Developing Digital Fabrication Culture Through Big Scale Collaborative Projects

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ABSTRACT

In this paper, we describe an innovative approach to incorporating digital fabrication and hands-on learning into a low-income, culturally diverse school's culture and curriculum. Beam Center, an expanded learning opportunity program (ELO), worked closely with the students and classroom teachers of Brooklyn International High School to construct two distinct big-scale collaborative, multidisciplinary projects that reinforced academic subjects as well as taught technical skills to the students. Drawing on interviews from students' and teachers' experiences, we argue that big-scale collaborative projects (BCP) co-designed by creative practitioners from the ELO and educators from the school community serve as a "low-floor, high-ceiling" entry point for learners, teachers and school administrators. Additionally, we suggest that BCP are ideal for re-imagining the educational status quo, particularly in STEM education, and presents a method to serve better the educational needs of low-income and recent immigrant students. We share lessons learned in the partnership development between the Beam Center and Brooklyn International High School and its impact on the students, teachers and administrators.

Keywords

project-based learning, digital fabrication, astronomy, English, STEM, expanded learning opportunity (ELO) program, art, big-scale projects

1. Introduction

From the Next Generation Science Standards (NGSS) to the White House Maker Faire, there are broad calls for educational approaches that teach engineering and design while fostering creativity and inventiveness [1, 2].

Even though the power of the Maker revolution is to democratize invention and give everyone the tools to change the world [3], the movement has been criticized for focusing on a "white male nerd" population [4]. Leah Buechley in her keynote at the 2013 Stanford FabLearn Conference on digital fabrication in education pointed out that 85% of the covers of the leading makers' magazine, MAKE, featured white boys and men and no African American subjects had yet been featured [5].

Nonetheless, some programs are designed with the intent to create a more inclusive experience. It is important to identify and understand them and recognize how they can inform more equitable digital fabrication education and practices. Arts and aesthetics can be a reference point to engage and excite students from underserved populations in STEM+C projects [10, 11]. The inclusion of aesthetics plays a crucial role not just in initial engagement but also in how deeply invested and motivated students are to learn multi-step projects and complete complicated tasks over time [6]. One example is the Exploratorium After-School Tinkering Program that successfully serves predominantly African American, Latino/a and Asian American youth from populations with restricted access to education and economic growth [12].

In this paper, we describe Beam Center's implementation of two big-scale collaborative projects (BCP) with the students and teachers of the Brooklyn International High School (BIHS). BeamWorks is a program of Beam Center that serves public high schools with predominantly low-income, minority and recent immigrant populations in New York City.

2. Design Choices for Equity-Oriented Teaching and Learning

The activities that we present, Poetry Machine and Personal Planetarium, were designed with the goal of widening the definitions of learning, science, art, design and intelligence. They support imagination, creativity and play in a learning environment that promotes collaboration and links the program to a social endeavor. Both activities involve a range of different disciplines and experts, and purposefully integrate diverse tools, materials, methodologies and media with the goal of promoting reexamination of students' conception of the same phenomenon [7, 8]. These principles have been considered to promote equity in teaching and learning [12].

In the context of teaching a newly immigrant population, English language learners (ELL) often require multiple ways to externalize and communicate their processes and thoughts. Engaging in project-based learning can help these students to overcome the moments of struggle that are essential to exploration, experimentation and learning. These activities were designed to create a safe-space where students have an object to point to — “an artifact that may be rickety or lopsided, but yet has resolved the problem that so puzzled the learner” [9]. This process of becoming stuck and then ‘unstuck’ is an opportunity for teachers and facilitators to offer suggestions in terms of student’s ideas and goals with the focus of expressing project complexity in students’ own terms. Blikstein (2013) suggests that these environments can provide “visceral design experiences and new levels of frustration and excitement, which students normally do not get to experience in school,” helping students to conceive failure as a productive activity and support the exploratory mind of the students [3].

These BCP activities had an essential community component that served to leverage the skills of each student towards a common goal. The contribution of their design to a larger collective project allowed for individual artifacts to expand in meaning. The large-scale project generated opportunities for students to learn to work together, share tools and ideas, provide peer assistance and embrace their intellectual diversity. Students claimed new roles as leaders and teachers as the project activities unfolded. This dynamic also served to create connections among community members (teachers included) while increasing student motivation and engagement in the activity as a shared goal.

3. Implementation

Beam Center is a community of learning and discovery for young people from 2nd grade through high school, based in Brooklyn, NY. Guided by artists and makers with experience in technology, imagination and craft, young people develop practical skills, character, courage to think for themselves, and capacity for collaboration and invention while engaging in Beam Center activities. BeamWorks is a program of Beam Center that serves students from public high schools with predominantly low-income, minority and recent immigrant populations. Our programs can be conducted in-school or out-of-school and involve varying levels of collaboration with classroom teachers. BeamWorks uses big-scale collaborative projects (BCP) as the centerpiece of their hands-on learning interventions. The projects are crafted to fit and serve the population of students involved, and whenever possible, are designed in collaboration with classroom teachers or school administrators. Since 2012, Beam Center has worked with Brooklyn International High School on several BCP initiatives. Brooklyn International High School serves an immigrant population (100% free-lunch and 100% English Language Learners) with restricted access to educational and economic opportunities.

This paper will describe two projects that staff from Beam Center and students from Brooklyn International High School (BIHS) worked on together in the spring of the 2015 school year: Poetry Machine and Personal Planetarium.

Poetry Machine is an activity co-designed by Mark Kleback, a creative practitioner at Beam Center with experience in interactive electrical engineering, and two BIHS teachers: John Derian, a Physics science teacher, and Ben Walsh, an English teacher. The activity consisted of the creation of an interactive 4 feet by 8 feet board that read magnetically attached laser-cut words and tweeted the overall content on the board through an Arduino microcontroller. Most of the activity took place inside BIHS during English and Physics classes, but students also traveled to Beam Center to use the laser cutter during school hours. The BIHS teachers generated the original concept and aligned it with curriculum standards. Beam staff worked with them collaboratively on how to execute the idea technically as well as how to engage several sections of students throughout the school day and over the 6-week period of the project. The students worked with Beam staff to build the BCP and the students generated the actual language content—the words—that created the overall meaning and output from the Poetry Machine.

During the Poetry Machine activity, students analyzed poems in their English class and, based on those readings, chose a list of words used to create their own poems. Those words became artifacts as they were designed in Inkscape, laser-cut and painted by the students. Students then learned about electricity and electromagnetism. The students learned how to design words and laser-cut them from corkboard. They learned how to program an Arduino to write words into EEPROM chips, and subsequently used an Arduino to read multiple chips in order to form a poem. They learned how to use the Twitter API to post tweets, and how to interface the Arduino to this API using Python. They fabricated a board to display the poetry, and used magnets to connect the words to the board so the Arduino could read them. The poem could be tweeted by pressing a button if the student wished. The final Poetry Machine was installed in a BIHS hallway for other students and passersby to see.

Figure 1: Poetry Machine at Brooklyn International High School

Beam staff worked with 90 students overall, in the classroom 2 days per week for 4 hours per day for 6 weeks. This was the first big-scale project for either BIHS teacher, but they had experience doing small team projects using digital fabrication with and without Beam Center.

Personal Planetarium is a BCP activity designed by Heather Kramer (teacher and professional development trainer with expertise in astronomy learning activities), Brett Van Aalsburg (professional welder and sculptor) and Mark Kleback (see previous activity). The activity was part of the Beam Youth Leadership & Learning program which had three overall goals: 1) the creation of the BCP, a 11 ft high x 8ft diameter geodesic dome-shaped planetarium, constructed from welded steel and covered by black textile, and with Arduino-controlled fiber optics, 2) teaching an astronomy curriculum as an academic subject to the high school students, and 3) instructing the teens about how to facilitate project-based learning activities with younger children. For 15 weeks, 12 participants went to Beam Center for 3 hours every day of the week (15 or more hours a week). Working with Beam staff, primarily out-of-school at Beam Center, the students created the geodesic dome, learned 8 art-based science projects focused on different aspects of astronomy, and also learned skills of public presentation, small group management and teamwork. Their experience included a visit to the Rose Planetarium at American Museum of Natural History and a sky-gazing trip to Floyd Bennett field with the Amateur Astronomers Association of New York.

Figure 2: Personal Planetarium with BeamWorks teens at Beam Center

After completing the Personal Planetarium activities, the teens had the experience of publicly presenting the geodesic dome and teaching the astronomy projects to young children (grades K-5) at a local public school STEAM fair in May 2015. Some teens were engaged as summer counselors in local day camp programs where they could continue to use their experience.

4. Preliminary Analysis of Interviews

We present insights from a preliminary analysis of eight participants, two teacher interviews and Beam Center personnel. We cluster the insights into four categories: big-scale collaboration, academic connections (English comprehension and/or STEM concepts), technology perception, and social endeavor.

Big-Scale Collaboration. Students expressed pride in the fact that they participated in creating something they couldn't have done by themselves or even in small teams. There is learning embedded in the process of building the BCP that is related to the unique aspects of the project itself (i.e., building a geodesic dome) but also connected to the experience of working in a large team. Students commented: "We did something that I never dreamt about doing," "People didn't know how we did it," "No one has done this before" and "This requires so many people that no one can do it by themselves." There was also a sense of ownership of the BCP, as teachers observed, "They [the students] can do something that can be a showcase outside school and shows their work. They can go and present it, and they really like that." For students, pride, ownership and "belonging" to a project transcended the physical possession of the object. This can be especially engaging since the creation of a BCP object is beyond one person's reach. The end result of the project is only possible when a large group of students work together. Students also expressed pride in learning how to collaborate with such big groups. Comments included: "We have many more good ideas that we don't have in small teams," "I know better how to work with people I don't know" and "What you need to do is to give people and ideas a try because each one has a different experience." Collaborative big-scale projects get students out of their team dynamic "comfort zone" and push them to be open to a wider range of ideas and work methodologies. Finally, students were more aware of the professional processes of building big-scale projects. A teacher noted, "They learn that debugging is not just a thing for software but also in hardware." Students also recognized this: "The inspiration for the project is very important," "First you need to design and figure out the prototype," "Prototypes are models" and "Otherwise, you are going to make a big mistake that you don't know about. But if you build it [the prototype], you'll know how to fix it."

Academic connections: English comprehension. BIHS serves an exclusively new immigrant, English-language-learners from international populations; therefore activities that promote using English are very important. We were especially interested in how the poetry machine would promote language use and discovery. During the interviews, students commented about the process in which they decided which words to fabricate. They analyzed a large number of poems and grouped the words depending on their frequency of appearance. Student comments "I know which are the most common words, I should learn those words," "Every poem is about what you love" and "I want to know which words I can use instead so I don't have to repeat so much" reflect their deeper thinking about the words. One student's statement "choosing the words was very important, because it was a lot of work to build them" shows how digital fabrication provides a different framework in which students can internalize language in a useful way. Ben Walsh, their English teacher said "They [students] start seeing language as something almost mathematical" and "Students valued a word as physical object, in a way they never did before because it requires so much effort to create each one."

Academic connections: STEM concepts. During the interviews with students from the Personal Planetarium project, the students showed a very good understanding of astronomy mechanisms like moon phases, ocean ties, cosmological dimensions, the life of stars and many more astronomy concepts. There is not enough space in this paper to describe them in detail. Another paper is also needed to adequately explain the specific skills in digital and general fabrication the students gained. Some examples of specific skills are: leading educational activities with younger children, sewing, welding, soldering, programing Arduinos, laser cutting, and woodworking. STEM concepts that were introduced or reinforced in the activities included assessing structural strength, principles of electromagnetism, application programming interfaces (API), and use of fiber optics.

Technology perception. The digital technology used in these projects was integrated in ways that are not typically seen in school settings. The intention of this design was to expand the conception of engineering and technology for the students. Comments by students "I didn't like technology but now I know it can be applied to art and art to our lives," "Technology can help to represent things, like stars," "I know how a battery car works now" and "You can use technology to connect to technology" show how they understood in a new way how technology was integrated into their lives. The BCPs are less about technology itself being the focus, and more about what technology can be used for. These BCP activities show technology can be used in new, surprising and creative ways, which spark learning and engagement.

Social Endeavor. The last cluster of insights from students' comments reflected on the relationship between the projects and social activities that were connected to them. The social experiences embedded in the ELO program expanded the students' roles and views of themselves in social contexts. Comments like "It was hard but now I like kids," "I'd like to work with kids because one day I'm going to be a father and I need to know to be with them" and "Kids are fun; I might as well have fun with them" are examples of how student perceptions of working with children changed over the program. Another set of student comments was related to showing their work to the public. "My favorite part was to communicate what we did," "I liked to write the blog post" and "People didn't know how we did it" are some examples of how the presentation of the project work expanded and deepened the aggregate meaning of the program for the students.

5. Lessons Learned

Both collaborative projects had benefits for students, but the process and individual results were very different for the in-school and out-of-school programs. The in-school program (Poetry Machine) was co-designed by BIHS classroom teachers, which led to an overall higher level of excitement and engagement for the classroom teacher. Many more students could be involved, though each student's contribution to the overall project was smaller and there was less room for deviation and "tinkering." The out-of-school project (Personal Planetarium) allowed for a smaller number of students to have a more immersive experience and a deeper relationship with Beam staff, including the ability to use a wider range of tools, experience greater skill-building techniques and have more room for individual collaboration and design re-iteration.

The current collaborative relationship of Beam Center and BIHS is the result of three years of working together, which started with smaller scale projects. This long-term relationship has created a sense of trust and a willingness of educators to let "crazy stuff" happen in the classroom. Communication among the classroom teachers and Beam staff was also a critical element to success.

6. CONCLUSION

Big-scale Collaborative Projects that involve teachers, students and professional makers can provide a supportive environment for bringing digital fabrication into educational settings. Aspects of these projects, such as the flexible of work flow, approachable project design, and the high-quality expertise and finishing skills that professional makers contribute are aligned with improving equity in these environments.

BCP also help to teach a big range of general and digital fabrication skills. The long-term engagement with students in terms of time and duration (ranging from 6 to 15 weeks, and 60 to 225 hours in total) gave participants enough time and practice to master the use of tools. This can be especially useful for beginner participants; they can gain technological skills while experiencing the possibilities that technology can create. Projects co-designed by professional makers provide a workflow framework, real-life uses of technology and domain areas, professional know-how and real-project aesthetics. In the case of the Poetry Machine, students were able to build the large-scale project without having to worry about the prototype design phase.

When designed with specific learning goals in mind, BCP can provide organic opportunities to connect students' creative ideas to subject domains, like English or Astronomy. BCP can link art and technology to expand the notions of science, engineering and technology and provide a different example of their applications than those typically provided in formal education at schools. These elements serve, directly and indirectly, to promote diversity and equity in schools. By opening up possibilities and engaging students who typically do not have the resources to participate in creative, technology-based projects, it expands minds and opens door for opportunity and continued learning.

The level of teacher or administrator engagement on the overall effect of school culture change is a question that requires further investigation.

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