"Getting it to Work:" Exploring Student-Driven Problem Solving in Computational Making

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ABSTRACT
This paper presents findings from a year-long after-school program that engages youth from local communities in computational making and community problem solving. Our goal is to understand how self-directed computational making activities contribute to shifts in students' self-efficacy and perception of themselves as people who can pursue careers in STEM. During the first, skill-building semester, our preliminary findings suggest that when youth have the opportunity to work through self-directed projects, they engage in a variety of strategies to set goals and work through challenges. We believe that this work contributes to a growing field-wide understanding of novice designers' problem scoping practices and their nuanced perceptions of challenge.

Author Keywords
Makerspace; computational making; project-based learning; problem scoping;

CCS Concepts
•**Applied computing** → *Education;*

INTRODUCTION
Only a more diverse STEM workforce can effectively address the most difficult global, emergent challenges we face, yet young people from historically underserved communities continue to face barriers to participating in STEM enrichment activities [8]. Maker spaces can provide an important social context for youth to draw on their existing expertise, learn from and with other community members, and practice the habits of mind and skills that can prepare them for a wide range of STEM fields [9]. While many programs connect STEM with solving real-world problems, there is a need to better understand how these programs influence students' perceptions about STEM, themselves, and their communities.

In this project, we study the implementation of the *Innovation Institute*, a makerspace program led by The New York Hall of Science. The *Innovation Institute* uses social entrepreneurship and computational making practices to engage local high school youth in exploring patterns, opportunities, or challenges in their communities and designing artifacts in response to those observations. We hypothesize that social entrepreneurship components and problem scoping practices in conjunction have the potential to deepen students' engagement with computational tools, and may contribute to positive shifts in students' self-efficacy. In studying this program, our overarching goal is to generate evidence that will deepen our understanding of practices that motivate students, especially students from historically underrepresented groups, to pursue and persist in education pathways that prepare them for STEM occupations. We also seek to deepen our understanding of the systemic barriers that may impact a young person's participation in STEM educational pathways.

In this paper, we briefly describe the *Innovation Institute* program and report our preliminary findings from the first five months of the program (we are currently in the middle of the first year). During this first semester, we were interested in observing 1) how students used and perceived the resources around them (peers, facilitators, online documents) as they devised and worked on self-directed projects, and 2) how students identified and navigated challenges that arose while working on these projects. Our preliminary findings deepen our understanding of how students pursue self-defined goals and their perceptions of the challenges that arise along the way. We believe that this research contributes to a growing collection of literature on problem scoping practices in informal or self-directed learning environments.

LITERATURE REVIEW

Our Theoretical Model
Our program model posits that when youth have the opportunity to deeply explore personally relevant problems, and to use the problem-solving approaches of engineering and computer science to respond to these problems, their perceptions of these disciplines will positively shift [3]. Accordingly, our program is situated within a framework with three core elements: (1) making practices, (2) computational problem-solving, and (3) social entrepreneurship. As we present findings from the first, skill-building semester, we focus our analysis on the first two elements.

First, we draw from existing maker practices to support students in learning how to design and construct personally mean-

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ingful artifacts [9]. For our work with the *Innovation Institute*, we also conceptualize making as a social and cultural practice, and recognize making as "rooted in community-based forms of surviving and thriving" [10].

Second, in this model, we focus on computational approaches to problem solving, which are essential to daily practice across a wide range of engineering and computer science careers. As outlined by Weintrop et al. [11], computational problem solving practices include programming, choosing suitable computational tools, and trouble-shooting. In addition, there is a growing recognition of computational *making*, and its potential to transform how and what people learn in STEM disciplines [6].

Third, we use social entrepreneurship as an approach to build linkages between STEM and community impact, and to encourage young people to recognize themselves as active agents of social change. In the coming months of the *Innovation Institute*, students will complete long-term projects based on community explorations. While little rigorous research on the impact of these activities on youth exists, some programs are using the tenets of social entrepreneurship to invite young people into civic engagement, design, and engineering [4].

Problem Scoping

Problem scoping refers to the stage in the problem-solving process in which the investigator frames a problem, considers the broader context, and continuously evaluates the problem space [7]. Understanding ill-structured problems is an important skill for many STEM-related fields, yet many young people lack opportunities in formal education to practice solving loosely-defined problems [7]. In our model, we anticipate that problem scoping will be a key phase of the program that will need to be carefully documented. Research has shown that novice designers may spend too little time defining the problem and gathering information, prematurely deciding on a solution [1]. For our study, we draw on this existing field of literature to observe how students engage in problem scoping when working on self-directed projects.

METHODOLOGY AND CONTEXT

Research Site and Participants

The *Innovation Institute* program is held at The New York Hall of Science (NYSCI). NYSCI's immediate neighborhood is home to many new Americans, with almost two-thirds of residents born outside the United States. The program involves two cohorts of participants in two consecutive years. We are currently in the course of the first year of the program, and this paper presents our study on the first five months of the first year implementation.

First Cohort of Participants

Participants were recruited through NYSCI's school and community outreach program. The first cohort of participants consists of 17 high school students aged 13 to 18 (M = 15.2 years old, SD = 1.48), 9 are male and 7 are female (one student chose not to report their gender). Our research participants represent diverse socio-economic backgrounds, and many reside in the NYSCI's surrounding neighborhood. The students' participation in this program is on a voluntary basis, but a group of students receive school credit (7 of 17 students in the first year cohort).

Module	Description
Ready Maker	Prototyped a physical board game; created a digital version using Ready Maker, a digital game design software.
Arduino	Worked on a self-defined project using a microcontroller and sensor.
Tinkercad	Used TinkerCAD's capability to program circuits; Designed and printed a 3D shape.
P5.js	Explored how to use code to program interactive, digital art.

Table 1. Program modules for the first semester

Program Design

The program runs from August to June, and is broken into three parts: 1) a week long bootcamp in August, which ran for six hours a day, Monday to Friday, 2) semester one, focused on skill building, and 3) semester two, will focus on community problem solving and long-term project building. During the first and second semesters, workshops are held once a week for three hours after school, and once a month, students attend a longer, six-hour weekend session. This paper reports findings on the first skill-building semester, which spanned from August to December, 2019. During this time, students completed four projects, each centered around a different computational tool (see Table 1).

Two makerspace facilitators design the curriculum emergently, meaning that many activities and lessons are designed as student needs and interests emerge. During each workshop, there are two researchers and two facilitators present.

Research Design

We use an integrated model of research and practice, where a team of researchers closely work with the program team throughout the program. Our research team documents the program using multiple qualitative data sources including surveys, videos of workshops, and student interviews. Based on embedded assessment models [5], and reflection activities used by our makerspace team, we designed a "reflection booth." There, researchers asked reflective, open-ended questions about challenging moments, successes, and perceptions of the program in general. For this paper, we focus our analysis on data collected during two reflection booth sessions; one was held at the end of the Arduino module (Table 1), and the other at the end of the first semester.

The reflection booth was set up in the back of our regular workshop room. Researchers asked students to voluntarily come to the booth at any point of the workshop to reflect on their progress. In these guided reflections, we prompted students to think about their process – how they decided on a project idea, what challenges arose during the project and how they worked through them.

PRELIMINARY FINDINGS

Our preliminary analysis focuses on students' problem-solving practices, and in particular, examines their problem framing approaches while working on self-directed projects. We present our findings on two aspects of problem-solving: pursuing self-defined goals, and working through challenges.

Defining and Pursuing Goals

Understanding how students set goals and frame problems is of importance in our analysis, since it is a core practice of the problem scoping process [7]. In addition, goal setting behavior is closely tied to our larger questions regarding student self-efficacy and identity.

Students in our program were encouraged to freely explore and devise a project that was personally relevant to them and select relevant resources for their projects. To understand what different strategies students use to set their project goals, we studied the transcripts of the reflection booths. Our analysis suggests that while each student developed their own strategy for framing project goals, we can group these various goals into two main categories: 1) result-oriented and (2) skill-oriented.

Result-Oriented

Some students devised an idea for a final product before beginning work. For them, skill building was often seen as a means to achieving a final product. Some of these students originated project ideas themselves, while others used online resources to find projects ideas. When we asked students what their initial goal or idea was, students in this category often responded with, *"I wanted to make...,"* or *"I wanted to do. . . "* For example, Jonah (age 14) explained, *"Originally I wanted to do a labyrinth, but I was cocky and I didn't know what I was doing."* After trying to replicate a project he found online, he encountered technical challenges using the microcontroller. Like Jonah, we observed that other students who initially had a specific product in mind often had to redefine or simplify their goals as they encountered challenges. Tim (age 16) explained that for his Arduino project he first wanted to use a joystick but soon felt overwhelmed, *"I hooked it up – it was really hard to work with because there were a lot of numbers coming in and I didn't know how to use them [. . .] So then I was like, "what's the next thing I can use to turn?"* He kept the broader goal of his project the same (use something to control a motor), but changed the specific type of sensor after his first idea proved more complex than he expected.

Skill-Oriented

Other students defined their initial project goal around a skill or concept they wanted to learn. Jesse (age 14) described exploring different sensors before settling on one project idea. He described, *"I was experimenting with other sensors because I didn't really know what an Arduino was [...] So I guess I wanted to start out a bit simpler, getting the basics done, before transitioning to anything more complex."* This quote illustrates Jesse recognizing a lack of knowledge that prevented him from completing a more complex project. He set a skill-oriented goal in order to later "transition" to a more complex, result-oriented goal.

Another student, Carlos (age 14), explains that he initially chose an idea for his Arduino project because he wanted to *"challenge"* himself. He explains, *"I didn't know what most [lines of code] were, so I wanted to learn [...] I was hoping that I would know what these were by the end, and I know that this is a potentiometer and it controls the brightness of the display. I thought this was really cool."* Here, we see that Carlos sees his project as a means to achieve a goal of deepening his understanding about code and microcontrollers. He used code that he found online to program a game with a joystick, and before too long, he was able to get it working the way he expected. He then spent time adding pieces to his code, making his project more personalized.

Working Through Challenges

Working through an open-ended problem is often very different from the structured problem-solving approaches students experience at school, and much less is known about how young people make sense of complex, self-defined problems. In our analysis, we found that students frequently described challenges they faced throughout the workshops, and we observed that they perceived challenges in different ways. For example, some students described challenges in learning how to use a new tool or software, whereas some others associated challenges with social and emotional experiences. Here, we first briefly discuss some of these categories that emerged from our data, and then we present our findings on different practices that students used to work through these challenging moments.

Interpretation of "challenge"

Translating an Idea. Some students described initiating a project as a challenge, i.e., generating, translating and communicating new ideas about their project. One student, Alex (age 15), reflected, *"we always have an expectation in our heads, so what's always challenging is how to put what we think on the paper. It's very hard for me to express what I think into the project."* Before beginning to work on his design in Tinkercad, Alex described having a very clear idea of what he wanted the final result to look like, but knowing how to realize that vision was *"challenging"*. However, he also mentioned that his favorite moments of the program were right after facilitators introduced a new tool, when he was able to *"think about all the possibilities."* This suggests that, while we see that open-ended projects create challenges for students in thinking of and realizing their own ideas, these challenges can motivate students to further their explorations.

Troubleshooting. Understanding a new system, or as students frequently mentioned, *"getting it to work,"* was often described as a difficult aspect of their projects. During one reflection, Tim described the process of identifying an underlying problem, explaining that it was easy to make mistakes when working with an unfamiliar system because they were not immediately recognizable as mistakes. He explains, *"you have to trace back your steps – I think learning how to do that is really important, but also really hard to teach because you've just gotta make those mistakes and figure out how to do it afterwards."* Tim's comment supports our claim that a loosely-structured program grants students opportunities to practice important problem-solving skills. Many other students described similar processes, recognizing both the frustration they experienced while troubleshooting these problems, and also the importance of going through this process.

Social-Emotional Challenges. Students also described social and emotional challenges – staying motivated, navigating frustration, and working on a team. Anju (age 13), for example, emphasized the importance of keeping a calm emotional state as she worked through a problem with her Arduino. *"Instead of being angry and accidentally breaking the sensor, I tried to stay calm, and at that point I was thinking, 'I have to keep on trying. I have to make this work – I can't just give up.'"* When asked what motivated her to persevere, she said knowing that her classmate was able to get the same sensor to work helped her persist through the challenge. She also mentioned that it was her second attempt at working with a sensor, so there wasn't enough time to start over again. Those two factors, peer support and limited time, *"fueled [her] not to give up."*

Challenging Preconceived Ideas. Other students, rather than focusing on a tool or skill that was challenging, they described how certain ideas or practices challenged their existing way of thinking or doing things. Some of the students described the lack of scaffolding and initial instruction as different from what they experience at school. When learning how to work with a 3D printer, Anju offered this observation – *"[Learning about 3D printers] showed how complex something can be when you don't have a template. In school, usually there's a model for you [...] Here, it's in your hands; you have to be really independent."* Anju described this as a positive challenge – emphasizing that it felt powerful to take control over a computational system. Carlos also described that it was challenging for him to think about creating art using technology. He explained how he normally has control over his hands, but when using technology, he has to *"tell it what to do."* While he thinks that it's easier to make art with your hands, it was a *"cool challenge,"* to think about art in this way.

Practices for Working Through Challenges

Students understood and approached challenges in different ways, and our findings show that students' strategies for working through challenges fall into three main categories. 1) *Researching a Problem:* Many students used online resources to research possible ways to fix technical problems that arose, including youtube videos, help forums, and curated online resources sheets from facilitators. 2) *Troubleshooting:* Many students demonstrated troubleshooting practices, particularly around challenges that arose when trying to work with the physical Arduino system. Students often described this process as "trial and error." 3) *Asking for Help:* Many students worked through challenging problems by asking their peers or facilitators for assistance. Almost all students worked one-on-one with a facilitator at some point during these projects. Before reaching out to facilitators, many students described turning to their peers for help first.

CONCLUSION AND FUTURE WORK

Our preliminary findings of this year's *Innovation Institute* program suggest that when students have the time and freedom to define their own goals and pursue those goals using their own process, they use skill-oriented and results-oriented strategies for framing and pursuing those goals. We believe that this work contributes a growing field-wide understanding of novice designers' problem scoping practices and their nuanced perceptions of challenge. Additionally, we hope that this study can guide other institutions in implementing and researching similar computational making programs. As we move forward into the second semester, turning towards community observations and long-term project building, we plan to implement a participatory design and critical ethnography framing as to better equalize hierarchies of power among students, researchers, and practitioners [2]. By engaging students as co-researchers, we hope that we can more holistically and equitably understand shifts in students' self-efficacy and perception of STEM careers.

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