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DIYbio Things

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<https://escholarship.org/uc/item/90h1s0hf>

ISBN

9781450331456

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Publication Date

2015-04-18

DOI

10.1145/2702123.2702235

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DIYbio *Things*: Open Source Biology Tools as Platforms for Hybrid Knowledge Production and Scientific Participation

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ABSTRACT

DIYbio (Do It Yourself Biology) is a growing movement of scientists, hobbyists, artists, and tinkerers who practice biology outside of professional settings. In this paper, we present our work with several open source DIYbio tools, including OpenPCR and Pearl Blue Transilluminator, which can be used to test DNA samples for specific sequences. We frame these platforms as *things* that gather heterogeneous materials and concerns, and enable new forms of knowledge transfer. Working with these hybrid systems in professional and DIY settings, we conducted a workshop where non-biologists tested food products for genetic modifications. Our findings suggest new design directions at the intersection of biology, technology, and DIY: i) DIYbio platforms as rich tools for hybrid knowledge production; and ii) open source biology as a site for public engagement with science.

Author Keywords

DIYbio, publics, design things

ACM Classification Keywords

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

INTRODUCTION

The past decade has seen a shift from biology being treated as a natural science and towards domains within biology—e.g., computational biology and synthetic biology—being framed as engineering fields. For instance, complex biological systems are being modeled *in silico* with modern computational platforms, while synthetic biology treats biological elements as engineered building blocks, enabling the design of new biological organisms. Alongside these advancements in professional research, new initiatives—from health advocacy groups to low-cost genetic testing services and biology hobbyist communities—involve

members of the general public in various practices that interpret, critique, and construct scientific knowledge.

One way of orienting this space for HCI is in terms of *publics*—groups of people who come together around issues and work towards resolving shared concerns [5]. Within this larger framing, we focus on DIYbio (Do It Yourself Biology) as a movement that is concerned with enabling open access to biology [7]. Emerging publics of hobbyists, artists, and scientists explore this issue by experimenting, tinkering, and playing with biology outside of professional laboratories. These efforts innovate low-cost tools and materials for at-home experimentation, share expert and amateur knowledge, conduct public outreach events, or address biology problems such as genetic health testing, bio-fuels, or food production with DIY tools.

DIYbio things

DIYbio coalesces around diverse materials, methods, and people. Not unlike Latour's hybrid assemblies [8], which materialize heterogeneous ideas and relationships between human and non-human actors, DIYbio projects gather organic and digital components, expert and amateur knowledge, and public and professional concerns. This aligns DIYbio tools with *design things*: modifiable, active, and evolving artifacts, rather than the finished outcomes of professional science [1]. Framed in this way, *things* can produce new knowledge beyond their function, “opening to its users new possibilities of action and interaction” [1]. Within CHI literature, DiSalvo et al. discuss designing *things* to engage HCI with issues and support publics [6]. In this paper, we explore how DIYbio *things* materialize concerns regarding open access to biology and give rise to discourse around the future of biotechnology.

We present our work with several DIYbio platforms (Fig. 1): OpenPCR [9], an open source thermal cycler for replicating

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CHI 2015, April 18 - 23 2015, Seoul, Republic of Korea
Copyright 2015 ACM 978-1-4503-3145-6/15/04...\$15.00
<http://dx.doi.org/10.1145/2702123.2702539>

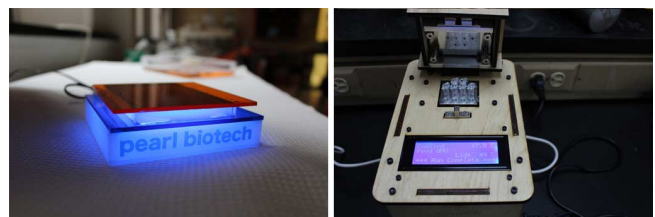


Figure 1. PearlBiotech transilluminator and OpenPCR.

specific strands of DNA (*e.g.*, genes); the Pearl Blue transilluminator [10], a tool for visualizing the results via gel electrophoresis; and the Dremelfuge, a 3D-printed attachment for a dremel, which serves as a centrifuge. We first studied these tools in a university biology laboratory and compared them against professional equipment. We then conducted a workshop whereby non-biologist participants used these tools, along with several other off-the-shelf kits and parts, to test food products for genetic modifications. With a framing of DIYbio platforms as *things*, our findings reveal that tools such as OpenPCR give rise to heterogeneous ideas, expertise, and concerns. We conclude by discussing how HCI research can re-envision open source biology tools as platforms for i) constructing hybrid knowledge, and ii) supporting public engagement with biology and other scientific domains.

RELATED WORK

DIY initiatives have been of great interest to the CHI community [3]. We see open source biology tools as parallel to the more widely-studied DIY platforms— Arduino, Raspberry Pi, PICAXE, or the dot.NET gadgeteer, which support hardware prototyping outside of professional settings. DIYbio tools such as OpenPCR enable non-experts to screen organic materials for genetic traits such as GMO's, diseases, or genealogy and can be seen as parallel to other citizen science sensors (*e.g.*, air quality monitors). This DIYbio "sensing" is not unlike low cost monitoring of factors such as air quality [*e.g.*, 14]. Similar to how current HCI systems allow crowdsourcing of ecological and environmental data collection [*e.g.*, 13], low-cost biology tools can serve as platforms for collecting and analyzing biological data on a larger scale. Prior work has explored the intersection between DIY, computation, and biology through an earlier study of DIYbio initiatives [7], or the development of computational biology tools [12]. We contribute by examining how DIYbio tools can support community engagement with science from the bottom up.

EXTRACTING AND VISUALIZING DNA

PCR (Polymerase Chain Reaction) is a process that enables testing a DNA sample for a specific sequence or gene. The results of PCR can be visualized with gel electrophoresis, which applies a high voltage across a gel. This process separates DNA segments based on their size, which can in turn be visualized by staining and illuminating the gel.

OpenPCR and Pearl Biotech

While PCR is a well-known, 30-year-old established procedure, recent DIY innovations have made work with DNA more accessible outside of professional settings. OpenPCR is an open source, low-cost (600\$) thermal cycle kit, which requires simple assembly before use. Arduino (a low-cost microcontroller) serves as its backbone, regulating a peltier heating/cooling element based on temperature data from a thermocouple sensor. OpenPCR can be programmed using a simple GUI interface on a Mac or PC. Likewise inspired by the open hardware movement, the Pearl Blue

Transilluminator provides a safer and more affordable (\$300) way to visualize electrophoresis results. The device relies on blue light transillumination and works with non-toxic SYBR safe DNA stains such as GelGreen. After electrophoresis, gel can be placed over the device, with DNA segments appearing as illuminated "bands". While lab-quality equipment for testing DNA (*e.g.*, centrifuges, PCR machines) can cost thousands of dollars, these open source tools are more accessible to the general public, especially if shared by DIY collectives.

TESTING FOOD FOR GENETIC MODIFICATIONS

Motivation

Our research aims to understand how open source biology tools might catalyze broader scientific participation as we envision near term consumer-level technologies for DNA testing. We chose GM food as an example use case for these platforms for several reasons. First, many off-the-shelf kits, primers, and protocols already exist for GMO analysis, making food testing more accessible than other types of tests. Second, the use of GMOs is a widely debated topic in the United States: the potential for GMOs to produce higher food yields and alleviate world hunger problems is often pitted against the drawbacks of heavier reliance on pesticides, unanticipated mutations, or the risk of invasive species effecting local ecosystems.

Background and initial testing

Our work uses an off-the-shelf (\$200) primer and reagent kit from Carolina Biological [4], which supports testing up to 24 samples for the CaMV 35S promoter, a sequence present in transgenic plants. In addition, this kit includes a control primer for tubulin, a gene present in all plant material. A positive PCR reaction for tubulin thus confirms that DNA was extracted correctly from the food product.

Prior to organizing the workshop, our interdisciplinary team of interaction designers and biologists tested the DIYbio tools and the GMO kit in a professional laboratory over the course of four months. We experimented with several DNA extraction protocols, PCR settings, and gel staining procedures and compared results from the DIYbio tools against output from professional biology equipment. Our final PCR reaction consists of 40 cycles: 94C 20 seconds; 54C 40 seconds; 72C 60 seconds. With these settings, we were able to accurately isolate the tubulin and 35S sequence from control genetically-modified corn leaves. A base pair ladder, which consists of known-size DNA sequences, was used to determine a best-fit equation for computing the size of PCR product based on the distance it travels through the gel. Our isolated tubulin and 35S PCR results were within 7 and 6 base pairs of the expected primer lengths, respectively, which is within the acceptable margin of error in biology research [2].

WORKSHOP WITH LOCAL DIY COMMUNITY

Working with a local DIY community, we organized a workshop whereby participants were invited to bring food

products for genetic testing. The workshop was held at a local hackerspace, with 4 participants (1 female) completing the entire workshop from start to finish, and 4 others stopping by and participating in some of the steps throughout the day. In addition to the GMO testing kit and the DIYbio tools, we also provided an electrophoresis apparatus and micropipettes from a laboratory.

Goals and methods

Our workshop goals were twofold. First, for the participants, the aim was to learn about available DIYbio tools and to determine whether their food items were genetically modified. Second, the researchers' goal was to understand the challenges and opportunities for public participation in biology. The workshop began with a brief overview of the steps involved in DNA extraction, PCR, and electrophoresis. Participants then extracted DNA from their food products, following our printed instructions and demonstrations. Participants were shown how to use the OpenPCR machine and load their samples. During the PCR reaction, which lasts about two hours, participants practiced loading samples into an electrophoresis gel, using food coloring for demonstration. Upon completion of the PCR, participants ran electrophoresis on their DNA samples. The gel was stained and visualized using the PearlBiotech transilluminator. An image of the gel and calculations of the PCR product size were emailed to participants.

Participants brought in a range of food samples for testing: an organic persimmon, organic pasta, chocolate, and cheese crackers. The electrophoresis results indicated that all participants successfully isolated DNA from their samples (based on the tubulin positive control reaction). The pasta, chocolate, and cheese cracker samples also turned out positive for the 35S promoter (GMO). The workshop was audio-recorded and photographed. Workshop audio was transcribed and coded to themes using an open coding scheme. This data, along with post-workshop feedback was used to synthesize three areas within our findings (below).

DIY making

Throughout the workshop, participants emphasized wanting to make all the tools involved in the protocols completely DIY. First and foremost, participants brainstormed ways to replicate the professional lab equipment we brought (gel box and pipettes) using off the shelf and cheaper components. For instance, participants discussed ways to create DIY pipettes by milling out fixed-volume indentations on a metal tray (Sul, 10ul, etc.) and then using an eyedropper to extract and apply these volumes. Likewise, participants discussed ways to build the electrophoresis apparatus from scratch using a laser cut casting tray or tupperware. Interestingly, participants also talked about reverse-engineering the DIYbio tools themselves. Having learned the steps of PCR, for instance, participants discussed how they could create an even cheaper and more transparent PCR machine using Arduino, thermocouple, computer fan, and heating elements.

Knowledge sharing

In addition to ideating new DIY tools, the workshop also led to many instances of knowledge and expertise sharing. Our workshop relied heavily on the expertise of and feedback from professional biologists. In addition to the text-based instructions that we provided for the protocols, and every step had to be demonstrated by the workshop organizers. Participants relied on demos from biologists to learn basic lab techniques such as pipetting, and to understand how to set up the PCR reactions and load their samples into the electrophoresis gel. In addition, participants also discussed and shared their own understanding of biology concepts, and researched information online during the workshop. For instance, it was not uncommon to hear participants discuss questions such as the difference between DNA and RNA, the base pairs and their role in the human genome, inherited traits, or the difference between mitochondrial and cell DNA.

Engaging with broader issues and concepts

Finally, our workshop resulted in discussions surrounding the broader scientific and socio-political issues related to genetic testing. Participants discussed a host of GMO-related topics, including the US legal system which enables patenting of certain genes, or Monsanto's monopoly on some types of corn and the effects of cross-pollination with organic farms. Several conversations also addressed the use of OpenPCR more broadly, such as, for instance, running genetic tests on human DNA, or speculating on DIYbio tools given the FDA's most recent regulation of 23andme.com, a public genetic testing service for diseases and ancestry. These and other examples show how the workshop and DIYbio tools were situated within broader contexts by participants.

DISCUSSION AND IMPLICATIONS

We began this paper by discussing DIYbio communities as *publics*: motivated by enabling open participation in biology, practitioners are making, experimenting, and Some of these efforts have effectively innovated low-cost tools that replicate the functionality of hard-to-access lab equipment. Returning to our initial framing of DIYbio platforms as *things*, our work offers several points of reflection for HCI. First, the tools themselves are assemblies of hybrid elements: electronics (e.g., the Arduino) interface with organic and chemical materials (e.g., DNA, primers), and the steps for testing DNA require organic, plastic, digital, and analog components. Hands-on work with these heterogeneous materials led participants to share and co-construct knowledge, as well as to reflect on the broader issues at the intersection between biology, technology, and DIY (e.g., government regulation of genetic testing). Finally, the DIY nature of the work inspired participants to ideate ways to modify the tools to support broader access and transparency. These findings reveal how DIYbio platforms are aligned with a view of *things* as artifacts that materialize relationships between human and non-human actors, and continue to evolve rather than being treated as finished products. For HCI, this suggests opportunities to re-envision DIYbio

platforms as i) rich tools for expertise sharing; and ii) instruments for public engagement with science.

Rich tools for hybrid knowledge production

Our workshop participants relied on demos from professional biologists in addition to text-based descriptions, and inspired participants to research and share biology information independently. For HCI, this presents opportunities to apply tablets, phones, and PCs as education and outreach tools for disseminating biology knowledge. Going beyond text-based tutorials, these can capture the unique hands-on nature of wetlab biology work and appropriately fit into a lab or hackspace setting. For instance, within the context of extracting DNA, certain techniques such as pipetting, vortexing, or centrifuging could be presented on multi-touch tables, phones, or tablets. These tools can also be deployed in laboratories and hackspaces to collect data from biology experiments and share this information between professionals and amateurs.

More broadly, scaffolding tools can serve to connect hobbyists with professionals and enable new forms of mentorship and learning. For example, social media or crowdsourcing systems might be used to troubleshoot problems in biology protocols, optimize procedures, or make certain steps easier or safer. The design of systems that can be situated in and fluidly drawn upon in a (DIY) lab space presents new challenges and opportunities. How might technology be embedded in a laboratory setting and easily accessible and interacted with during biology work? How can new interaction techniques and data visualization methods be leveraged to foster productive collaborations between biologists and designers, as well as artists, hobbyists, tinkerers, and hackers?

DIYbio as a site for public engagement with science

With open access being a key concern for DIYbio, HCI systems can invite members of general public—beyond people already interested in GMOs and tinkering—to participate in biology projects. On one hand, new interactions and data visualizations can shift scientific machines (microscopes, PCR machines, etc.) from collecting data and towards also sharing information with larger audiences. At the very least, foregrounding interactions with tools in DIY and professional settings can demystify lab practices and involve a range of stakeholders in scientific discourse. Moreover, virtual and physical assemblies can support in-silico modeling and crowdsourced DNA analysis. Finally, as primer design still remains a challenge (for both professionals and amateurs), and new sharing and collaboration tools can be deployed to make this process easier for non-experts.

The challenges for HCI range from the practical considerations for fluidly attributing metadata (e.g., GPS, time or care instructions) to the information collected by distributed groups; to the mechanisms for sharing this

information with stakeholders such as novice practitioners, policy makers, or the wider public; and the higher-level implications of mediating dialogues across these groups. This presents opportunities to rethink hardware platforms (e.g., microscopes) as instruments of public debate, and in turn re-envision modes of science making across DIY and professional labs.

CONCLUSION

In this paper, we presented our work with several DIYbio tools and protocols. We frame these platforms as *things* that coalesce hybrid materials, knowledge, and concerns. Aligned with this framing, our workshop shows how involvement with these tools supports ideation, expertise sharing, and engagement with broader biotechnology issues. Our findings suggest DIYbio tools as platforms for hybrid knowledge production and public engagement with science, in and outside of biology domains.

ACKNOWLEDGEMENTS

This work was supported by NSF IIS-1211047.

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