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Mobile Bioengineering Lab: A Hands-On Workshop Series to Bring Experiments to 8th Grade Science Classes

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Abstract

This Complete Research paper describes the Mobile Bioengineering Lab, a program designed to provide hands-on learning experiences in life sciences and bioengineering to underserved students within the community. We aimed to introduce accessible and exciting aspects of bioengineering to students who have had limited exposure to engineering, intending to develop long-term interests in science, technology, engineering, and mathematics (STEM) and promote diversity in these fields. This outreach initiative was conducted as a collaboration between a middle school biology classroom at a bilingual school and a bioengineering-related club at a large public university during the 2024-2025 academic year. The 7 lab-based workshops engaged students in tangential real-world applications of bioengineering, ranging from DNA extraction and planaria regeneration to an Arduino representation of gene circuitry, while helping students develop confidence in communicating research and scientific findings.

To evaluate the educational impact of these workshops, we solicited feedback through surveys that assessed changes in students' knowledge, engagement, and interest in bioengineering and STEM. The results of these assessments will be used to refine future labs and shared with the schools within the district for potential replication. By directly engaging with students from marginalized backgrounds, we intend to empower the next generation of scientists and engineers, advance DEI objectives, and encourage a more inclusive STEM environment.

Here, we describe the progression of the workshop series, including volunteer engagement and workshop deliverables, survey design, and the results of the outreach initiative on the students. By providing these deliverables and results, we aim to make the introduction of bioengineering's basic principles digestible to K-12 students and broaden the impact of this initiative.

Introduction

Bioengineering, synonymously referred to as biomedical engineering, first developed as a field in the 1950s when engineers in academia developed an interest in biomedical challenges [1]. As the field matured and established its own identity, academic programs were gradually developed with emerging guidelines for curricula. For an institution to receive ABET accreditation for a bioengineering program, the curriculum must include (1) application of engineering principles, life sciences, and relevant mathematics, (2) exploration of biomedical dilemmas, (3) analysis and synthesis of biomedical engineering devices, and (4) performance of biological measurements and explication of resulting information [2].

Although bioengineering has significantly evolved over time, it is seldom introduced in traditional K-12 classrooms. This may be due to the interdisciplinary and sometimes niche concepts, as well as its perceived inaccessibility, which stems from the associated experimental costs and pedagogy necessary. In response to this, educators have developed outreach initiatives to introduce bioengineering principles to K-12 students [3], [4].

Despite an increase in representation of marginalized groups in the last decade, the composition of the STEM workforce still exhibited large disparities in 2021. Approximately one-third of those in the workforce identify as women. Hispanic and Latino individuals accounted for 15%, Asians made up 10%, followed by African-Americans comprising 9%. Those from indigenous backgrounds held less than 1% of these roles [5]. With this educational context in mind, and motivated by a desire to increase diversity, the Mobile Bioengineering Lab was developed.

In the Mobile Bioengineering Lab workshop series, a group of undergraduate students in a bioengineering-related club (Biomedical Engineering Journal Club [6]) at the University of Illinois Urbana-Champaign strived to provide hands-on learning experiences and promote life sciences and engineering to underrepresented students within their community. This initiative was developed to address gaps in STEM accessibility and engagement among low-income and minority students, who often lack exposure to interactive engineering education [7]. This limited experience is often attributed to economic constraints as a result of insufficient school funding, social barriers due to a lack of role models, and a shortage of qualified teachers [7], [8].

By merging participatory activities with opportunities to apply classroom knowledge, learning becomes more engaging and memorable. Also referred to as experiential learning (EL), this strategy employs the motto “Do, Reflect, and Think and Apply,” where a student actively engages in a task or concrete experience, reflects on that experience, and extrapolates what was learned to other scenarios [9]. This approach can improve comprehension and retention of scientific concepts while fostering an environment to ask questions, conduct experiments, make observations, and think critically. A 2019 meta-analysis over 43 years of EL studies demonstrated that students who engage in these activities firsthand show greater learning outcomes compared to those from traditional, lecture-style learning methods [10].

Lastly, the interaction between university students and middle school students creates a social dynamic for mentorships, where middle school students can envision themselves as future engineers and pursue similar paths in a STEM-related field. Albeit weaker than EL, strong mentorship in research experiences and scientific-related endeavors has been shown to leave a positive impact on students, promoting a sense of belonging and interpersonal connection [8].

Objectives

In this study, we sought to share effective strategies for introducing bioengineering concepts to students with minimal exposure to engineering and life sciences while growing the students’ confidence and interest in STEM. By providing enriching workshops aligned with the core

8th-grade curriculum, this series aimed to increase student understanding and confidence in scientific experimentation, potentially influencing future educational and career interests in STEM. In summary, our objectives included:

1. To assess changes in confidence and interest in STEM topics among students before and after participation in the workshop series,
2. To measure student comprehension and retention of bioengineering and biology principles taught through workshops,
3. To document effective methods for integrating bioengineering into middle school curricula, thus providing a replicable model for STEM outreach in diverse educational settings, and
4. To explore how exposure to university students as mentors affects students' perceptions of higher education and STEM careers.

Study Population

The Mobile Bioengineering Lab collaborated with an 8th-grade science teacher at a local bilingual school in the community surrounding the University of Illinois Urbana-Champaign. The prescribed curriculum focuses on a genetics-centered core biology course. In total, there were 47 students across three 45-minute class periods, ranging from 16-18 students per class period. The workshops chosen and the order of presentations aligned with the core curriculum taught across 8th-grade biology courses in the Champaign, IL Unit 4 School District.

International Prep Academy educates many students who have emigrated from a Spanish-speaking country or background. To accommodate these demographics, classes at this school are taught bilingually in both English and Spanish, with the exception of science courses (which are taught in English with supplementary handouts in both languages). Many of these students come from diverse and low-income backgrounds with limited opportunities to explore engineering. According to the 2023 Illinois Report Card, 57.1% of all students attending this school are considered low-income [11]. Beyond this, the school demonstrated a 43.7% proficiency rate in science in comparison to 45.1% and 51.8% in the district and state, respectively [12].

Methods

Volunteer Participation

To successfully recruit undergraduate students to aid in this outreach initiative, the Biomedical Engineering Journal Club advertised within their group at the beginning of the academic year to begin developing materials for the first workshop (**Fig. 1**). As the semester began, the group created advertising flyers featuring a QR code linked to a sign-up form. Flyers were distributed across campus to attract students interested in participating in the workshop series. The only restriction for students participating in the Mobile Bioengineering Lab was to be enrolled as an undergraduate student at the University of Illinois Urbana-Champaign.

As a result, more than 20 undergraduate students from various engineering or life sciences majors assisted in either developing the deliverables and/or presenting the workshops. Volunteers indicated their workshop preferences on the sign-up form, and the outreach initiative coordinator contacted them as preparations for deliverables and materials were underway. Those that were to attend the workshops at the school first passed a background check required by the school. Approximately 5 student volunteers visited the school for each workshop, rotating between the class periods. On average, there were 3 volunteers per class period, which permitted a 1:4 instructor-to-student ratio when considering the student volunteers and classroom teacher.

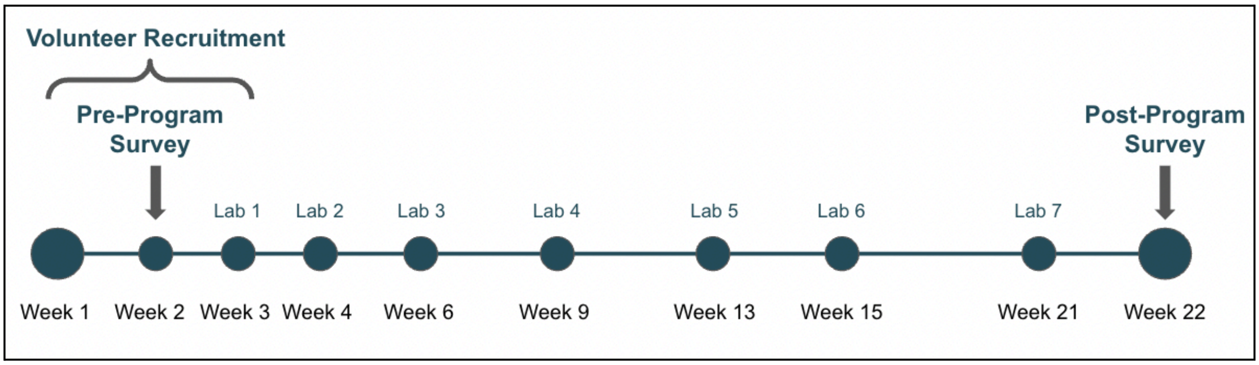

Figure 1. Study Timeline. The first six labs occurred within the fall semester, followed by the final lab in the spring. Weeks correlate with the school's weeks of instruction (i.e., school breaks are removed from the timeline).

Workshop Design

During the preceding summer, each workshop's content and completion date were determined in collaboration with the classroom science teacher. Labs were scheduled approximately biweekly in the fall and once in the spring semester, working around occasional scheduling conflicts. Throughout the school year, student volunteers met a few weeks before the workshops to perform a practice demonstration of the lab (**Fig. 2A-B**) and develop a slideshow and protocol (**Fig. 2C**). Objectives and descriptions for each workshop are described in **Table 1**. Materials and reagents were purchased through online vendors approved by the university, such as Carolina Biological Supply, Walmart, and Amazon.

At the start of each workshop, volunteers spent approximately 10 minutes presenting a slidedeck with contextual background information, as well as an overview of the protocol. Any reagents prepared prior to the workshop by the student volunteers, such as the agar agar gel (**Fig. 2A-B**) and red cabbage juice pH indicator, had their preparation processes explained in the slidedeck.

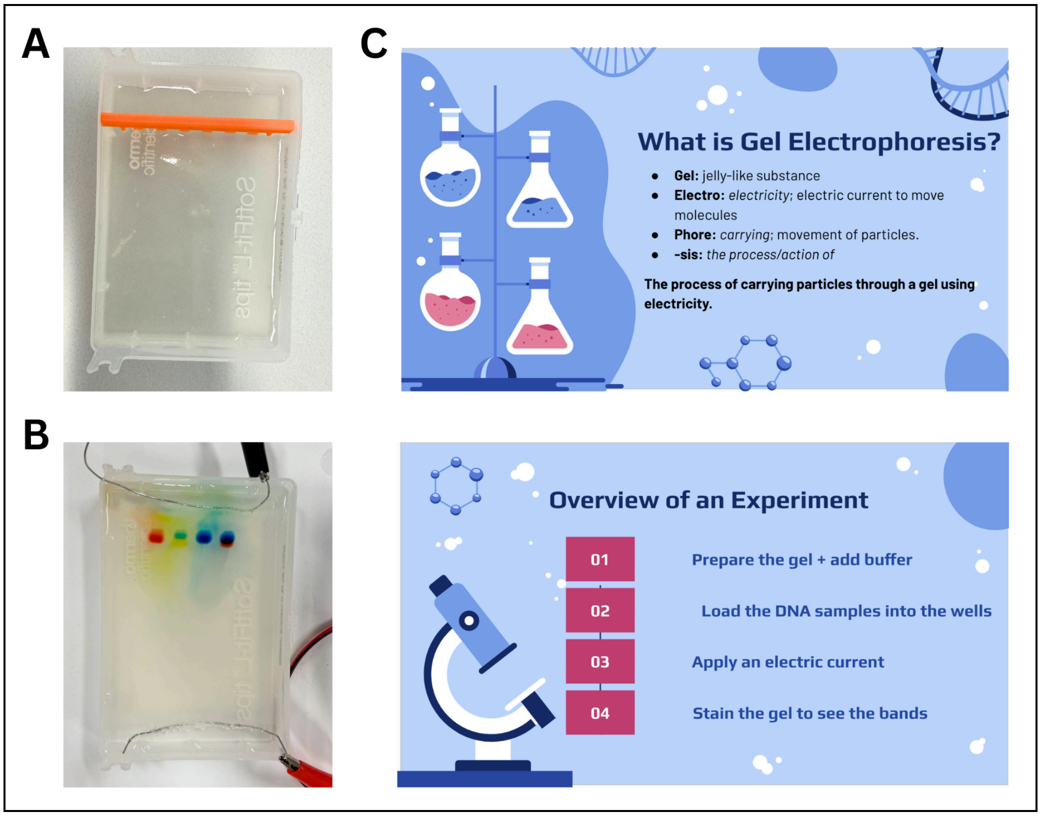

Figure 2. Preparation of Materials and the Slidedeck for the Gel Electrophoresis Simulation. **(A)** Agar agar gel preparation with a 3D printed gel comb in a pipette tip lid. **(B)** Practice demonstration of gel electrophoresis after 20 minutes of runtime. **(C)** Representative examples of the slidedeck explaining gel electrophoresis presented to students before the experiment.

Survey Design

Participating student feedback was collected through surveys eliciting

1. Quantitative responses employing the Likert scale to gauge participants' interest in STEM and assess their perceptions of the program's effectiveness,
2. Qualitative, open-ended questions given a relevant prompt, such as their notions of STEM and opportunities for general feedback, and
3. Clear, multiple-choice questions that request demographics, educational aspirations, and yes/no and multiple-response answers relevant to the program.

Surveys were designed to engage students' thoughts on the workshops and interest in STEM. They were designed to take approximately 10 minutes each. The pre-survey (14 questions) was offered in English before the workshops began, and the post-survey (22 questions) was offered in both English and Spanish at the conclusion of the program. The post-program survey solicited additional feedback about the workshop program.

Questionnaires began by inquiring about the participants' demographics including gender, race and ethnicity, and whether their parents have a STEM-related career. The survey then questioned the students' thoughts related to STEM, engineering, and biology, asking for three words that came to mind given the topics. Additionally, a 5-point Likert scale was used to quantitatively investigate their confidence level and interest in the aforementioned fields. We then inquired about their educational and career aspirations, including the highest level of education they are interested in pursuing.

In the pre-program survey, students were asked about which workshops sounded the most interesting. In the post-program survey, we solicited feedback about the workshops and the program as a whole, including the impact of the student volunteers and their potential mentorship dynamic. Example questions included

- *Quantitative*: Using a multiple choice grid, "On a scale of 1-5, the presenting undergraduate students were (1 - not at all, 5 - extremely)" for the prompts "interesting," "easy to understand," "fun," "interactive," and "confusing."
- *Qualitative*: "Is there anything in this program that can be improved?"

Table 1. Overview of Workshops in the Mobile Bioengineering Lab.

Workshop & Objectives	Description
1. What is Bioengineering? & Edible DNA Model *Provide an introduction to the field of bioengineering to the students; teach students about the structure of DNA and its components in an interactive and engaging way*	● Provided an overview of bioengineering, including its role in healthcare, technology, and other subsequent fields. ● Students engaged in interactive discussions and learned about real-world bioengineering projects related to their curriculum. ● Students built a model of a DNA double helix using edible materials (marshmallows and licorice), where each part of the model represented different components of the DNA structure. This helped students visualize and understand the arrangement of nucleotides and the importance of the helical structure.
2. Strawberry DNA Extraction *Educate students about DNA and its importance in organisms*	● Students extracted DNA from strawberries using common household items. ● This activity illustrated the presence of DNA in living things and provided a visual and tangible experience of extracting genetic material.
3. Gel Electrophoresis Simulation	● Students learned about gel electrophoresis by performing a demonstration using colored dyes in place of DNA. ● The agar gel solution was prepared prior for safety concerns and class period length.

Teach students about DNA separation and commonly used techniques in biological research	● Students poured the buffer on top of the gel, pipetted the dyes into the wells, and set up the power supply of batteries. ● Due to time constraints, students only saw the beginning of their simulation, so a demonstration was started prior to class beginning to show the students the later stages.
4. DIY pH Indicator *Teach students about pH levels and its necessity in life sciences research, as well as how to test for acidity and alkalinity*	● Students tested a red cabbage juice pH indicator with various household substances to determine their pH levels, learning about acids, bases, and the pH scale. ● Students compared their pH indicators' results to pH paper supplied by their teacher. ● The pH indicator was made before the workshop due to time constraints and the need for a stovetop and blender.
5. Regenerative Medicine and Planarians *Educate students about model organisms used in regenerative medicine research*	● Students learned about various cuts that can be made and the properties of regenerative organisms. ● Regeneration after fragmentation of the planaria was displayed in the classroom for students to observe over a few weeks.
6. Gene Circuits (Arduino Representation) *Introduce students to the concept of genetic circuits and how they can be simulated using Arduino*	● This workshop involved building a simple genetic circuit using Arduino components. Students understood how to program the Arduino to simulate gene expression, using LEDs to represent genes that can be turned on or off by environmental signals. An Arduino-controlled blinking LED circuit was used to represent genes turning on and off. ● For a real-world example, we focused on the lac operon in E. coli, a genetic switch that controls the expression of genes involved in lactose metabolism. ● Due to the scope of the class and limited computers available, code was provided to the students. Students still participated in an exercise on reading the code in Arduino software, also referred to as sketches.
7. Presenting Research: Bioengineering Research Today *Develop students' presentation and communication skills in the context of research*	● Initially, the goal of this lab was for students to work together to research a genetic disorder to practice presentation skills. The teacher requested it to be cancelled due to time constraints. ● Instead of a presentation on the current state of bioengineering research, as well as how research is presented and communicated, a mystery game was developed for students to use their knowledge of the central dogma to uncover what genetic disorder a patient had. If time permitted, students briefly shared their results to practice their presentation skills.

Data Collection & Analysis

Student assent and parental consent forms were designed to enroll students in the study. During a class period, the researchers informed the students about the study, and parents were notified of the documents by email. Students were officially enrolled into the study upon completion and return of both forms, granting them access to the pre- and post-program surveys. Students were not required to consent to the study in order to participate in the workshops. The questionnaires and methodologies of this study were approved by the Institutional Review Board at the University of Illinois Urbana-Champaign (project number IRB24-2077). Upon receipt of the surveys by voluntary consenting participants, the PI de-identified the responses for the researchers to perform a blind analysis using Excel. Plots were generated using GraphPad Prism.

Results

Students performed the experiments as described in **Table 1**. During each workshop, students followed along with a copy of the protocol that coincided as a worksheet after a presentation was delivered. Examples of student worksheets for the Regenerative Medicine & Planarians and Gene Circuits workshops are included in **Appendix A-B** in English and Spanish. Beyond the quantitative survey results, we include qualitative observations below for each workshop.

Survey Results

The post-program survey captured the responses of 10 students (out of a total of 47) who gave consent to share data, including 4 students who had also completed the pre-program survey. Self-reported demographic information of the participants is recorded in **Table 2**.

Table 2. Demographics of Participants. The demographic information represents the students who completed the Post-Program Survey and provided assent/consent for n = 10 students.

Attribute		Students
Gender	Female	6
	Male	3
	Nonbinary	1
Ethnicity/Race	Hispanic	7
	Caucasian	2
	Caucasian/Asian	1
Parent in STEM	Yes	4
	No	2
	Unsure	4

After completing the Mobile Bioengineering Lab, we probed students' perceptions of the workshop volunteers in the classroom using middle school-friendly descriptors (**Fig. 3**). Students indicated that their interactions with undergraduate volunteers were profoundly positive, such that the positively connoted characteristics ("friendly," "helpful," "fun," "interactive") all accumulated average scores above 4. In contrast, the negatively connoted word ("confusing") was used in relation to instructional exchanges, and responses indicated a lower level of agreement with this assessment (2.7).

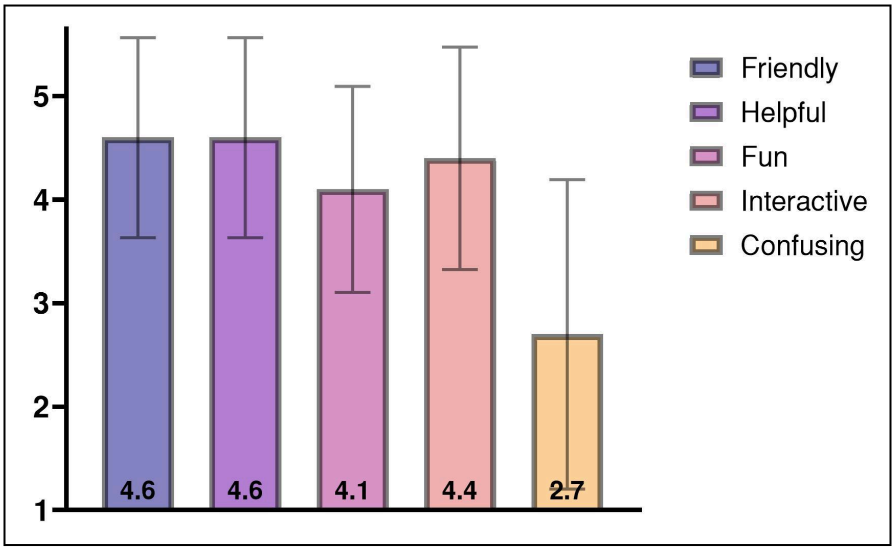

Figure 3. Student Perceptions of Volunteer Interaction and Presentation in the Classroom. Likert scale responses are shown as mean values with standard deviations, from 1 ("not at all") to 5 ("extremely") for the given characteristic (n = 10 students).

Next, the students reported that they found the labs approachable and were willing to participate, but their confidence levels varied across different aspects of the experience (**Fig. 4A**). Confidence in "Participating in Labs" and "Completing a Scientific Experiment" received the highest ratings (4.0 and 3.8, respectively). Conversely, "Understanding the Concepts & Techniques in Lab" and "Pursuing a Career as a Scientist or Engineer" received lower marks in comparison. Lastly, the impact of the program on students' previous perceptions ("Program Affecting Previous Responses") received a mean score of 3.3.

The students were then asked to rank their interests surrounding the fields of STEM and Bioengineering (**Fig. 4B**). Using a 5-point Likert scale from 1 ("not at all interested") to 5 ("extremely interested"), we quantified similar average interest scores related to STEM (3.1) and Bioengineering (3.2). Alongside this reporting, students' desire to learn more about both STEM and Bioengineering (both averaging 3.2) was consistent with the general interest in these subjects. However, when inquiring about the pursuit of a career in either of these fields, we noticed a slight decline in interest. Interest in pursuing a career in STEM was observed to be slightly more attractive (3.2) compared to Bioengineering (2.9).

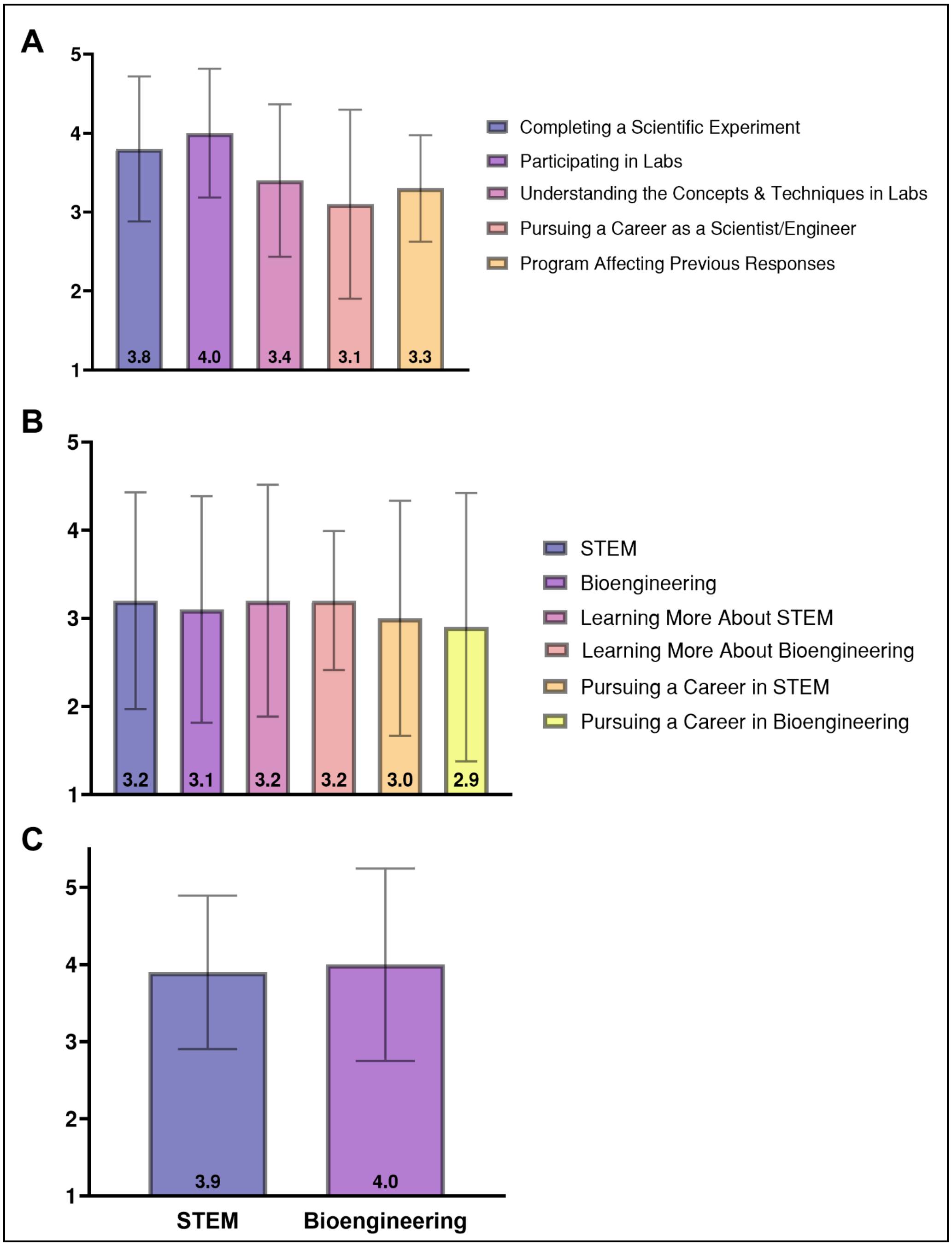

Figure 4. Student Outcomes Following Bioengineering Workshops. (A) Student confidence in completing scientific activities, including the program's impact. **(B)** Post-workshop STEM interest and career aspirations across surveyed topics. **(C)** Student reflection in comprehension of STEM and bioengineering concepts learned. All data (n = 10 students) are Likert-scale mean values with standard deviations, where 1 represents the lowest level ("not confident at all"/"not interested at all"/"not at all") and 5 represents the highest level ("extremely confident"/"extremely interested"/"extremely").

Next, students self-reported their comprehension and retainment of the STEM and Bioengineering topics taught throughout the workshop series (**Fig. 4C**). Although the Mobile

Bioengineering Lab primarily focuses on bioengineering and its life sciences foundation, the students reported similar ratings for both STEM (3.9) and Bioengineering comprehension (4.0).

Participants were then asked to indicate the workshops they enjoyed in the Mobile Bioengineering Lab (**Fig. 5**). The most popular workshop series was the Strawberry DNA Extraction (selected by 8/10 participants), followed next by the Gene Circuits workshop using Arduino (6 votes). The Gel Electrophoresis Simulation, Regenerative Medicine & Planarians, and the DIY pH Indicator all were favored by 5 participants. The least hands-on workshop, Presenting Research: Bioengineering Research Today, received preferences from 2 participants. Lastly, we collected qualitative feedback on the workshop series (**Table 3**). When asked if the Mobile Bioengineering Lab should continue, 9 responses stated "Yes," alongside 1 "Maybe."

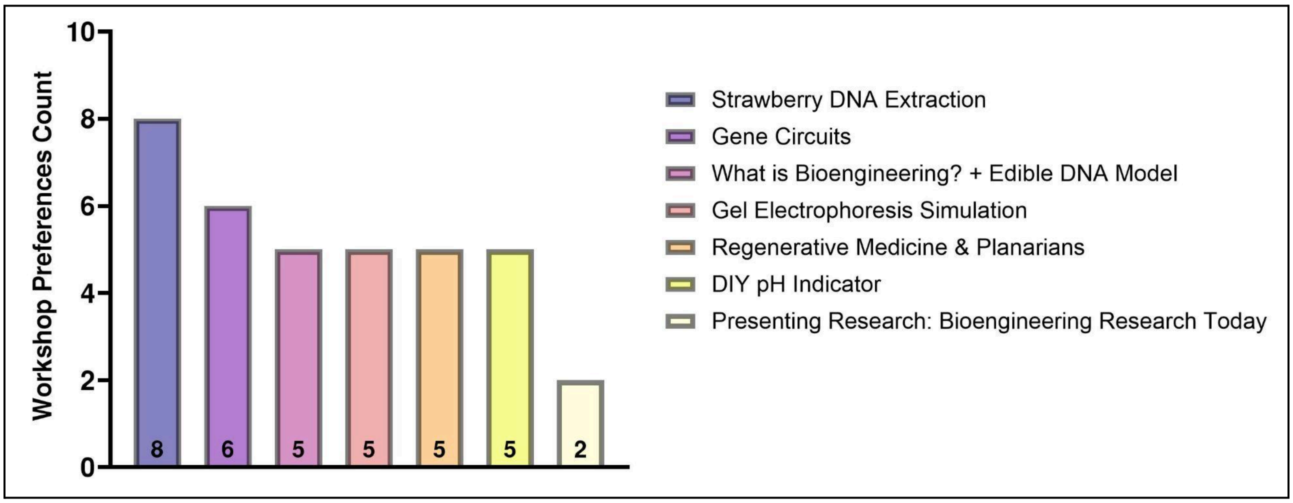

Figure 5. Student Workshop Preferences. Students were prompted to select all workshops they enjoyed throughout the workshop series (for n = 10 students, with 36 total responses).

Table 3. Representative Student Feedback on the Workshop Series.

Is there anything in this program we should continue implementing?	"Teaching new concepts about science and helping us learn about things we've never learned before"
	"The [Edible] DNA model was very fun [because] we had the chance to do hands-on activities that I enjoyed and [afterward] I understood [DNA] better."
	"[Continue] doing the same projects and experiments"
	"The strawberry DNA extraction"
	"Pretty much everything EXCEPT the gene circuits."
Is there anything in this program that can be improved upon?	"Teach more about engineers [in general], since that's what I am most interested in"
	"First, I need to learn [core biology concepts], so that I can improve."

What is Bioengineering? & Edible DNA Model
Most students had not heard of the field of bioengineering, and those that did commonly associated it with prosthetics and biomechanics. The students found tissue engineering fascinating, especially when provided the Vacanti mouse as an example of foundational work in the subfield of tissue engineering. When building the Edible DNA Model, many students recognized the different components found in DNA but were confused on how to read a DNA sequence; for example, they assumed that three nucleotides in a sequence (i.e., what is usually written to represent an amino acid) meant that three nucleotide representative marshmallows were to go on a toothpick. Also, because the DNA sequence was written horizontally on the protocol, many students tried to place as many marshmallows as possible on one toothpick, rather than using another toothpick to continue the sequence vertically down the helix (depicted with a licorice strand). An alternative approach we observed students take that differentiated from the protocol was applying Chargaff's rule, which states which nucleotides pair in DNA, to pre-build these marshmallow nucleotide pairings on toothpicks before assembling the model.

Strawberry DNA Extraction
Most students understood the concepts presented and how to conduct this lab. Many students were astounded to see the clump of extracted strawberry DNA within the solution (**Fig. 6A-B**). The students sometimes found it challenging to relate the technical terms used in actual DNA extraction, such as lysis buffer and isolation, to this experiment. Students were first introduced to these terms and the corresponding materials (dish soap and rubbing alcohol, respectively) at the beginning of class. These terms were then reinforced in the protocol.

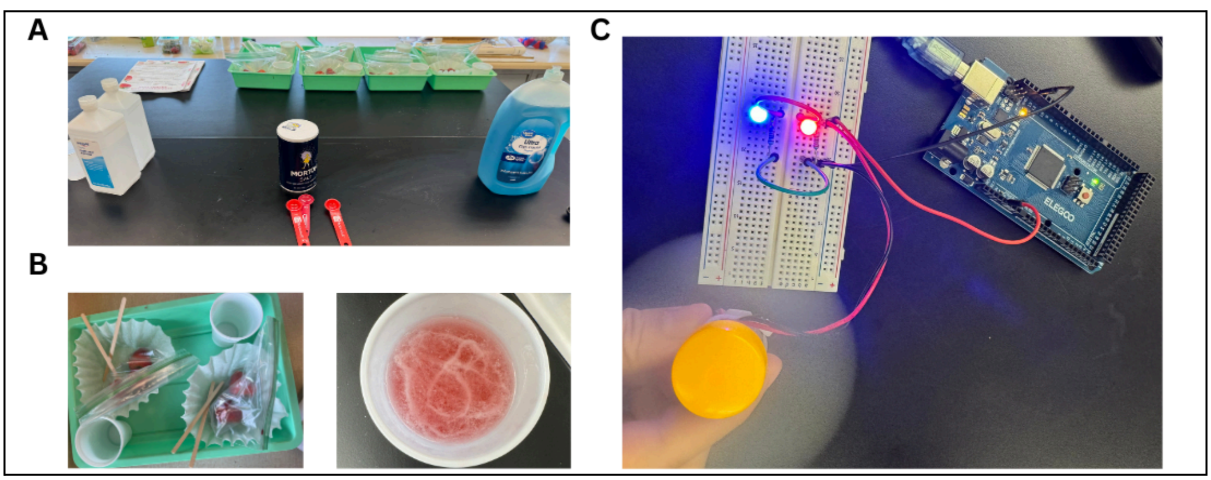

Figure 6. In-class Material Preparation and Student Results for Workshops 2 and 6. (A) Classroom setup for communal materials and reagents for the DNA workshop. **(B)** Material organization for group distribution and strawberry DNA extraction results. **(C)** Students used an Arduino, a breadboard, and a motor to spin a fan after building their blinking LED circuit.

Gel Electrophoresis Simulation
As this experiment was the closest to a research laboratory in terms of technique and materials, many of the students were ecstatic to participate. Students struggled with using the plastic transfer pipettes to add the solution to the wells, often resulting in a broken gel. Because of this, we asked students in later class periods to practice with pipetting in water prior to pipetting into the gel. In this workshop, we included a “mystery DNA” that was a combination of two different dyes that became apparent once the gel ran; students found this to be the most interesting aspect.

DIY pH Indicator
Students enjoyed making educated guesses on what the pH of the tested household items, such as lemon juice, dish soap, and baking soda, and then comparing these guesses to the measurements obtained with their red cabbage juice pH indicators. Students were curious and enthusiastic in using the pH paper provided by their instructor as a comparison to their pH indicators. Observations showed that the results from both methods were highly similar.

Regenerative Medicine & Planarians
We presented a variety of methods in which students could cut the planarian flatworm–e.g., horizontal, vertical, transversal, oblique, by fragmentation–and asked the students to predict planarian regeneration based on their cuts. Students were excited to come into the classroom to observe their regenerating planaria each school day over the next few weeks.

Gene Circuits (Arduino Representation)
Most students quickly became familiar with a solderless breadboard due to the interactive explanation, where the students practiced reading how current flows through a breadboard with prepared circuit examples. However, the inner workings of how electrical components interact with one another and the component’s role still seemed foreign to most students. For example, students appeared familiar with the concept of a resistor and an Arduino but kept inquiring about why it was necessary for the lab. Upon completion of the circuit, many students were intrigued by the blinking LED and began to tinker with the other materials in the Mega kit, such as the motor and fan, and began to implement it into their Arduino-controlled circuit (**Fig. 6C**).

Presenting Research: Bioengineering Research Today
Students enjoyed learning about seminal bioengineering discoveries. The lab was noted to be slightly confusing due to the utilization of the central dogma and redundancy in the RNA codon table to unscramble the mutated DNA sequence, but the students enjoyed the brief “literature review” wherein they learned about different genetic disorders from provided weblinks.

Discussion
Researcher observations were corroborated by quantitative student feedback noting that the most engaging workshops included the Edible DNA Model, Gel Electrophoresis Simulation, Gene

Circuits (Arduino Representation), and the Regenerative Medicine & Planarians (**Table 3**). Based on survey results, the Strawberry DNA Extraction excited students the most. The edible facet of the DNA model was appealing to the students, since having learned the basics of DNA and the central dogma the week prior made the lab's content more comprehensible. The other 3 most popular workshops and their content that followed were more novel to the students.

Our observations are further evidenced by other biology-related, hands-on activities implementing Arduino, which demonstrate notable improvements in students' comprehension of cause-and-effect relationships. The Gene Circuits workshop engaged students, as it required that the student groups collaborated and problem-solved to understand how circuits and Arduino functioned and its relation to complex gene circuits. Consequently, this increases their learning engagement and understanding of scientific concepts, as previously shown [13]. Furthermore, the exciting nature of the gel electrophoresis simulation that closely mimicked a useful lab technique made this workshop fascinating for the participants.

The use of live animal models in a classroom setting has been found to elicit positive emotions in learners and increase experimentation competency and confidence [14], which we observed during the Regenerative Medicine & Planarians experiment. Students were perceptive to work with the flatworms and were amazed when watching them regenerate in front of their own eyes. This real-world phenomenon was accessible to students and made them feel like scientists.

Challenging Workshops

Albeit previously noted as engaging, one of the most challenging workshops was the Edible DNA Model. This could be attributed to it being the first workshop in the series, as well as the confusion in reading a DNA sequence. This is one example of further clarification and refinement required for the protocol and the background slidedeck, which could be alleviated by having the students practice reading DNA sequences or performing a short demonstration of model construction. Having students write the complementary sequence to the given sequence prior to building the model could also rectify this problem. Nevertheless, one student stated that after the hands-on activity, "I understood [DNA] much better" (**Table 3**).

As recognized from the students' workshop preference responses, the Presenting Research: Bioengineering Research Today was difficult for students. Although they enjoyed learning about the cloning of Dolly the Sheep and the breakthrough of AlphaFold, the activity afterward proved challenging. This workshop was completed in groups where each student followed a document on a laptop with an accompanying worksheet to solve the unknown genetic disorder of a hypothetical patient. This activity was a culmination of their genetics and DNA classroom content, testing their ability to employ the central dogma and synthesize and convey relevant information. However, a small mistake was made in the mystery game; in a given RNA codon table, the amino acid Leucine was encoded by a multitude of codons. This resulted in some groups having the incorrect final DNA sequence, thus being unable to identify the patient's genetic disorder. The finalized version of this workshop addresses these areas of confusion.

Gene Circuits also proved to be another difficult workshop for the students, despite its popularity. In recent years, there has been a push to implement electronics instruction into classrooms in response to the shifting norms in technology. However, the existing approach requires foundational knowledge in mathematics, physics, programming, and other relevant areas. Subsequently, it has been identified as demanding extensive time and dedication, making it challenging to be practical and useful in K-12 education [15]. Therefore, the current version of this workshop may be better suited for experienced students or classes that can devote more time to the topic. In place of the Gene Circuits workshop, a potential application of Arduino and circuits in a bioengineering-context that may be more comprehensible to 6th to 8th-grade students could employ biosignal acquisition and processing with simple circuit filtering.

Inclusivity & Learning Styles

Consistently, we documented that providing visuals (such as videos or images of related content) was useful in helping students understand the concepts, given the limited time for students to perform the lab within the class period. This observation may also be attributed to a spoken language barrier between volunteers and students. Studies on visual learning methods in STEM instruction found it augments the learning experience and that students are more likely to explore new problem-solving approaches [16]. In a study regarding effective learning styles in a fundamental biology course, auditory learning for information processing coupled with visuals to illustrate structures and processes were found to be the most beneficial [17]. Students were also engaged by the opportunity to record their observations and answer questions directly on the protocol worksheets, which included images. In some of the labs, the teacher collected completed protocols for participation points, thus motivating some students to complete the lab more thoroughly and suggesting that a completion-based grading system linked to existing classroom gradebooks could be beneficial in future workshops. Some classrooms may choose to implement a more strict scheme in measuring comprehension of bioengineering principles.

Peer Mentorship & Volunteer Impact

Studies have demonstrated greater learning outcomes for students who collaborate with peer mentors [18]. By our observations, active assistance provided by the undergraduate volunteers was productive for most students in the class. As the program progressed, students began to remember the volunteers' names, which facilitated the development of mentorship and friendly relationships. The introduction of different volunteers throughout the sessions appeared to further engage the students, consequently permitting them to inquire about the volunteers' university experiences, personal interests, and scientific knowledge. Simultaneously, we also observed that students that were not comfortable with English relied on their classmates who were fluent in both English and Spanish; they also frequently referred to the Spanish protocol version. This further supports the notion that peer-mentored learning fosters and grows a learning environment for both the mentor and mentee [18], regardless of the (difference in) experience levels. In addition, undergraduate student volunteers found the initiative to be rewarding and enjoyed interacting with younger students within their community.

Student Feedback & Program Assessment
In general, the 8th-grade students responded positively to the workshops, especially to those that reaffirmed their misunderstandings of classroom content or completely new concepts. However, not all students benefit from solely participating in hands-on workshops, as this approach may not suit every individual's learning style. Consequently, it is imperative to complement these workshops with relevant classroom instruction or lecture to offer a variety of learning opportunities for students [10], [19]. This need to be flexible and adaptable around various aspects of educational programming in the K-12 space can be evidenced in many ways. For instance, a planned workshop could not come to fruition due to scheduling conflicts in the classroom. Leaf Chromatography was initially planned at the midpoint of the series, when students were learning about plant cells and chlorophyll in their science class. Though the prepared slidedeck and protocol were not tested in the classroom, this workshop's documents are shared alongside the other Mobile Bioengineering Lab deliverables on the website.

Overall, the post-workshop survey results exhibited generally positive attitudes toward scientific topics, with encouragement toward continuing the workshops. Certain factors such as having a parent with a career in STEM could certainly lead to a distribution of perceptions, confidence levels, and career aspirations. Throughout the workshop series, various labs had relevant queries for them to report their findings and ideas on their protocol. These positive responses may be the result of this implementation by providing another reinforcement of the goals of the lesson. The students' virtually unanimous opinion for the Mobile Bioengineering Lab to be continued in the future is the strongest indicator of success for the program; students enjoyed learning about bioengineering and supplementing their science education with experiential learning.

Limitations
The low survey response and consent rate (specifically with regards to the pre-survey) may be due to a language barrier, as the pre-survey was only offered in English. This could have restricted participation among students not comfortable with English, consequently skewing the participant demographic and limiting the generalizations of our findings. Resultantly, our ability to conclusively compare the effectiveness and impact of the Mobile Bioengineering Lab across a representative sample of the participants and longitudinally throughout the workshop series is limited. Furthermore, the current survey lacks directionality for some motivations; that is, there are not enough pointed questions toward mentorship dynamics between the volunteers and students. A greater variety of questions may have provided greater discernment into the

activities. Given the age demographic of the participants, these subtleties may not be easily comprehensible and may have led to disengaged responses.

Financial Considerations & Accessibility
The total cost of the presented workshop series was approximately $500 for 47 students, or approximately $10 per student for 7 workshops (**Appendix C**). This actual cost was 60% less than the initial estimated budget of $1300, in part due to purchasing from licensed vendors through the university, but mainly attributed to ongoing selection of less expensive materials throughout the workshop series. Throughout the development of this series, we prioritized purchasing from accessible and cost-effective retailers. Moreover, certain substitutions could be made with commonplace classroom, lab, or household items. For example, should pipette tip box lids be unavailable, a plastic alternative such as a travel soap box could suffice. Finally, this total cost does not account for the use of laptops or the ELEGOO Mega 2560 The Most Complete Starter Kit for the Gene Circuits workshop, as the school already had these materials purchased. As the Arduino Mega kits contain multiple breadboards and components, purchasing 3 kits for a class of 20 students in groups of 2-3 would be sufficient for the Gene Circuits workshop. These notes are further emphasized on our accompanying website (https://mobile-bioe-lab.super.site/), where educators can access the improved deliverables.

Conclusions & Future Directions
In this study, we have presented the development, implementation, and reflection of the Mobile Bioengineering Lab. The ability to integrate bioengineering and its principles into classrooms creates an engaging and interactive learning environment. We anticipate that early and attainable exposure to laboratory techniques and knowledge, such as demonstrated in Mobile Bioengineering Lab in its current form and future versions, will encourage students to pursue careers related to STEM.

Survey results indicate that this workshop series was mildly successful in its goals of employing experiential learning to (1) further confidence and interest in STEM topics, (2) measure student comprehension and retention of bioengineering principles throughout the series, (3) record and share methods to integrate bioengineering into middle school classrooms, and (4) explore the potential impact university students might have on the 8th-grade participants. This was completed through the willing engagement of volunteer bioengineering undergraduate students, active observation in the classroom, and deployment of a post-program survey. However, further work needs to be done to expand and appropriately measure topics (1) and (4) in particular by garnering a larger survey sample size.

In hopes of continuing this relationship between the university and this school, we aim to use this study's results to advance the current deliverables. Future studies will include both English and Spanish translations for surveys to maximize participant responses, as well as more clear-intentioned questions given the goal of this program. We also plan to collaborate with Spanish-speaking undergraduates to form stronger mentor-student relationships for those who are not comfortable completing the activities in English. To further the impact of the workshop series, all deliverables (including the original presentations and protocols, as well as the modified versions based on feedback) and materials will be published online [20]. We aim to test future workshops focused on other bioengineering subfields (such as biomechanics and signal and image acquisition) in the classroom before public release. As this workshop series continues to expand, the outcomes will be reflected on the website for educators and those interested in developing activities toward their own initiatives' benefits.

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Appendix

A. Workshop 5 protocol (English & Spanish)

Name: ______________________________

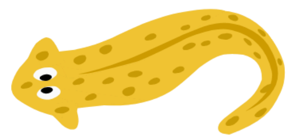
11/22/24 - Biomedical Engineering Journal Club

PLANARIA WORKSHOP

Explore how planaria regrow and learn the science of regeneration!

Materials:

- Gloves
- Planaria in petri dish
- Scalpel
- Magnifying glass



Protocol:

1. Put on your gloves. Label your petri dish with your and your partner's name.
2. Use your magnifying glass and look at the planaria closely. Write down the your observations below.

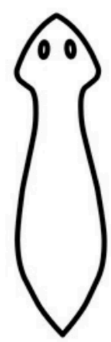
	Observations
Color	
Shape	
Movement	

3. Please circle which cut you will be performing.

Horizontal *Vertical* *Transverse*

Oblique *Design Your Own*

Draw how you will be cutting your planaria in the diagram on the right.



4. Perform your cut. Predict how many planaria will regenerate: ___________

5. Carefully bring your petri dish to the designated area. Check on your planaria and watch regeneration over time!

Nombre: ______________________________

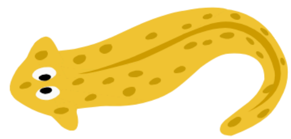
11/22/24 - Biomedical Engineering Journal Club

TALLER DE PLANARIAS

¡Explora cómo las planarias se regeneran y aprende la ciencia detrás de la regeneración!

Materiales:

- Guantes
- Planaria en una placa de Petri
- Escalpelo
- Lupa



Protocol:

1. Ponte los guantes. Etiqueta tu placa de Petri con tu nombre y el de tu compañero.
2. Usa tu lupa para observar de cerca la planaria. Escribe tus observaciones a continuación.

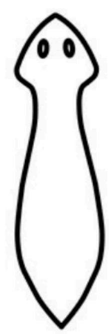
	Observaciones
Color	
Forma	
Movimiento	

3. Marca con un círculo el tipo de corte que realizarás.

Horizontal *Vertical* *Transversal*

Oblicuo *Diseña Tu Propio Corte*

Dibuja cómo cortarás tu planaria en el diagrama de la derecha.



4. Realiza el corte. Predice cuántas planarias se regenerarán: ____________

5. Lleva con cuidado tu placa de Petri al área designada. Observa tu planaria y mira cómo se regenera con el tiempo.

B. Workshop 6 Protocol (English & Spanish)

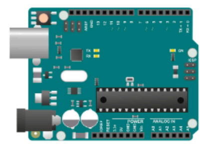
Name: ______________________________ 12/4/24 - Biomedical Engineering Journal Club

GENE CIRCUITS (ARDUINO)

Code genes like circuits! Use Arduino to flip switches and bring biology to life.

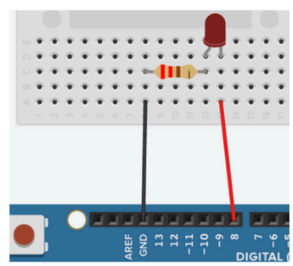
Materials:

ELEGOO Mega Kit: Arduino, Breadboard,
2 Jumper Wires, Resistor, LED



Protocol:

1. Open your Mega kit and grab your breadboard, an LED, 2 jumper wires, 220 Ω resistor, and Arduino.
2. On your breadboard, put your LED and resistor in **series**.
3. Connect a jumper wire from ground (GND) to the same row as your resistor. Connect a jumper wire from a pin (pick a pin from 0-13) to the same row as your LED.
   Write your chosen pin number here: _______



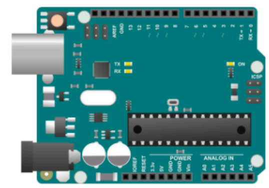
4. What would happen if you chose pin number 0 in your circuit but wrote pin 13 in your code? ________________________________
5. Raise your hand for a volunteer to run your Arduino code.
6. What does each part represent/what is its purpose?
   - LED: ________________________________
   - Resistor: ________________________________
   - Entire Circuit: ________________________________
7. What does it mean if the LED is on? What does it mean if the LED is off?

____

Nombre: ______________________________ 12/4/24 - Biomedical Engineering Journal Club

CIRCUITOS GENÉTICOS (ARDUINO)

¡Codifica genes como circuitos! Usa Arduino para activar interruptores y dar vida a la biología.

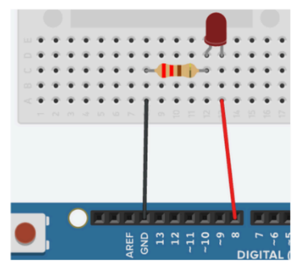


Materiales:

ELEGOO Mega Kit: Arduino, Protoboard, 2 Cables de Conexión, Resistencia, LED

Protocolo:

1. Abre tu kit Mega y saca tu protoboard, un LED, 2 cables de conexión, una resistencia de 220 Ω y el Arduino.
2. En tu protoboard, coloca el LED y la resistencia en **serie**.
3. Conecta un cable de conexión desde tierra (GND) a la misma fila que tu resistencia. Conecta otro cable de conexión desde un pin (elige un pin del 0 al 13) a la misma fila que tu LED.
   Escribe aquí el número de pin que elegiste: __________



4. ¿Qué pasaría si eligieras el pin número 0 en tu circuito pero escribieras el pin 13 en tu código? ______________________________
5. Levanta la mano para que un voluntario ejecute tu código en el Arduino.
6. ¿Qué representa cada parte y cuál es su propósito?
   - LED: ______________________________
   - Resistencia: ______________________________
   - Circuito completo: ______________________________
7. ¿Qué significa si el LED está encendido? ¿Qué significa si el LED está apagado?

____

C. Cost of Workshop Materials

Workshop(s)	Material	Quantity	Approximate Cost
1	Toothpicks*	1000 count	$6
1	Colored Marshmallows*	Three packs of 16 oz bags	$36
1	Licorice*	Two 5 lb tubs	$24
2	Strawberries	Three 2 lb tubs	$15
2	Ziplock Bags	50 count	$3
2	Non-iodized Table Salt*	26 oz container	$2
2, 4	Dish Soap*	75 fl oz bottle	$6
2, 4, 6	Coffee Filters	200 count	$3
2, 4, 5	Plastic Cups	200 count	$9
2, 5	Isopropyl Alcohol*	Three 32 fl oz bottles	$9
3	Empty Pipette Tip Box Lids‡	30 count	Volunteer provided
3	20 Gauge Stainless Steel Wire*	One 164 ft roll	$10
3	3D Printed Combs	2 count	$0.30
3	9V Batteries*	100 count	$66
3	Agar Agar Powder	2 packs	$12
3	Alligator Clips with Leads*	Three packs of 4	$18
3	Portable Scale	1 scale	$6
3	2 oz Sauce Containers	100 ct	$15
3	Light Corn Syrup*	One 32 fl oz bottle	$8
3	4 Food Coloring Dyes*	3 packs	$11
3	Measuring spoons (tbsp/tsp)	1 pack	$7
3, 5	Plastic eye droppers*	100 ct	$7

3, 4	Baking Soda	16 oz container	$2
3, 4	Distilled Water*	3 gallons	$5
3, 5	Latex-Free Kids Gloves	100 ct	$28
3, 5	Latex-Free Adult Gloves	100 ct	$16
3, 5	Microwave safe bowls†	10 bowls	$10
4	Red cabbage	3 heads	$9
4	Lemon Juice*	Two 48 fl oz bottles	$21
4	Vinegar*	128 fl oz bottle	$4
6	Scalpels	20 ct	$10
6	Planaria	120 ct	$66
6	Eggs	1 dozen	$3
6	Petri Dishes†	Two packs of 20 ct	$14
6	Magnifying glasses	20 ct	$10
7	ELEGOO Arduino Mega Kit*‡	10 kits	School provided
7	Laptops with Arduino IDE‡	N/A	Volunteer provided
			Total: $471.30
			Potential Additional Costs (Mega Kits): $660.00

*: Indicates excess material remaining given the number of students; it is recommended to purchase less of this material.
†: Indicates all of the material was used given the number of students; we suggest more of this material is purchased for those recreating.
‡: Indicates that this material was provided by the school or a volunteer.

Additional Notes: Potential costs of the ELEGOO Arduino Mega Kit are denoted below the provided total, where each kit is approximately $66.00. The listed cost of Mega Kits ($660.00) above was for approximately 50 students, although only 4-5 kits were used per class period. As previously noted, three Mega Kits should suffice for one class of 20 students. Laptop purchase was not included due to the variability in cost, nor was the cost of empty pipette tip lids. Arduino IDE is a free software. *Materials, costs, and alternatives are published* [20].