The Biophysicist

Bringing Biophysics Outreach to a Rural County Fair

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Received: 21 November 2022
Accepted: 13 April 2023
Published: 7 July 2023

Introduction

We designed and implemented a distinctive set of interactive biophysics-related displays for our local county fair to promote more science, technology, engineering, and math (STEM) engagement with rural school children. This effort to engage with a hard-to-reach audience in a venue that is not suitable for many kinds of traditional scientific displays necessitated a unique list of demonstration design criteria, including being able to attract the attention of an average fairgoer, being exceptionally rugged, being transportable, and being able to fit into the fair's indoor booth. Through a combination of using pop culture to engage students, building fun and interactive displays, and emphasizing real-world connections with our lessons, we were able to deeply engage with hundreds of children over a diverse socio-economic range. We envision that others hoping to do similar projects will create unique displays that reflect the community, school, and research interests. To best facilitate the creation of other unique fair booths, we describe both the specific activity and also the design requirements, the pitfalls, and the kind of results one can expect from this kind of outreach activity.

The process of enticing rural students to enter a STEM career is long, complex, and dependent on many factors. Most kindergarten (K) to grade 12 influences, including school funding and teacher training, are out of the control of specific colleges or STEM educators. However individual proponents of STEM education are not entirely powerless; well-designed grassroots efforts can target populations that lack access to STEM resources, and these programs are associated with increased STEM motivation and attitudes in school-aged children (1, 2). This supplementation of school-based instruction is one of the driving motivators behind many university-sponsored STEM summer programs, science camps, and open houses (3, 4). Although these programs have a clear effect on students' perception of STEM fields (3, 5, 6), they are intrinsically limited to reaching only those children whose parents are aware of these opportunities and who actively engage with such programs.

America has a long-standing disparity in science education and accessibility (7, 8). Although various facets of this issue are present in both rural and urban schools, rural STEM accessibility is often less talked about (7, 8). Yet, rural students trail suburban counterparts at every step of secondary STEM education, and this problem compounds over time; rural students are less likely than suburban counterparts to enroll in college (62% versus 68%), graduate from college (36% versus 47%), or enter into a STEM field (13% versus 17%) after graduation (9). This socioeconomic leaky pipeline is particularly self-defeating for rural families hoping to keep adult children nearby, because well-paying rural jobs are increasingly STEM intensive. For instance, in 2016, almost 37% of all employment in rural communities was STEM or STEM adjacent: education and health care positions consisted of 22% of all rural jobs; farming and agriculture (increasingly categorized as STEM) constituted over 10%; and scientific management administrative roles made up over 5% (10). Also, the concentration of STEM-related jobs in rural America is predicted to continue increasing over the next decade (11). One approach to prepare rural people for these future jobs is to conduct more robust outreach activities, but such efforts are predicated on identifying effective ways of reaching this population.

One inventive strategy to engage rural, hard-to-reach families is conducting STEM outreach activities at local county fairs. Around two-thirds of all American counties have local fairs, with some of these events drawing over 1,000,000 people each year (12). These events are a long-standing American tradition that have food and entertainment, provide a platform for young people to feature achievements, and showcase local goods, farming, and manufacturing (13). These venues also present a unique opportunity for science outreach because they seem to be one of the few large-scale events that rural families attend reliably. Scientists and organizers in Minnesota and Iowa, in particular, recognized this potential for STEM outreach decades ago, and both states now incorporate a STEM day into the state fairs. Both of these programs are well funded, well run, and are held in high esteem. The Iowa State Fair draws over 100,000 people a day, exemplifying how a 1-d STEM festival within the fair can reach a very large population (14).

Although STEM days are an excellent way to promote STEM in rural populations, they are difficult to replicate due to significant infrastructure and money requirements. As an alternative, here we describe a STEM outreach event that we run as a university-sponsored vendor at the local county fair. The program has a modest budget (US$500 for booth rental and US$1,000 or less for activity development) and infrastructure (2 professors and 4 undergraduates). This STEM outreach model has several advantages over the large statewide STEM days. First, planning is simplified due to the small scale of the program. Second, the program runs for the entire duration of the fair and thus engages with a larger percentage of fairgoers than a 1-d event. Third, because county fairs are local events, this project is well positioned to strengthen community relations between rural families and the local university hosting the STEM booth.

This article details both the process we took to design and implement STEM displays at a local county fair and the end result. The parameters and design requirements necessary for this kind of outreach event are different from a standard scientific demonstration and are outlined in the following. This scaffold will be useful for those interested in conducting a similar program through the host institution. In discussing the scaffold, we also describe our specific project and assessment, which are likely most useful as real-word examples of how these design decisions can be implemented.

Scientific and pedagogic considerations

We constructed this activity to be displayed at our local county fair (Rockingham County, Virginia). Our team consisted of a group of engineering students who built the displays during the first year of a 2-year-long engineering capstone project. This setup worked well; it afforded us ample time to design and make the display, along with additional time in the second year of the capstone project to iterate on our displays. However, other shorter timelines are also likely to work well; we envision that a display could be designed and built through members of an extracurricular club or in a single semester-long capstone experience within any STEM discipline.

Choosing a topic

The most common science demonstrations are easy, quick, and visually interesting (15, 16). We wanted to create a novel outreach activity that had these attributes but was also tailored specifically to the interests of local children. In addition, we wanted a display that went beyond simple *cool science* to ideas that had everyday applications for nonscientists. We also wanted a theme that channeled the knowledge of the creators. In our case, the authors have research interests in muscle diseases, so we decided early in the design process that our displays should incorporate muscle or neuronal biochemistry. In considering this topic, the engineering students were struck by how similar descriptions of the action potential and actin and myosin crossbridge formation were to processes they were learning in electrical and mechanical engineering classes. This inspired us to design the project around the similarities between neuromuscular biochemistry and robotics. Scientifically, we aimed to explain how your nervous system conducts electricity through neuron depolarization and then how muscle cells respond to this electrical impulse through actin and myosin crossbridge formation. We reasoned that this topic is relatable to everyone: all children think about how they move or how strong they are, and all parents bear witness to the kids' increasing coordination and strength.

Design criteria

In following both the engineering and the pedagogic backward design process, we spent significant time defining requirements that would be critical for successful fair displays:

(a) The display must have a *hook*, a way to gain initial attraction to visit the display booth, which extended beyond the science. In addition, this hook must have wide appeal to children and be *fair glitzy*; we are, after all, competing with rides on the midway and funnel cakes.
(b) The science presented must be obviously relevant to everyday life.
(c) The science involved must map to specific state-dictated STEM learning objectives from K to grade 8 (or higher). This allows these exhibitions to serve as school outreach displays during other times of the year. At the beginning of the design process, we defined specific learning objectives for each age level, and these objectives guided the display design.
(d) The display must be interactive across a wide age range.
(e) The display must be rugged enough to survive a fair, with the potential of being in an outdoor booth with rain, mud, animal poop, or indoors with crowded conditions and kids' sticky cotton candy fingers.
(f) The display must be able to be left alone overnight without significant safety or security issues.
(g) The display must be transportable in a normal-sized truck and movable over rough surfaces.
(h) The display must be able to be easily assembled, disassembled, and fixed by volunteers who did not initially design or make the display.
(i) Each display's *story* must be completed quickly, preferably under 2 min.
(j) The display must be large enough to see from at least 10 ft away.
(k) The entire ensemble of displays must fit in a fair booth space (10 $\times$ 10 ft was standard for our fair).

Criteria (c), (h), (i), and (j) are common for STEM outreach activities. In contrast, criteria (a) and (b) are not normally strongly considered when designing outreach activities, and criteria (d) to (f) preclude the use of most instrumentation, chemicals, and specimens that are normally found in science outreach activities.

Specifics in addressing the criteria

Design criterion (a) requires the most preplanning and must be considered before the other criteria because it dictates what the eventual outreach activity will entail. This step took several months to develop. To best connect with rural families, we first considered a farm-specific display. Specifically, we explored a booth theme on how genetic alterations could increase crop yield and animal dressing percentage. This idea was abandoned for 2 main reasons; we suspected that although this would be interesting to the parents, it would not hold the interest of children and thus violate criterion (a). Also, genetically modified organisms have become political, which could undermine our goal to forge connections with the community (17).

We next considered topics that addressed health concerns of rural families. Rural communities tend to have higher rates of chronic health problems, including cardiovascular disease (18). We designed experiments to visualize how both electricity and chemicals stimulate normal (and abnormal) muscle contraction by reanimating chicken feet or pig hearts with a battery or potassium chloride. Although this would certainly be interesting and educational, we could not devise a viable strategy to satisfy criteria (f) and (j). Exploring this theme further, we considered topics that would allow us to talk about both engineering and muscle biology; the idea of a living machine. Such a display does not have to involve (often small) biologic material, which is a positive. In addition, this concept is prevalent in pop culture, especially in science fiction and comic books. To gauge interest, we surveyed over 500 local elementary school children (K to grade 5) in 5 local schools about half-machine and half-human fictional characters. In 2020, students liked Ironman the most, although all the characters we listed (Characters in the movie *Inside Out*, Winter Soldier, Baymax, and Luke Skywalker) were almost equally popular (Supplemental Fig S1). Luke Skywalker and Ironman had almost universal name recognition among our survey participants.

Using superheroes to engage with students is not unique; others have successfully melded science and superheroes to engage a wide variety of students from grade school through college (19–23). This theme seems to transcend demographic and socioeconomic barriers particularly effectively (24). Of note, the Marvel franchise is quite popular with rural student's parents, helping attract families to our booth (24). The drawback of using pop culture, and perhaps one reason it is not used even more often in outreach activities, is the potentially short shelf life of a given character.

One initial concern with using a commercial character was copyright laws. In consultation with members of our arts and media department, we found that the US government's fair use policy exempts displays such as this from most name and likeness copyright rules (25). Our exhibition did not sell anything, was adapted for a specific educational purpose, and used modified images that were pertinent to educational goals. We suggest checking with either institutional lawyers or media experts at this stage of idea development just in case. Being easily recognized and enticing to children (and parents) was especially important in the high-distraction environment of the fair. Despite the necessity of an additional precautionary legal step, we recommend using pop culture icons in this type of display.

Because our work was conducted in Virginia, criterion (c) dictates that we align our lessons to the Virginia Standards of Learning for grades 3 to 6 (Supplemental Table S1). Taking the time to consider what children already know, what they are learning about, and where they are developmentally was an important prerequisite for all volunteers. This helped calibrate the story to an appropriate educational level. Our approach of integrating state assessment tools into our display differs from traditional backward design; in our case, most of the assessment tools are preexisting. We defined the larger learning objectives and then developed signature activities that meet those objectives with guidance from the state-sponsored assessment for a variety of grade levels. A table outlining this pedagogic method and age-specific outcomes was distributed to local teachers who interacted with our booth, and this made it easier for us to integrate these displays with local schools and conduct additional outreach events during the school year (Supplemental Table S1). In short, the process of mapping STEM topics to various education levels drastically increased the versatility of our displays and expanded our stakeholder base to local schools.

We found that criterion (d), creating an interactive display, was one of the more difficult benchmarks to achieve effectively. Much of science and most science demonstrations involve observation, but children often learn better when they touch and manipulate the objects they are studying (26). Interactive displays help maintain kids' interests and also allow them to physically become part of the learning process (27). In exploring this design necessity, it became clear that many options are not viable due to safety issues, space concerns, or other restrictions. Thus, our displays used mainly push buttons, cranks, and picking up golf balls, so this particular project had no specific safety precautions. However, even these *safe* options presented unforeseen challenges for inclusive involvement. For instance, buttons needed to be placed at a reasonable height to accommodate both kindergarteners and middle schoolers. Discovering these hidden impediments to a broad audience necessitated that we test our displays with many children of different sizes during the design phase. This testing also alerted us to just how unpredictable children can be; students would sometimes push, hit, or otherwise abuse the displays. Although the displays were designed to withstand this kind of environment (criterion [e]), it, nonetheless, underscored the need that children have adult supervision while interacting with and visiting our displays.

Additional considerations

In total, our fair booth had 4 displays. This required a minimum of 2 volunteers, and 3 were preferable. At any given time, 1 volunteer is talking to a group of children, and the other is resetting the displays. We only staffed our booth from 3 to 9 PM, during the busiest times of the fair. The displays were unplugged and draped with cloths when we were not present. Because manning this booth requires significant time and effort, we tried to pay students with help from the university outreach office. We also contacted our local academic fraternities, such as Alpha Chi Sigma, Beta Beta Beta, and Theta Tau, to help man the booth because students in these clubs need a certain number of outreach hours, and the fair provided an excellent way to accumulate these hours quickly.

Outreach activity details

A wide breadth of children and adults interacted with this booth, from home-schooled Mennonite farm families who have rarely seen a science display to suburban kids. Therefore, the college students who ran the booth needed to be nimble enough to tell the story of how our bodies are like machines in multiple different ways. Almost all children and adults were receptive to this narrative, but challenges included working with people with short attention spans and having to condense a complex story into a simple narrative. To help with both of these problems, we divided the narrative into 4 core lessons: an overview of how information flows through our body, a mechanistic view of how our neurons depolarize, a schematic of how muscles contract, and a demonstration of how we can take advantage of these molecular mechanisms in real life. Each of the displays also included a practical engineering skill used for building the displays that could be discussed with older children, providing additional versatility (Fig 1). Although we intended children to go through all the lessons in order, each station could act as a stand-alone display.

Lesson 1: neural connections

The first display, and the main attraction to our booth, is a printed poster of an 8-ft tall Ironman mounted onto plywood (Fig 2A). Four buttons, one for each limb, when pressed send a ping-pong

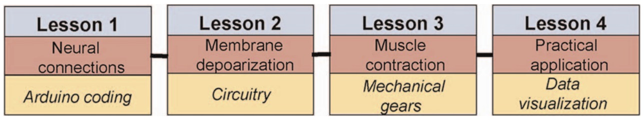

Fig 1. Overview of each display with the main biochemical topic (in red) and engineering topic (in gold).

ball through visible tubes from Ironman's brain to a specific hand or foot, where a light turns on to simulate Ironman's suit thrusters. The display functions by connecting Vex motors (Vex Robotics, Greenville, Texas) to the buttons. When a button is pressed, the motor turns a paddle wheel, releasing one ball stored in the hopper through the acrylic tubing, and also activates another motor group that opens and closes various ducts to guide the ball to the correct location (Fig 2B). Each hand and foot light up, and this is synchronized to activate once the ball reaches its designated location. This represents nerve impulses traveling from the brain through the spinal cord to the extremities. In practice, this display appeals most to younger kids (pre-K to grade 4). Our explanation of this phenomenon includes active participation such as asking the child to make a muscle themselves or kicking an imaginary soccer ball, as well as the built-in interactive visual cues on the display that describe how information travels from your brain to

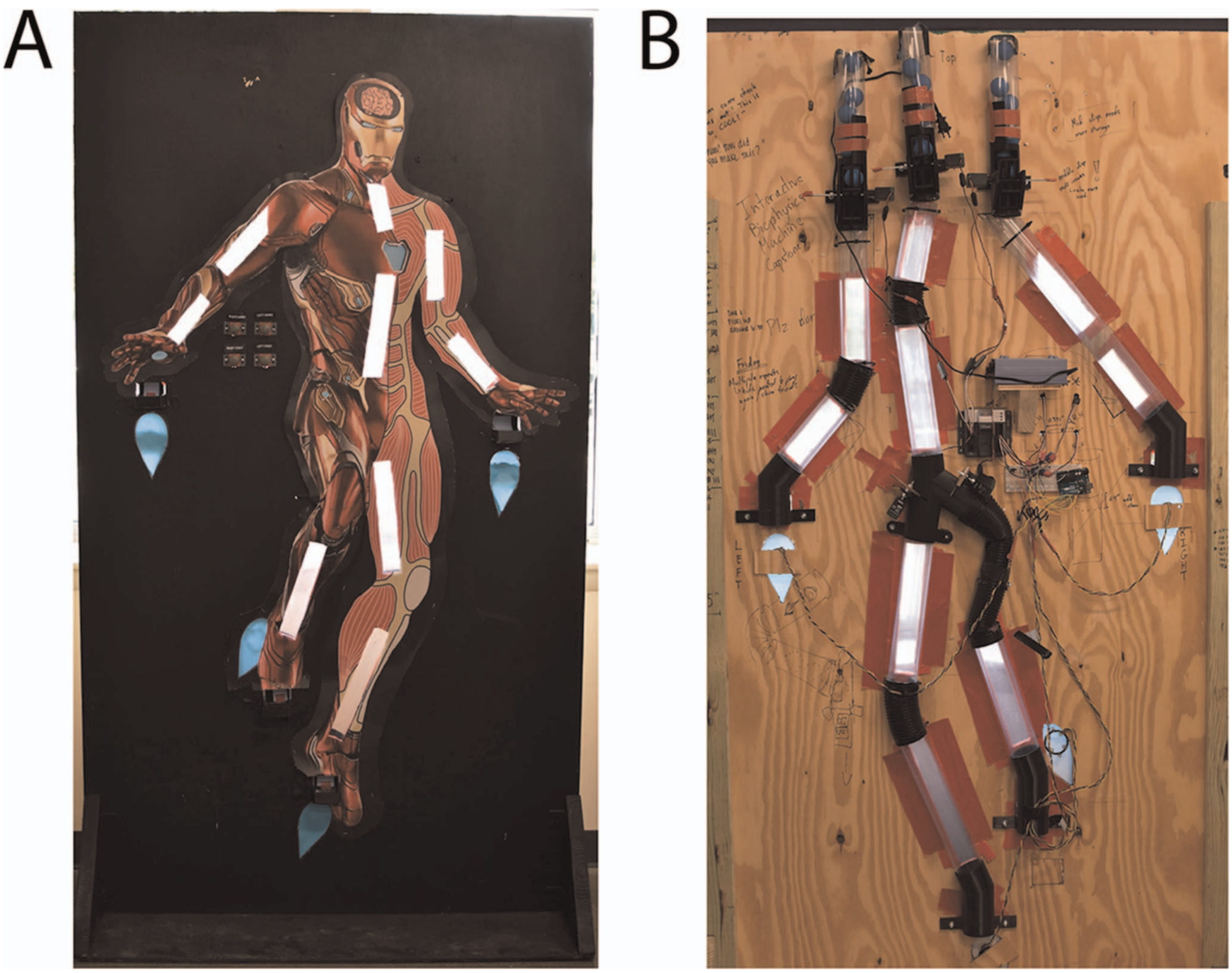

Fig 2. (A) Front display of Ironman, showing where nerve signals travel; and (B) back display of Ironman, showing the engineering and circuitry of the display. This display was positioned in the front corner of the fair booth, so both sides were visible to fairgoers.

your extremities. Both examples of engagement connect this science lesson to everyday life. Older children (and adults) are more drawn in by the electrical and mechanical components of the display, which are readily visible. Specifically, people can see the electrical wiring, the tube network that includes several 3-dimensional (3D) printed pieces, and the small motors that control the ball path. This kind of open design, thus, provides multiple avenues of initial engagement, from biochemistry to engineering.

Our learning objective for this display was for participants to explore how the brain communicates with the body. In subsequent displays, this was expanded to include a variety of different scales, from subcellular through system biology. Using storytelling and call and response, we addressed multiple levels of Bloom's taxonomy (Supplemental Fig S2): name the structures involved in these signaling events (remember); recall and explain what is happening at each stage (understand); connect the different stages together (apply); and at the end of all the lessons, explain how the brain can control a myoelectric prosthetic (analyze).

Lesson 2: membrane depolarization

The second display connects the macromolecular concept of neurons relaying signals to the biochemical concept of membrane depolarization. Because biochemical gradients are both ubiquitous and often hard to understand, we aimed for a simplistic yet accurate display that only involves a single ion pump and a single ion pore (Fig 3A). When describing this process, we use gravitational potential energy as a proxy for a concentration gradient. Golf balls, which here represent ions, start on a retractable shelf at the top of a large hollow box with an acrylic sheet over top. This shows the high concentration of ions at the beginning of the biologic process. A button on the side of the board retracts a solenoid that was holding the shelf in place, thus releasing the shelf from its upright position (Fig 3B). The *ions* then fall (in a manner that resembles Brownian motion) through several ion channels that are built into the board into the collection basket below. To reestablish the concentration gradient, children must actively transport the balls from the bottom basket back up to the top shelf, in a similar energy-requiring mechanism to that of an ion pump. We point out that the hard part in creating this system is establishing the gradient and that the activation signal is relatively minor. We relate this to Ironman by pointing out that this biologic system, like an electrical wire, moves electrical charges. Because both neurons and electrical wires move charges through a system to relay information, our bodies act very similarly to an electric machine.

Our learning objective for this lesson is for participants to understand how electricity can *enter* a cell in the form of ion flux. Again, through storytelling and call and response, we ask participants to name the stages of membrane depolarization (remember), recall what happened at each stage (understand), and connect the neural signal (ping-pong ball) from lesson 1 to the membrane depolarization in this lesson (apply).

Lesson 3: muscle contraction

The third display aims to teach participants about actin and myosin crossbridge formation. Rotating gears, powered by a child turning a crank, move a series of paddles, resulting in the pushing of a ladder over a track installed on the top of the gears (Fig 4A). The gears and paddles represent myosin, and the ladder represents actin. As the 2 symmetric cranks are turned, the myosin paddles drive the 2 halves of the actin ladders closer to the center of the sarcomere. These cranks can only be turned if a lever that controls a mechanical wedge and exit pallet is first disengaged. This lever represents calcium and teaches children that there are 2 requirements to initiate muscle contraction: calcium and energy. The gears in this display were printed 3 dimensionally, and the frame was constructed from aluminum extrusion piping. The actin ladder was created from a polyvinyl chloride pipe, and the myosin heads were made of aluminum piping.

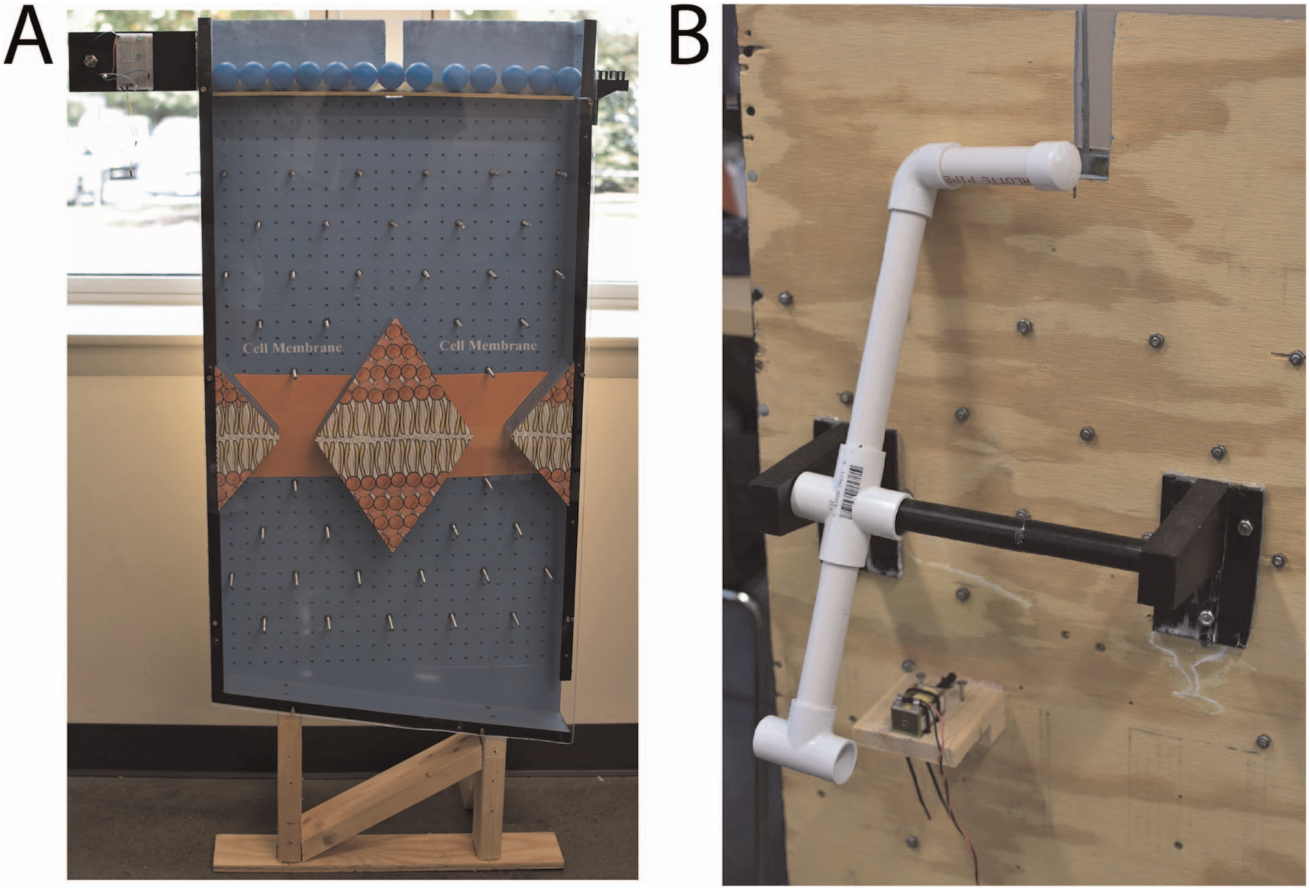

Fig 3. (A) Plinko board showing how ions (ping-pong balls) move through channels within the membrane; and (B) mechanism controlling the top ping-pong ball platform.

The gears were designed to have holes that could fit metal bearings, which held the myosin heads. This allows the heads to oscillate in a rowing motion when the gear rotates. As the gears are turned, each head will come into contact with the actin ladder in a sequential pattern and push this ladder closer to the center. When describing this lesson, we repeat the action from lesson 1, such as making a muscle, and this time talk about the physical muscle movement. To link this to Ironman, we point out that muscles look similar to small machines in your body. We assess participant learning by asking them to recall how the brain sends signals (remember) and how cells receive signal via electricity (remember). We then ask participants to explain to us how muscle cells convert this electrical energy into mechanical energy (apply).

Lesson 4: practical application

To tie each lesson to our central theme and to show why these lessons are practical in the real world, our fourth display is a mechanical arm connected to one of our student helpers with an electrical lead (Fig 4). The mechanical arm is controlled by the electrical impulses in the person's arm measured through a muscle sensor and is activated by a bicep curl, thus providing direct proof that we have electrical signals controlling our muscles. To create a small and inexpensive display of what the biologic electrical signal looks like, we programmed a Raspberry Pi system (Cambridge, UK) to visually display the electric readout on a small liquid crystal display screen (3 $\times$ 4 in). This electric readout also interfaces with a custom MATLAB, version R2023a (The MathWorks, Natick, MA) code to control the mechanical movement in the 3D printed arm (Supplemental Material). If the readout is below a certain threshold, the arm remains down, and if the readout is

A

B

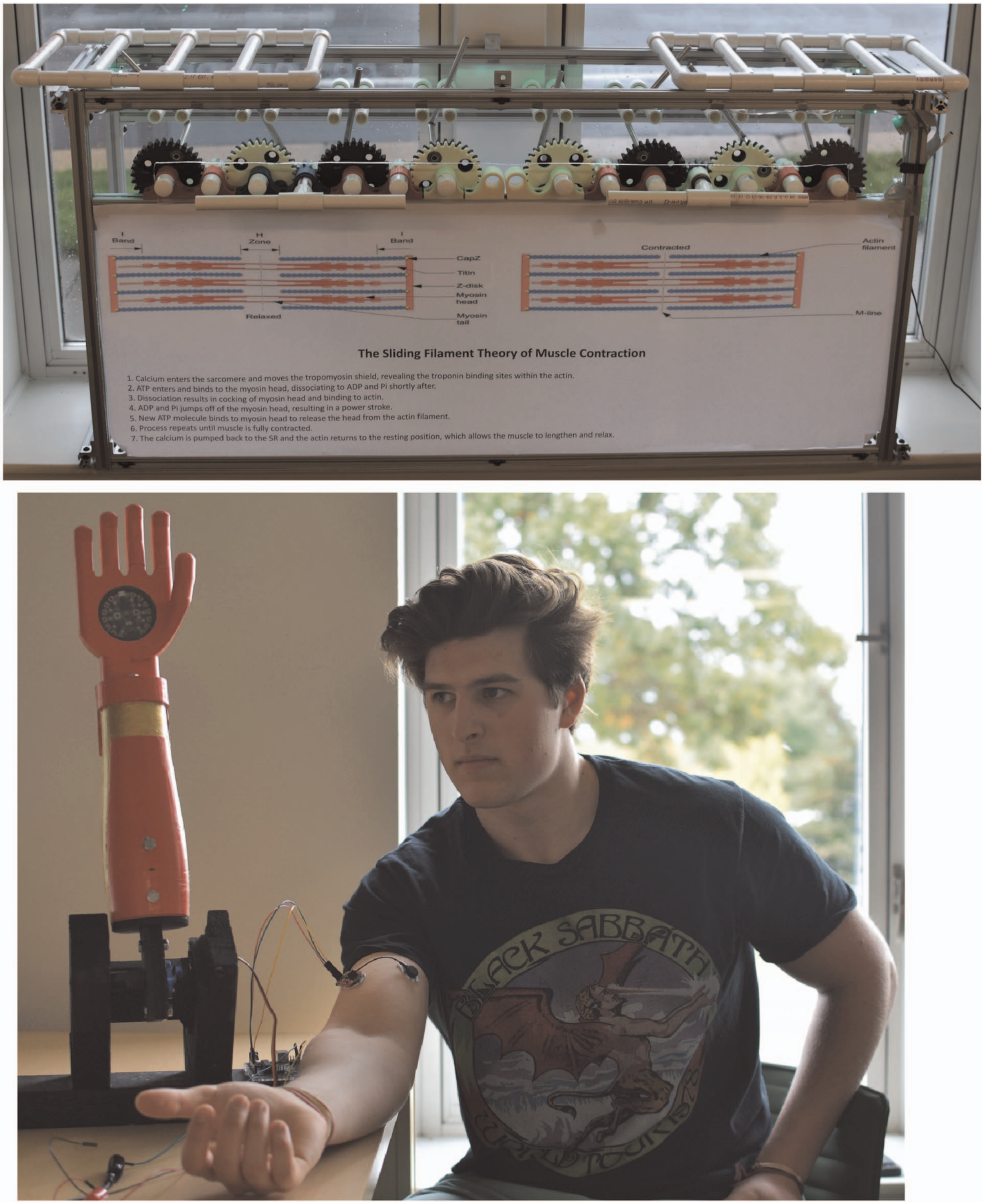

Fig 4. (A) Actin and myosin filament display; and (B) prosthetic arm and muscle sensor display.

above the threshold, the arm moves upward, mimicking the motion of the person connected doing a bicep curl. Depending on the inclination of the children, this might lead to conversations about how "we are just like Ironman" or how this technology underlies modern prostheses, or how this technology could be useful on the battlefield. The tendency of participants to use these basic science concepts as a jumping-off place for other ideas was both common and encouraged. Our primary learning objective for this lesson was to understand how engineers use the body's own processes to create myoelectric prosthetics (analyze).

Impact and assessment

Our original assessment plan was for children to fill out a questionnaire about scientific attitudes after they engaged with our booth. This incorporated elements that included both conventional survey questions (e.g., did you learn something new about the nervous system from the exhibit?) and observational data (e.g., how many students were contributing during the call and response), which focuses on socioemotional aspects and engagement of students (28, 29). This approach proved limiting; many younger participants either could not read or did not understand the questions being asked on surveys, and the sheer number of participants limited the ability of presenters to capture the interactions faithfully. Also, families often did not fill out our surveys at all or only partially answered them. These factors created substantial data gaps that belied the level of interest we observed. For the people who filled out the surveys, though, the feedback was quite positive. When asked if they learned something new about the nervous system from the exhibit, 69.2% (198 responses) agreed or strongly agreed (Supplemental Fig S3). When asked if they wanted to learn more about STEM in the future, 58.6% of participants (198 responses) said yes, and 38.9% of participants said maybe. Additional comments, written by both kids and adults, included the following: "Great presentation broke down for kids"; "Hands on is always a great way to learn! This was awesome!"; "Great demonstration and good explanations geared at both children's level"; and "I really love seeing what makes things work, and the science aspect is truly amazing."

Further research revealed that we are not the only ones to experience problems in assessing this population of students; others report that informal STEM learning arrangements present unique challenges, such as collecting data and quantifying impact (30, 31). In response, we transitioned our measurement tool to one that exclusively collected information on the number of people who visited the booth. Because our original goal was to increase scientific interest in this particular population and because the number of booth visits is implicitly linked to interest, we deemed this an appropriate method. In the future, we hope to expand this kind of unobtrusive observational assessment to not only count the number of people but also determine how much time they spend at the booth, how often they return to the booth, and how many questions they ask (32–34). We also are exploring building interdisciplinary collaborations with our communication studies department to aid volunteers assessing the displays. One idea is to have the volunteers keep reflective diaries to capture the experience. Through a collaborative autoethnography (i.e., qualitative research process), we hope to capture the impact of this type of outreach on the students. These alternate assessment tools are being actively researched, and implementation will inform how we improve the booth from year to year.

Anecdotally, one major impact of this booth was simply increasing the community realization that our university provided outreach opportunities for kids. Virtually all caregivers said that they did not know about any of the other STEM outreach activities on our campus. In addition, dozens of elementary teachers asked about how they could arrange university-led science demonstrations at schools. Preparing for this reaction by providing pamphlets or quick response codes for other STEM events is strongly recommended.

On average, over 800 people per year interacted with these displays during the 6-d fair. This represents roughly 1% of the total number of people who visit the local fair each year. Depending on the age of the child, each display takes roughly 1 to 3 min to complete (criterion [h]); overall, most children spent 10 min at the booth in total. Most groups at the fair ranged from 1 to 6 people; larger groups can still interact with the displays, but the booth (10 $\times$ 10 ft) quickly becomes uncomfortably crowded. Given the booth size and the length of time it takes to show people around, we estimate that the maximum number of people we could realistically reach is around 1,200. We suspect we could improve the number of interactions if we either rented a second booth for additional space or if we were to move to a larger outdoor venue. Both of these changes would bring new challenges, such as additional costs and the need for more volunteers, but this could be feasible with sustained institutional support.

Conclusions

We described how we used a set of location-specific parameters to manufacture a specific outreach activity at the county fair. This project generated significant engagement with a cohort of people in rural communities who are normally difficult to reach. This, in turn, strengthened ties with the local rural community and encouraged broader community engagement with the sciences. Our particular theme, involving the neuromuscular system and Ironman, resonated with the professors, volunteers, and the audience by relating to everyday experiences with the body. We wrote this article not to suggest that others copy our exact example, but instead, to motivate others to initiate a similar outreach program to more fully engage with hard-to-reach student populations. If done thoughtfully, with an eye toward cross-discipline collaboration, these displays can appeal to many people, can be versatile, and can act as a high-impact ambassador for the sciences.

SUPPLEMENTAL MATERIAL

The three supplemental figures are available at: https://doi.org/10.35459/tbp.2022.000232.s1. Supplemental Table S1 is available at: https://doi.org/10.35459/tbp.2022.000232.s2. The MATLAB code for the mechanical arm is available at: https://github.com/ongmf/Lesson-4-Code/tree/main/ (35).

ACKNOWLEDGMENTS

CJM and NTW were funded by the National Science Foundation (MCB 2024182). We thank the first undergraduate design team: Will Sullivan, Lauren Dargan, Jenna Lindsey, and Ryan Matta.

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