Exploring Design Trade-offs in Incorporating Making Activities Into High School Science Curriculums

Grace Ann Flanagan-Hall, Northwestern University, graceahall2@gmail.com
Jue Wu, Northwestern University, JueWu2015@u.northwestern.edu
Kinnari Atit, University of California Riverside, kinnari@ucr.edu
Kay E. Ramey, Northwestern University, kayramey@u.northwestern.edu
Mark Vondracek, Evanston Township High School, vondracekm@eths.k12.il.us
Kemi Jona, Northeastern University, k.jona@northeastern.edu
David Uttal, Northwestern University, duttal@northwestern.edu

Abstract: This study seeks to explore design tensions in introducing making activities into high school physics classrooms by examining making in semi-informal settings. Through participation in an after-school program and/or summer internship, high school students used Arduino-compatible hardware and software to develop their own scientific instruments for use in classroom physics laboratories. Here we present findings on students' roles as co-designers and how that influenced their learning and engagement. Furthermore, we discuss issues of accessibility in designing activities in terms of physical and computational affordances. Regardless of prior experience, students were more engaged using pre-assembled robots with defined projects compared with materials and methods traditionally utilized in makerspaces. Additionally, the graphical programming language associated with these robots was more accessible than script-based languages generally used to program Arduinos. This suggests, that to provide equitable access to -- and engagement with -- electronic making, more material and computational scaffolding are required than what is generally provided in conventional makerspaces for implementation in high school classes.

Introduction

Efforts to improve U.S. students' educational outcomes have often focused on improving their engagement, performance, and retention in science, technology, engineering, and mathematics (STEM) disciplines. One way of improving students' STEM outcomes is through 'making' (e.g., Blikstein, 2013). In making, individuals design, build, modify, and/or repurpose objects using electronics, hardware, and tools. Advocates of making suggest that it is a powerful way to promote learning as students seek out STEM knowledge (e.g., Barton, Tan, & Greenberg, 2016). Making engages students in science and engineering practices (Koh & Abbas, 2015) and supports development of 21st century skills, such as problem-solving and critical thinking, which are essential for success in STEM fields (Martin, 2015). Making has also been suggested as an avenue to breaking down barriers of learning and attainment in STEM. "Anyone can make…anyone can change the world" (Hatch, 2014, p.14).

Although makerspaces are now common in a variety of informal and out-of-school contexts, there is little evidence that the maker movement has been successful in involving a diverse audience. These activities continue to be dominated by white men who have resources to invest in technology and materials (e.g. TASCHA, 2012). Likewise, many out-of-school makerspaces present barriers to entry (Lewis, 2015), such as a lack of computing experience (e.g., AAUW, 2000), the vague purpose of these venues, and the absence of a clear goal (Lewis, 2015). One way to mitigate these barriers is to move making activities into the regular school day, where they can be made accessible to all students. Yet, moving making from informal into formal high school settings presents significant challenges of its own, such as the pressure to align activities with curricular standards, to assess learning outcomes, and to work within time constraints imposed in schools.

In this study, we examine the feasibility and challenges associated with introducing making activities into high school physics classes through extracurricular activities. Using methodological principles of design-based research (DBR; Design-based Research Collective, 2003), we explore ways to bridge the divide between the playful exploration of informal making activities and the structure of traditional schooling, all while providing students with exposure to tools and skills relevant for success in STEM careers. We asked high school students and a physics teacher to act as co-designers and design a set of making activities to be adopted within a typical high school physics curriculum. Specifically, students were given an open-ended charge to explore ways to use Arduino-based hardware and software to design and program scientific instruments that could be used by other students to collect data and test scientific concepts during physics laboratory experiments (after Resnick, Berg, & Eisenberg, 2000). Our goal is to explore the design tensions in introducing making activities into high school physics classrooms and understand the implications for student engagement and learning, ultimately providing insights for others who seek to bridge the informal-formal divide.

Methods

Phase one: After-school “Arduino Club”

Seven eleventh and twelfth-grade boys participated in the “Arduino Club” after-school program. The program met for one hour, once a week, for one school year. Students were recruited for the club by our partner teacher from his advanced level physics class. The group consisted of one Hispanic student, one Asian student, and five Caucasian students. All had prior computer programming experience, but only one student was familiar with Arduino programming language.

The aim of the program was to design scientific instruments using an Arduino micro-controller and various sensors. To examine what kinds of hardware and software were best suited for this purpose, students attempted to design instruments using different equipment in two separate iterations. The first iteration included the following equipment: *Arduino Starter Kit*, *Elego UNO Project Super Starter Kit*, and *Kuman Project Complete Starter Kit.* These kits contained a few pre-planned activities users could actualize using the Arduino. Pre-written, editable script in the Arduino programming language was also provided. The second iteration equipment was from *Makeblock*. *Makeblock* produces Arduino-based, programmable, robotic equipment for kindergarten through high school students (see Figure 1). Kits provide instructions on how to build specified robots that collect data and carry out tasks using different sensors (e.g., a motion sensor, an accelerometer). Robots and sensors are programmed using *mBlock* software, a graphical programming medium modeled off Scratch 2.0 (MIT) (see Figure 1).

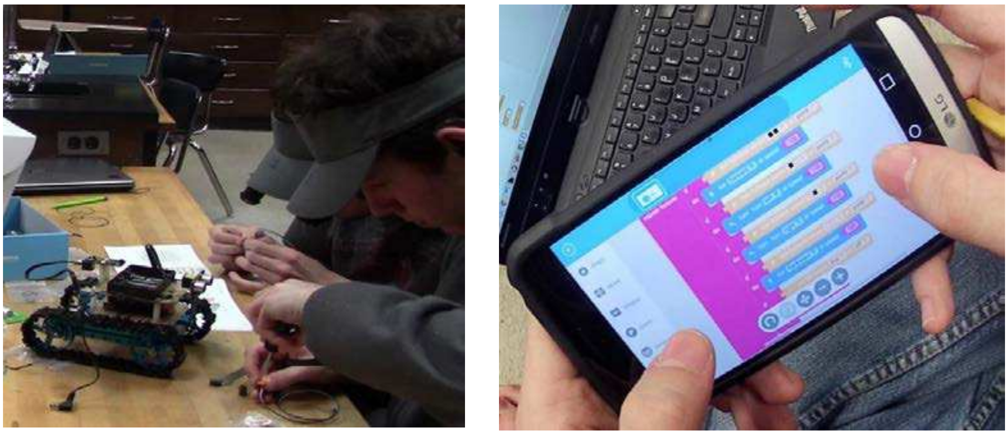

Figure 1. Students in the after-school club work first with Arduino kits (left) then later with Makeblock kits (right).

To examine the process and challenges associated with designing the instruments, data was collected using both “visor cameras” (see Figure 1) and a stationary video camera. The visor cameras (small cameras attached to the brim of a tennis visor) captured point-of-view audio and video from each student. The stationary camera captured interactions across the entire group. Additionally, researchers took ethnographic field notes focusing on students’ use of the technology, problems encountered, and supports or scaffolds utilized to address those problems. Furthermore, background questionnaires and researcher interviews were completed to understand students’ prior technological experience and their interest and engagement with regards to the assigned materials and tasks.

Phase two: Summer internship

During the subsequent summer, six high school students participated in a forty-hour internship. Students were recruited for the internship using an application process developed by our partner teacher. Participants were selected to try and replicate the demographics and skill level of a regular high school class. Student interest, prior technological experience, and their availability to attend the internship were also considered during the selection process. As a result, participants included two girls and four boys. Of those, two students were Black and four were White. The girls had no prior programming experience, while all four boys reported some experience.

Students were divided into two tri-stratified groups based on prior programming experience. Each group was composed of one student with no prior experience (i.e., novice), one student with some programming experience (i.e., intermediate), and one student familiar with Arduino programming language (i.e., advanced). Working with the partner teacher, students were asked to create physics labs (and write associated lesson plans) that utilized *Makeblock* robots and add-on sensors (e.g., light and gas sensors). Researchers used identical methods as in Phase One to collect data.

Findings

Using the iterative principles of DBR, we examined whether the open-ended Arduino equipment or the *Makeblock* robotic equipment would provide the most amenable hardware and software for designing scientific instruments to be used in high school science classes. Our observations through the after-school club revealed that open-ended and unstructured equipment traditionally incorporated in making activities were too difficult for students to learn to use within time constraints of one-hour blocks. In line with traditional makerspaces, students were provided no guidance on how to use the equipment to design their scientific instruments. The lack of structure in the activities resulted in students not knowing how to proceed with the tasks using hardware and software at hand. For example, one student said, "I don't have much I can do until I go home and can read about the sensor [in the manual]," indicating the student needed more time to understand the materials than what was provided. Furthermore, students struggled to use the script Arduino programing language, saying things like, "I'm learning C++...Alright I don't know what's going on."

Due to a lack of structure in activities and challenges associated with using script coding, we observed that student interest in working with open-ended equipment waned. Throughout the year, five out of six students ceased to attend "Arduino Club" until *Makeblock* robots were introduced. Once this new equipment was utilized, the same students, who had expressed frustration while using the previous equipment stated, "Now we actually get to do stuff." This reaction suggests students felt they faced a functional block when working with fully open-ended equipment.

After observing challenges associated with the open-ended Arduino equipment, we focused on finding equipment that was more accessible and engaging to students. Thus, we tried *Makeblock* robotic equipment because of the scaffolding their graphical programming interface provides and the novelty and excitement generated from working with and building robots (e.g., Khanlari, 2013). Also, because these kits had more explicit instructions on how to use hardware to carry out specific tasks, we suspected that this would help students focus on how to use sensors and robots to design experiments relevant to high school physics, rather than spending their time understanding the utility of the equipment. When *Makeblock* robotic kits were introduced to "Arduino Club", students expressed greater enthusiasm for working with these kits than for the open-ended equipment. One of our advanced level participants was even inspired by *Makeblock* equipment to create a novel instrument using additional materials from Phase 1.

The mBot graphical programming language used to program *Makeblock* robots made designing with Arduinos accessible to students with all levels of programming experience. This accessibility was demonstrated through the summer internship, as one of our novice students stated, "I think being a beginner [block-based coding] was better, because you could see the flow of things, and everything had a color, and you could input it." Students with little to no exposure to computation were able to create code that programmed robots to collect specific data using sensors. For example, one physics lab the summer internship students created, called "Jakob's Mega Murder Mystery," used the concept of evaporation, a *Makeblock* robot, and a gas sensor to determine how an imaginary individual "Jakob" died. A novice student who had an avid interest in forensics connected that interest with the sensors and code to formulate this creative and engaging lab.

Additionally, we documented that robots were exciting for both genders, regardless of prior knowledge. One of the girls in the summer internship stated, "I think just being able to feel confident um or having seen something outside of what [I'm] normally doing helped me think about it in a different way. So I think having robots would have been incredibly beneficial…I think [it] would have shown me a world where you can apply this." Our partner teacher also noted that robots could be more engaging for students than the traditional labs. "Robots are cool and throughout the school year we had that after school thing…the whole robot notion, it just grabbed their attention…not everyone [will be interested] but I think it's more interesting to try than just using a stopwatch and a meter stick." This indicated that even advanced students, with a great deal of prior knowledge were engaged.

Moreover, allowing students to formulate their own lesson plans, as co-designers, led to an increased sense of agency and ownership of their own and their peers' learning. Allowing students to be experts on creating lessons that they could learn from led to them to think about the conceptual hurdles in learning new physics concepts and the technological tools used to investigate those concepts. For example, one student reflected on how important it was to her to ensure the activities she was designing were accessible to students with little programming knowledge, "If you're good at coding it's like riding a bike and once you learn how to ride a bike … you don't forget how to ride a bike, so you forget what it's like learning how to ride a bike. Or the trivial things to you are not trivial to someone else…They [coding learners] literally need the step by step to see it happen..."

Finally, mixed-experience groupings and collaborative work were important scaffolds for students when it came to programming the technology. When asked how students worked together within their groups, one student, who had no prior computer programming experience stated, "I think we worked really well together. It was nice having like, uh someone who knows a lot about [computer programming] and someone who's in the middle. Um so it was helpful letting us learn from them and it was nice having a group with different levels and we all came together with our own ideas and stuff." Our second novice student added that, "They [my other group members] explained it really well to me, which is hard to do." This indicated that intentionally grouping students with a range of prior knowledge provided all participants with the benefits of *relative expertise* documented by Penney, et al (2016). Our partner teacher noted the relative expertise served as an effective group scaffold, "[a novice student was] curious and able to bombard them [her group members] with the questions that she had and that's how she got what she needed…for someone who is new to this, to be able to talk it through, is very vital." In summation, using robotic kits, the associated sensors, and the mBlock programming language, students in the summer internship successfully created seven lesson plans covering topics including momentum, friction, acceleration, velocity, ultrasound, and electromagnetic radiation. The defined projects and kit constraints provided students with the structure necessary to deduce how to use the hardware and software available to create lesson plans, while implementing basic coding that would be accessible to all students in a high school physics classroom.

Conclusions and implications

Overall, our findings indicate a path forward for moving making activities into the regular school day, as part of required science classes, and demonstrate many potential advantages in doing so. Through a design-based research process, engaging students and our partner teacher as co-designers, we discovered activities and equipment that are not only interesting and engaging to students, but also fit within constraints of a high school curriculum. These activities simultaneously exposed students to sets of tools and activities (designing instruments to investigate scientific queries) that are more authentic to practices of professional scientists than labs typically done in science classes (Chinn & Malhotra, 2002).

The findings also challenge some assumptions of the maker movement and suggest important directions for future work. For example, despite arguments for a democratizing impact of making, our inability to recruit girls for the after-school club and the small number of girl applicants for the summer internship adds to the growing body of evidence suggesting that informal making contexts may not be perceived to be appealing and/or welcoming places for women. Furthermore, in contrast to open-ended, unstructured, activities advocated by many making enthusiasts, we found that some amount of structure and scaffolding is optimal, particularly for students who have less experience with relevant skills and materials. These findings suggest that it is not only possible to move making activities into high school science classrooms without destroying their benefits for learning and engagement, but that doing so (and doing so in ways that layer structure and scaffolding into the experience) may have democratizing effects that making experiences offered solely in informal spaces do not. Our research also demonstrates benefits of engaging students and teachers as co-designers in the DBR process to design activities that balance student interest and engagement with constraints inherent in moving making into schools.

Selected References

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