CRISPEE: A Tangible Gene Editing Platform for Early Childhood

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Abstract
We present CRISPEE, a novel tangible user interface designed to engage young elementary school children in bioengineering concepts. Using CRISPEE, children assume the role of a bioengineer to create a genetic program that codes for a firefly's bioluminescent light. This is accomplished through sequencing tangible representations of BioBricks, which code for the primary colors of light (red, green, and blue) to be turned on or off. The interface and curricular supplement expose children in early elementary school to concepts traditionally taught much later in school curricula through playful interaction and exploration. We discuss CRISPEE's concept and design, and share findings from its preliminary evaluation with children and adults.

Author Keywords
Children; education; play / games.

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

Introduction
Bioengineering is at the frontier of a wide range of scientific domains including space exploration, medicine, and food production. However, despite the relevance of bioengineering to solving pressing real-world problems, foundational

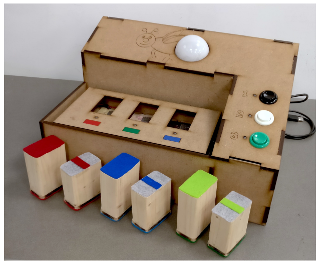

Figure 1: The current prototype of CRISPEE. Tangible blocks code red, green, and blue light to be either on (solid color) or off (colored line). Blocks are placed into the corresponding slots on the platform to create the genetic program of the firefly, with a colored output in the firefly's tail.

concepts of microbiology and genetics are not introduced to US students until middle school or later [1]. Young children (ages 5-7 years) are at a critical age to explore the world around them through a multidisciplinary lens, and educational advances in other domains (e.g. engineering, technology, computer science) have shown that children as young as age 4 are capable of learning core concepts of fields related to bioengineering [5, 4]. The goal of this work-in-progress is to describe our current efforts to develop a tangible, developmentally-appropriate tool to introduce children to foundational concepts of bioengineering. Using CRISPEE, children can explore how bioengineering can be used to solve problems in the real world.

CRISPEE is a novel tangible user interface for children to engage in bioengineering concepts, such as gene editing, through play and exploration. This paper describes CRISPEE's iterative design process, and discusses findings from preliminary evaluation with children and adults.

Background and Related Work

Bioengineering is a multidisciplinary field at the forefront of scientific progress, combining the fields of engineering and microbiology to create biologically-based solutions to real-world problems. One such solution is CRISPR/Cas9, a gene-editing tool that grants researchers the ability to make targeted changes to DNA sequences quickly and inexpensively [15]. CRISPR shows promise as a versatile method with applications in a broad array of domains, and its role in bioengineering will only grow as more applications for the technology are discovered. Gene editing protocols are not limited to CRISPR, and various methods exist for creating and inserting genetic programs into living cells. The MIT Registry of Standard Biological Parts [8] contains more than 20,000 biological parts, also referred to as BioBricks (i.e. DNA sequences with documented characteristics and functions which conform to assembly standards).

Bioengineering impacts a wide range of areas, from agriculture, to medicine, to environmental sustainability and space exploration. The advances and impact that this field offers, as well as the ethical questions that it raises, are going to become critically important in the future of today's children. However, currently, US education standards do not recommend exploring microbiology until 6th grade at the earliest [1], well after students have formed influential stereotypes and foundational ideas about STEM fields [18]. Until recently, engineering was also not taught to children before middle school, but current research has shown that young children (ages 5-7 years) can engage playfully and meaningfully in foundational concepts of engineering design [4, 6]. Engineering design is now recommended as early as Kindergarten [1]. Researchers have formed guidelines for designing technological tools that leverage children's natural ability to learn-by-doing [14], including the use of screen-free, tangible, highly-interactive platforms that support curiosity and self-directed play [2, 3, 17]. We applied the same principles in the design of CRISPEE, as we attempt to introduce children to foundational concepts of bioengineering.

This work draws upon other tangible interfaces for engaging children in bioengineering such as Synflo [13] and BacPack for New Frontiers [12], and interfaces that encourage tangible and virtual interaction with live cells [9, 10, 7]. Targeting children in grades 2-5, researchers found that students advanced their understanding of concepts like genes, DNA, and engineering [11]. Prior work on bioengineering tools for Kindergarten includes Garden G-nome, a digital workbench interface to explore genetics in plant life [16]. A major finding from this work was the importance of teacher buy-in through screen-free tangible technology. We cre-

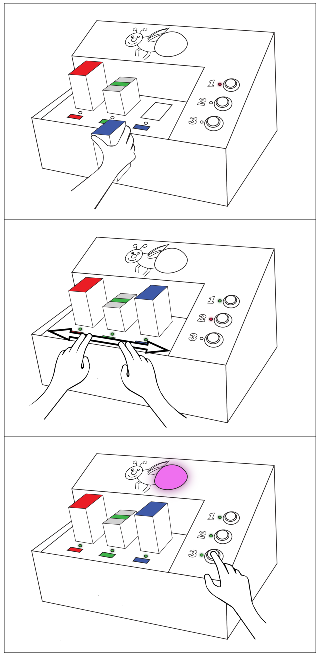

Figure 2: The three steps of interacting with CRISPEE. First, design: users place the tangible BioBricks into the corresponding slots on the platform. Next, mix: the user shakes the platform back and forth. Finally, test: the firefly lights up with the color output coded in step one.

ated CRISPEE, a screen-free tangible user interfaces for children ages 5-7 years, to be used in conjunction with a developmentally-appropriate curriculum that introduces concepts such as bioengineering and gene editing in playful, story-based ways.

Design Process

CRISPEE was created through an iterative design process in which we designed a series of prototypes in increasing fidelity. The current, fully-functional prototype is shown in Figure 1. We worked with educators and children to design the interface, and observed children playing with related and early prototypes to inform the direction of our design.

The design of CRISPEE was inspired by the form of gene sequencing machines currently on the market, to give children a sense of the types of tools that bioengineers use in their labs. We created a tangible interface made of large age-appropriate components and materials (wood, felt, and Velcro). BioBricks (i.e. genes) are represented by tangible wooden blocks, and LED indicators provide guidance and feedback through light output. Early iterations included a screen for guidance, but we removed the screen to comply with design guideline for early elementary school and per a request from educators.

An important design consideration was the cost of the final interface. We sought to create a toy that could be accessible to any classroom, so we designed the tangible blocks and enclosure with affordable materials and electrical components.

Early designs emphasized the order of the BioBricks, with ten tangibles each representing an output color. CRISPEE had five output lights in the order the blocks were placed. We changed this design from five outputs to one (the firefly's tail) to better reflect the concepts of genetically programing living organisms. The tangibles now represent red, green, and blue light, with each type of light having a block for "on" and a block for "off". The children program a light for a firefly, enhancing the meaning of the task.

Interaction

Interaction with CRISPEE is illustrated in Figure 2. The goal of the interaction is to help a firefly light up by creating a genetic program. Children accomplish this task using BioBricks (i.e. genes) that produce the red, green, and blue primary light colors, and by mixing the genetic material to light up the firefly. Children are led through the process using LED indicators and buttons which indicate the three steps of the bioengineering process: design, mix, and test.

In step 1, design, children program a light color by placing red, green, and blue tangible blocks representing BioBricks into the slots in the sensor platform. Once the first button is pressed, CRISPEE checks the program and gives feedback through LEDs in front of the sensors, showing green for correct block placements and red for incorrect. The blocks must be placed in the correct red, green, and blue slots for the program to read correctly.

Once the program is correct, children proceed to step 2, mix, where they mix their genetic program to insert it into the firefly's DNA. This is accomplished by physically moving the platform back and forth until all three LEDs on the sensor platform have turned green. In the final step, test, children see the firefly light up with the color combination created by their genetic program.

Throughout the interaction, lights next to the buttons flash red to indicate the next step in the protocol, and shine green when a step has been completed. Light feedback is also included in the design step to show the correctness of the program, in the mix step to indicate mixing progress, and in the test step to indicate that the genetic program has been successfully output.

Implementation and Fabrication

CRISPEE is implemented using the ATmega1280 microprocessor connected to arcade buttons, an accelerometer, LEDs, and conductive Velcro sensors. The tangible blocks are made of wood, felt, and conductive Velcro, with a resistor embedded in each block and connected to the Velcro. When the block is placed into the receiver slot, it is identified by reading the voltage drop across the block's resistor through a voltage divider in parallel with a known resistor. The conductive Velcro replaced an earlier iteration of the blocks and sensors that used metal rails to create contact, because reliable connections between the two flat surfaces were challenging, and the blocks moved significantly when the platform was shaken. The accelerometer is used to sense the platform movement in step 2 (mix).

We made the enclosure with laser-cut medium-density fiberboard and designed it to have interlocking pieces for aesthetics and strength. We used Velcro to attach the back and the faceplate of the platform so they could be opened and the electronics shown to children. CRISPEE was designed to be durable, with drawer slides under the moving platform to provide a solid and satisfying sliding action, and resilient blocks that could withstand being dropped or thrown. The toy has a satisfying weight so that it feels solid and doesn't move when the platform is being shaken.

Pilot Testing

We conducted a preliminary evaluation of CRISPEE with four children (grades K-3), and five adults who work directly with children in this age group. For all participants, we introduced CRISPEE with a story-based task that involves helping a living organism (a firefly whose body cannot light up) by reprogramming its genes to produce light in various colors. Core concepts were introduced throughout the session, to connect playful learning with domain content. We studied the usability of the interfaces as well as participants' experience engaging with CRISPEE.

Following a brief introduction to bioengineering and genetics, participants were asked to guess what the blocks represent, and to figure out how the interface worked with prompts from researchers. Once they successfully lit up their firefly for the first time, they were asked to reflect on the blocks they had chosen, and to investigate the different colors that they could create using CRISPEE. They were then asked about their enjoyment of the interface.

Pilot Tests with Adults

We asked adults who work closely with children to place themselves into the role of the child. All participants were able to place the blocks into the slots with the Velcro down and press the indicated button, and most could figure out what those lights indicate when the blocks were placed incorrectly. No adult could figure out the mixing mechanism until shown by a researcher; some thought that mixing the blocks meant moving them around to different slots.

The adults generally enjoyed the interface and thought that children would too. Many commented that they liked the different block combinations and the output colors, and that they thought children would enjoy matching the colors to the slots and trying different combinations. All of them commented that they were confused about the mixing mechanism, but once they were shown how it worked, they enjoyed the interaction of physically sliding the platform. Two commented that the buttons should have labels instead of being numbered.

Pilot Tests with Children
We tested the interface with four children, one kindergarten girl, one second-grade girl, and two third-grade boys. Children were led through the same process as adults, and after a post-task questionnaire were asked whether they would like to keep playing with the interface. These children generally understood the first step of the interaction, placing blocks correctly in the slots and pressing the first button to check their program. Some prompting was needed to help them relate the color of the LED to the correctness of the block placement. All of the children moved the bricks around in the slots when told it was time to mix the program, rather than moving the platform back and forth. Once they were shown the mixing action, they were able to remember how to do it as they played with it longer. They all expressed excitement when they successfully lit up the firefly and wanted to continue playing with the interface after this first interaction.

Figure 3: A kindergarten girl playing with the CRISPEE interface. She has placed the tangible BioBricks into the corresponding slots and is pressing the first button to check the accuracy of her program.

The kindergarten girl (shown in Figure 3) asked to keep playing with the interface after the post-task questionnaire, and played for an additional 17 minutes. She seemed to greatly enjoy the interface, cheering when she created a correct program and exclaiming "I made my favorite color!" when she made a cyan light. She spent some time trying to make her mom's favorite color (red) and tried different color combinations to achieve this. She talked through her logic as she placed blocks, choosing carefully and saying "that should do it" when she thought she made the program that would give her the color output she wanted. Once she figured out the on and off blocks, she began stating her planned output color and how she would achieve it, saying "so first I'm going to do red, the first color in the rainbow" and placing red-on, green-off, and blue-off blocks. She also explored what different color combinations would create, saying "now I want to try mixing blue and red."

The second-grade girl also enjoyed the interface. She was able to grasp the meaning of the on- and off-bricks very quickly, and was immediately able to place the blocks into the correct colored slots. After playing with the interface, she talked about how the blocks she was combining were helping the firefly. One third-grade boy was able to relate the concepts presented by CRISPEE to other forms of life, asking "Can we use the same genes for lighting a zebrafish?", showing that the interaction prompted further exploration of bioengineering principles. The other third-grade boy commented that he thought he and his peers would be too old for CRISPEE, confirming our goal age group of K-2. Both third-grade boys thought that a screen would make the interface more fun, but they did not say they thought the interface needed this screen to be more understandable.

Results and Discussion
Initial pilot tests of CRISPEE were promising and will drive further design of the interface. We received positive feedback from the adult pilot testers, who thought that the interface would be enjoyable for the target age range. Children enjoyed working with the interface and showed understanding of the connection between the blocks they chose and the color of the firefly, and the role of mixing in the process of creating their genetic program.

Several improvements need to be made to the interface for the next iteration. It is clear that the mixing step, while satisfying, needs additional work to make the interaction more obvious. Suggestions from the adult pilot testers included adding flashing arrows to the platform to indicate horizontal movement, and using separate LED indicators for the sensors and the mixing, as having different meanings for the same lights was confusing.

Other improvements include making the firefly bulb brighter, as some of the colors are hard to distinguish in bright ambient lighting conditions, and changing the action of the first button so that the program can be restarted at any point through the process.

Conclusions and Future Directions

We presented CRISPEE, a tangible user interface for engaging children in early elementary school with core concepts of biological engineering. Our goal is to expose children to domain concepts as well as to the promise and ethical concerns of this cutting-edge field at the intersection of science and technology. We believe that given developmentally-appropriate tools, young children can engage meaningfully with abstract concepts that were traditionally considered too complex for them to learn.

We plan to iterate on the design of the interface and to evaluate CRISPEE together with an accompanying curricular intervention within a classroom environment. We are also expanding the scope of CRISPEE to include a "design-a-biobrick" module, which allows children to engage more deeply with sequencing and DNA, and to program functions for BioBricks such as color value (e.g. dark or light) and sensor activation. Our curricular intervention will expand the story-based task into a full curriculum with bioengineering challenges that can be addressed with a diversity of physical and creative activities.

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REFERENCES

1. 2013. *Next Generation Science Standards: For States, By States*. The National Academies Press, Washington, DC. DOI: http://dx.doi.org/10.17226/18290
2. Shaaron Ainsworth. 2006. DeFT: A conceptual framework for considering learning with multiple representations. *Learning and instruction* 16, 3 (2006), 183–198.
3. Marina Umaschi Bers. 2012. *Designing digital experiences for positive youth development: From playpen to playground*. Oxford University Press.
4. Marina Umaschi Bers. 2017. *Coding as a playground: Programming and computational thinking in the early childhood classroom*. Routledge.
5. Douglas H Clements and Julie Sarama. 2003. Strip mining for gold: Research and policy in educational technology—A response to "Fool's Gold". *AACE Journal* 11, 1 (2003), 7–69.
6. Gerald A Goldin. 2013. *" Show Me what You Know": Exploring Student Representations Across STEM Disciplines*. Teachers College Press.
7. Zahid Hossain, Engin Bumbacher, Paulo Blikstein, and Ingmar Riedel-Kruse. 2017. Authentic Science Inquiry Learning at Scale Enabled by an Interactive Biology Cloud Experimentation Lab. In *Proceedings of the Fourth (2017) ACM Conference on Learning@ Scale*. ACM, 237–240.
8. iGem. Registry of Standard Biological Parts. Retrieved November 2, 2017 from http://partsregistry.org/Main_Page.

9. Seung Ah Lee, Engin Bumbacher, Alice M Chung, Nate Cira, Byron Walker, Ji Young Park, Barry Starr, Paulo Blikstein, and Ingmar H Riedel-Kruse. 2015a. Trap it!: A Playful Human-Biology Interaction for a Museum Installation. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 2593–2602.

10. Seung Ah Lee, Alice M Chung, Nate Cira, and Ingmar H Riedel-Kruse. 2015b. Tangible interactive microbiology for informal science education. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*. ACM, 273–280.

11. Anna Loparev, Amanda Sullivan, Clarissa Verish, Lauren Westendorf, Jasmine Davis, Margaret Flemings, Marina Bers, and Orit Shaer. 2017a. BacToMars: Creative Engagement with Bio-Design for Children. In *Proceedings of the 2017 Conference on Interaction Design and Children*. ACM, 623–628.

12. Anna Loparev, Lauren Westendorf, Margaret Flemings, Jennifer Cho, Romie Littrell, Anja Scholze, and Orit Shaer. 2017b. BacPack: Exploring the Role of Tangibles in a Museum Exhibit for Bio-Design. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction (TEI '17)*. ACM, New York, NY, USA, 111–120. DOI: http://dx.doi.org/10.1145/3024969.3025000

13. Johanna Okerlund, Evan Segreto, Casey Grote, Lauren Westendorf, Anja Scholze, Romie Littrell, and Orit Shaer. 2016. SynFlo: A Tangible Museum Exhibit for Exploring Bio-Design. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '16)*. ACM, New York, NY, USA, 141–149. DOI: http://dx.doi.org/10.1145/2839462.2839488

14. Seymour Papert. 1980. *Mindstorms: Children, computers, and powerful ideas*. Basic Books, Inc.

15. Alex Reis, Breton Hornblower, Brett Robb, and George Tzertzinis. CRISPR/Cas9 and Targeted Genome Editing: A New Era in Molecular Biology. Retrieved November 2, 2017 from https://www.neb.com/tools-and-resources/feature-articles/crispr-cas9-and-targeted-genome-editing-a-new-era-in-molecular-biology.

16. Orit Shaer, Marina Umaschi Bers, and M. Chang. 2011. Making the Invisible Tangible: Learning Biological Engineering in Kindergarten. *ACM CHI 2011 Workshop on User Interface Technology and Educational Pedagogy, ACM: CHI 2011.* (2011).

17. Amanda Strawhacker and Marina U Bers. 2015. "I want my robot to look for food": Comparing Kindergartner's programming comprehension using tangible, graphic, and hybrid user interfaces. *International Journal of Technology and Design Education* 25, 3 (2015), 293–319.

18. Amanda Alzena Sullivan. 2016. *Breaking the STEM Stereotype: Investigating the Use of Robotics to Change Young Children's Gender Stereotypes About Technology and Engineering*. Ph.D. Dissertation. Tufts University.