Growing Designs with biomakerlab in High School Classrooms

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Abstract
We report on the development and implementation of biomakerlab, a wetlab starter kit for synthetic biology activities in K-12. In synthetic biology, participants make their own DNA—gene by gene—and then grow their designs into real applications by inserting them into microorganisms to develop different traits and characteristics provided by the genes. High school students worked with biomakerlab to make logo designs using microorganisms they manipulated to produce differently colored pigments. Our analysis focuses on student engagement with production activities and design challenges in biomaking. In the discussion, we address differences and overlaps between traditional maker activities and biomaker activities for education.

Author Keywords
Biology design, fabrication device, high school.

ACM Classification Keywords
H.5.m: Information interfaces and presentation (e.g., HCI); Miscellaneous.

Introduction
Most current efforts to broaden access to K–12 maker practices have focused on developing fabrication activities and tools such as 3D printers, laser cutters, and other digital and traditional tools [13, 14]. Far

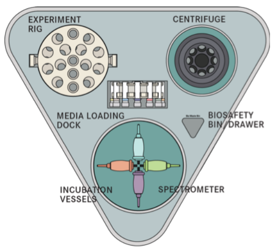

Figure 1: Design of biomakerlab

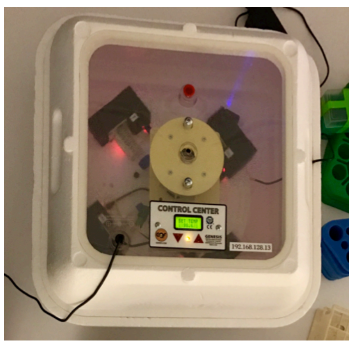

Figure 2: Prototype of biomakerlab

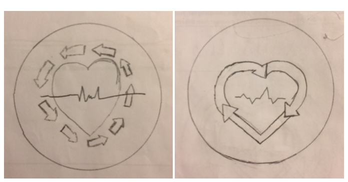
Figure 3: Two Iterations of a Student-Designed Logo for a Company Called "Blue Heart"

fewer efforts have focused on developing wet labs for equally important synthetic biology activities, where makers can manipulate organisms for creative applications. In synthetic biology, participants can engineer DNA—gene by gene—and then grow their designs into real applications by inserting them into microorganisms to develop different traits and characteristics. In this paper, we report on the design and recent implementation of a wetlab fabrication tool to promote bio design activities [20] in a high school classroom. Here, students worked on creating original logo designs that used pigment made from genetically transformed bacteria. Our analyses and discussion focused on students' engagement and experiences with this new type of maker activity.

Background

Paralleling the maker do-it-yourself (DIY) movement, the last decade has seen a steady growth in maker bioengineering, also called synthetic biology, garage biology, or bioDIY [7]. So far, these activities have been accessible and affordable only to university students and professionals at research universities [4, 17, 18], in undergraduate student competitions like IGEM [10] or at workshops at community biolabs [5].

Most efforts in K-12 education have concentrated on capturing students' understanding of and attitudes toward biotechnology [e.g., 2], such as their willingness to manipulate animal or human life. More recent work has started to develop educational activities appropriate for K-12 students. These include efforts to engage the public with synthetic biology issues in science centers [11], and designing interfaces for museum exhibits [16]. Curriculum design efforts with BioBuilder have adapted undergraduate activities for high school classrooms [8] while others have focused on developing analysis tool kits such as Bento Lab [1] and Amino Labs [9].

In promoting synthetic biology as a K-12 maker activity, we needed to address not only the design of a wetlab fabrication tool but also accompanying classroom activities and implementation. The facilities of university or professional contexts are appropriate for addressing wetlab setup and safety concerns. However many high schools, especially those serving underrepresented students, do not have such capacities. Our first goal was thus to adapt a professional fabrication tool called Biorealize [19] for use in high school classrooms by building what we call biomakerlab, a device that functions as an automated and self-contained wetlab.

The second goal was the development of curriculum activities to situate the use of biomakerlab. Here we drew on lab procedures developed by Kuldell and colleagues [8] in which specially engineered DNA are used to transform bacteria for production of differently colored pigments. We contextualized this activity, following a constructionist pedagogy [12], by having students create a real world design application for these synthetically created pigments. Unlike previous efforts that involve providing analysis tools to students (Amino or Bento) or those which primarily focus on lab procedures for building synthetic biology systems [8], our approach centers on having students learn about synthetic biology through a design application. This mirrors previous successful tactics in computer science education that situate the learning of computational concepts and practices in the context of designing real world software applications such as games [6].


Figure 4: Lab Materials

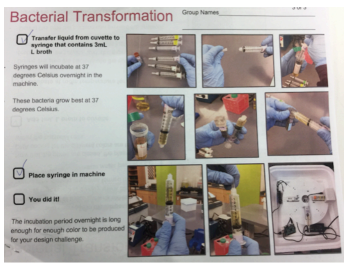

Figure 5: Lab Protocol Checklist


Figure 6: Students Placing Bacteria Cultures into the biomakerlab Machine

Participants, Tools and Activities

In January 2017, we conducted our synthetic biology design activities with two STEM elective classes for high school juniors (27 students) and seniors (22 students) at a charter school in a northeastern metropolitan city. Student demographics mirrored the school with 44% African American, 35% Caucasian, 13% Hispanic, 3% Asian, and 3% Multiracial students. The participating teacher, a trained biologist, is also the STEM coordinator of the school. The classroom teacher arranged groups of 2-4 students each.

The fabrication tool, called biomakerlab (Figure 1), contains a transformation module that includes a rotating incubator, a spectrophotometer, capsules that allow for cell distribution, and a media input/output outlet to supply media, nutrients, and other substances. For our study, we provided students with a prototype that included all the features except for the media input/output outlet (Figure 2).

Together with the classroom teacher, we developed a curriculum unit focused on sustainable manufacturing and design, which took place over four 90-minute class periods. Each group created a logo using biologically-produced pigment for a student-proposed company focused on sustainable design. Groups were assigned a particular color (based on the pigments produced) and industry (e.g., fashion, athletics, health) and asked to decide upon a sustainably manufactured product based on these specifications (e.g., sneakers made from recycled materials). Teams were then asked to come up with an accompanying company name and logo (see Figure 3).

For the design of the logo, groups engaged in the process of transforming existing bacteria (E.coli) with pre-designed plasmids (circular DNA for bacteria) to create different colored pigments (green, black, purple, or blue). This procedure involved use of the biomakerlab to incubate their transformed bacteria (Figures 4, 5, and 6). After producing the pigments, groups developed three physical versions of their logo. Two were 2D forms involving 'painting' with the transformed bacteria, one directly on nutrient agar in a petri dish, and another on filter paper placed on top of the agar (Figures 7 and 8). The third was a 3D logo that used sodium alginate, a compound that is regularly used in cooking (specifically 'molecular gastronomy'). Here, the alginate is used to encapsulate the transformed bacteria into raised shapes that were formed into the logos through the use of hot glue gun outlines (Figures 9 and 10).

In addition to photo documentation of the class and group work, we wrote field notes for each day. We also conducted focus groups with four randomly selected teams asking about their experience with the design challenge and lab procedures. We collected student worksheets focused on their company and logo design.

Findings

Here, we report on how students experienced agency in biomaking activities, their challenges realizing the physical logo designs, and the integration of wetlab making into a science classroom.

Student Agency in Bio Making – One of the key challenges of the project was to shift students' perception of learning about biology from a traditional science inquiry to a design or maker activity. Many

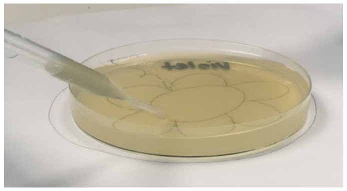

Figure 7: 'Painting' with Bacteria

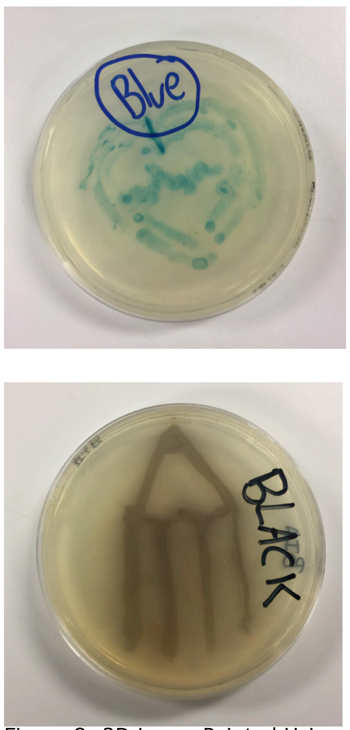

Figure 8: 2D Logos Painted Using Bacterial Pigment

students reflected on how having a constrained but open project allowed them to express their own ideas and creativity. Kristine[1] stated: "I feel like we did what we wanted to do. I mean, we had guidelines, but it was our ideas that went into the project." Dino added: "I liked how we had freedom for whatever we wanted to come up with for our logo and our name, and the way we wanted to draw—it was pretty cool." This was further aided by the fact that some students felt personal connections to their assigned contexts, as James described: "We got sports and athletics, [and since] me and [my teammate] were involved in sports and athletics… we have more a connection to it." Thus, because they were able to bring in their own voice into the process, these students started to perceive biology as a context for personal making and creation.

Student Challenges with Bio Making – In designing their logos, there were three main areas of difficulty that students faced. First, students spoke about their challenges with the actual construction tools. Cyra described using the hot glue gun in her design: "My arms started to hurt after… we had to practice on top of the petri dish… I kept messing up." James further described how this limited his logo design: "the glue kept like spreading out… so it was a bit harder to keep it detailed to like the same level [as] the logo that was drawn." From this perspective, dealing with the maker tools limited how well students thought they could express themselves through this activity.

The second challenge students described was the difficulty of dealing with the bacterial pigment. As Dino explained: "Tracing over the bacteria [on the petri dish] ... was kind of difficult, because it didn't really feel like I was doing anything [while] applying it." Unlike dealing with 'traditional' mechanical or electrical maker activities then, students described the lack tangible feedback when dealing with these microorganisms and their products. Not only were these materials initially invisible to the human eye, but also required days to grow and yield a tangible output (the pigments).

A third obstacle students faced was not having time to iterate on their designs within the confines of the unit. In describing the outcome of her logo, Cyra stated: "My plate didn't turn out the way I expected it to. It's not green, I can't really see the design, and… it's disappointing… But I'm interested in finding out what I did wrong and why what happened happened and how I can fix it." Because of the time it took to grow the bacteria and see the outcome, some students missed the opportunity to engage further with their design.

Integrating Bio Making into STEM – Creating a link between biology, making, and design allowed students to broaden their understanding of these three disciplines. As Laila noted, "We had to learn how to incorporate engineering and design in biology…Instead of strictly learning about one thing, you get to learn how to incorporate different other aspects that make it greater, better." As the students described, this interest in combining fields was helped by contextualizing it in issues of sustainability. Cyra stated: "We started [the unit by learning] where dyes come from and the chemical waste that comes from dyes… now I know that... it's affecting the world as a whole and that's not good." Understanding this further motivated Cyra to think about potential biological solutions: "It personally makes more passionate about using bacteria to create

[1] All these names are pseudonyms to preserve confidentiality.

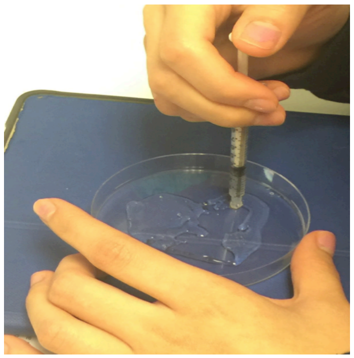

Figure 9. Using Sodium Alginate for Bacteria Encapsulation

Figure 10. Creating a Glue Gun Outline for Logo

dye rather than chemicals… We've always perceived bacteria as something negative [but] … for us to use it in a way that would benefit us is interesting." Thus, by contextualizing the design within an existing world problem and providing tools to solve this issue using synthetic biology, students were more interested in learning about the possibilities of biomaking and design.

Discussion

While much attention has focused on bringing various maker activities into K-12 classrooms [13, 14], few of these efforts have included biology activities. In making or designing with biology, students can use cells as fabrication units to grow or "make" desired colors, smell or materials for their applications. Our pilot implementation with the biomakerlab illustrated some of the opportunities and challenges in biomaking with high school students. In the following sections, we situate biomaking in the larger landscape of making.

On the surface biomaking is very unlike 'traditional' making activities that involve electrical, digital, or mechanical systems. Whereas the latter often involves interactions with everyday tools or materials (e.g., batteries, lights), biomaking is a less recognizable practice. It involves materials and tools that are present in students' regular science classes, but in service of new fabrication process that are simultaneously abstract (since they are less visible) and unfamiliar as compared with traditional science labs. Additionally, students have to shift in their approach from science *as inquiry*, in which they observe and study the natural environment, to science *as design* where they use their knowledge of cells to produce new and desired outcomes. This approach to science as design is an epistemological shift that is unfamiliar in concept and in practice to most students in K-12.

However, what biomaking has in common with traditional making is the idea of turning students into producers rather than consumers of applications. These parallels have also been observed in other maker-like activities such as writing and coding that engage students in producing text or software [15]. Our approach to synthetic biology as biomaking is not only a step into the future where we engage students with making or 'growing' their designs in the lab but also a link to the past in which students were first invited to making or 'coding' their designs on computer screen. More than three decades ago, Papert [12] provided tools such as the turtle as an "object-to-think-with" and pedagogy to turn children into producers of code. In biomaking we are now facing the challenges to create connections for these new design activities. Our pilot implementation with biomakerlab was a first step into mapping out this new territory.

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