design ideas to those of other kids;;
- an overarching game where kids earn points for contributing their ideas and participating in challenges, designed to sustain engagement and provide motivation to keep building and sharing,.

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