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LESSONS LEARNED FROM DESIGNING A MATERIAL BASED PROBE FOR GENERATING ELECTRICITY USING FOUND OBJECTS.

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abstract

We present a low-cost, making-based, educational design probe that aims to encourage students to confidently explore and make their own choices towards tinkering. We ask; how can we encourage novice makers to explicitly focus on the materials in their making process and consciously learn from them? We chose to explore this question by applying it to a specific application area, generating electricity using found objects. We designed a guidebook that prompted novice makers to reflect and document their thoughts related to the materials they would need to generate electricity (e.g., wind, water, sunlight, and vegetables), its properties (e.g the voltage across and current through the load), and their use in an application to generate electricity and contemplate its strengths and limitations in the context of the activity. We conducted a study using our guidebook, in which twelve high-school students explored a variety of materials to build simple applications that generate electricity. Our results show that students 1) were creatively resourceful, 2) showcased abductive reasoning with found materials, 3) demonstrated curiosity towards the role materials play in the experimentation structure, and 4) were resilient when faced with failure.

KEYWORDS:

materials, making, tinkering, design process

ack.

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INTRODUCTION

An integral part of making, is the desire to play with materials. The challenges one may face while creating, especially as a novice, may include unfamiliarity with a material, how it is going to work, how it will react with other materials, whether or not one material can be substituted for another, and the trial and error it will take to understand the materials' role in an overall creation. Novice makers include students with little to no exposure to the topic of experimentation at hand, students who have been exposed to the topic, yet have not applied that knowledge. The motivation behind this study lies in understanding how makers may learn through the process of making itself. Through this, the maker would be able to identify and understand the materials at play while tinkering.

In making, there are two distinct scientific procedures: "reproducing" and "following".

Reproducing involves iteration and reproduction, while following involves itineration. Itineration is often thought of as an application and verification of science, however, following is not the same as reproduction [7,15]. In the making process, makers follow the materials at play while creating. This process varies from prototype to prototype. In this study, participants move from station to station, following the way the objects react in the process of experimentation, in order to create their prototypes.

The role of materials has contributed to understanding the creative process of making. Materials (not just as objects) are part of the development of skills and practices [28]. "Through the use of things (materials), people create meaning in their actions and value these things (materials)" [12,19].

If makers were focused on activities that highlight the role materials play in learning, they may be able to identify these lessons which may otherwise have been neglected when trying to replicate predetermined outcomes. As a maker, one might consider various possibilities while creating. What is the thing they want to make, what are the materials they may need to make it, what are the materials that they have at their disposal and how many tries will it take for success? Some materials might be too heavy, some might not be malleable enough, some might simply not demonstrate the qualities they previously showcased.

With an introduction to seeing common materials in a new light, students would gain the confidence to explore and make their own choices in regards to experimentation and invention. By creating outside of a prescribed setting, the line between classroom learning and tinkering in maker space environments would also start to dissolve, a concept Cyd Cipolla introduces in Build It Better: Tinkering in Feminist Maker Pedagogy.

"We are asking if it is possible to break down the boundaries between a classroom space, a maker space, and a laboratory space" [5].

The overarching goal of our work is to enable makers to learn informally by focusing on the materials they use for making. In order to further understand how a structure where participants can explore the roles materials play, while experimenting, leads to learning from the materials themselves; this paper contributes by creating a design probe where participants consciously interacted with materials in order to complete their prototypes for generating electricity. The design probe (Figure 1) included a collection of found objects that were used to generate small amounts of electricity; with an accompanying guidebook that prompted the participants to work with the materials in the example experiments provided. The proposed framework offers an analysis of how the students behaved when working with found materials to prototype the experiments in the given guidebook.

Figure 1. Design probe contents.

— background +
related work

BACKGROUND + RELATED WORK

Feminist Maker Pedagogy

Dunbar-Hester (Beyond Dudecore) argue via Donna Haraway (Simian, Cyborgs, and Women) that the maker movement may present itself with "universal" appeal, an open forum for creativity and making, however, there are those who don't feel welcome in a world where "making technology" has long been associated with white masculinity [9, 13]. Copolla adds to Dunbar-Hester's observation, stating that her students had expressed that they had no reason to avoid maker spaces and that they just didn't feel welcome in those environments [5]. Those who did proceed to these spaces, arrived when they needed particular tools from the lab for their coursework, and realized they could go back whenever they needed to use the tools. For most of them, this small introduction was enough for them to visit the maker space on their own, with the confidence in knowing that they belonged.

Tinkering draws from feminist maker pedagogy [5]. This is an interdisciplinary pedagogy in which the "learn by doing" model employed in laboratory courses is brought to a wider application: one that assumes that what one "learns by doing" is not just the task at hand, but something fundamental about how the world fits together and how we fit into it. While working together, participants consider the radical potential of building from scratch in the digital age, the ethical imperative to re-write the world around them, and the philosophical experience of tinkering with knowledge itself [5].

Feminism, at all points, touches on the embodied and interconnected experience of beings in living systems. Making incorporates participants using material objects in exercises despite class, gender, and race dynamics being at play in the contemporary maker movement. Lastly, pedagogy describes a philosophy for teaching and learning, even as it challenges disciplinary boundaries, curricula, and the hierarchy of classroom spaces [5].

Feminist maker pedagogy assumes that any space, anywhere, is made for making and tinkering [11,18].

Role of Materials in Relation to Tinkering

The following example projects demonstrate the role of materials in tinkering.

Materials as Thinking Tools:

The Tinkering Studio in San Francisco is a dedicated making space that invites makers to engage in "thinking with your hands", a phenomenon for testing ideas, and responding to feedback using hands-on activities [29]. They are influenced by Papert's constructionism theory, which states that children learn better when they engage in activities that involve design, inventing, and creating and constructing meaningful tangible objects [25]. To enable "thinking with your hands", activities at the Studio involve using materials that the learners are familiar with on a daily level but invite students to use them in unfamiliar or unexpected ways. For example, as the artifacts change over time, learners understand through iterative design and testing how the materials behave and begin to understand the unique properties each material possesses in their prototypes. Facilitators are also held responsible for creating an environment where there is intellectual safety (freedom to experiment without educational consequence), creativity, and genuine interest in supporting learner's ideas rather than forcing them to follow a particular procedure or facts [29]. Materials play a significant role in creating such an environment. For example, supporting an environment where multiple approaches for learners to explore materials provides facilitators with evidence and insight into the way learners understand the topic at hand [29].

Materials as a Source to Practice Personalization:

Beyond dedicated maker spaces and tinkering studios, hobbyist do-it-yourself (DIY) activities have identified materials as a starting point to achieve personalization in the making process [35]. For example, Instructables is a popular DIY community where people share projects and describe how to build their design by sharing text descriptions, photos, and videos [4]. Tseng et al [35] found that however people cannot always replicate the projects as is and that sparks personalization and improvisation: "I usually do not have all the materials or tools required, so I have to improvise. Sometimes this works out… interestingly. But it also adds some personal touch". Personalization is "the fun part". These practices are also similar to IKEA hacking [27], where standard guides or tools, like instructions for assembly, can be engaged and reinterpreted by makers to create new structures [8].

Materials as a Means to Broaden Participation:

Researchers have explored the role of materials for making in impoverished contexts such as Brazil [34] and in situations where makers face lack of immediate or easy access to material resources [1], and have highlighted possibilities of how materials (physical and digital) may serve as a means to broaden participation. Sipitakiat et al. [30,31] built GoGo boards, an affordable microcontroller with sensing and controlling abilities, by locally manufacturing them in Brazil. The board also enables circuits to be built using found and existing materials such as broken electronics thereby allowing people to reuse found objects. People from different countries were able to adapt the board to their own needs to broaden participation, for example, school children from Mexico built a board entirely made with repurposed electronic components [3].

Somanath et al., [33] introduced augmented reality (AR)-mediated prototyping as a means to enable people to continue prototyping electronic circuits despite the lack of immediate or easy access to electronics. Their prototype tool, Polymorphic Cube, allows people to build a circuit using both real-world components and allows them to substitute missing components using AR. Their study found that makers were able to continue design thinking and implementation tinkering despite limited access to material resources.

Materials Help Create New Forms of Making:

A focus on exploring materials in a new or different way has also enabled new kinds of making. In Electronic Popables, Jie Qi and Leah Buechley explore paper-based computing through an interactive pop-up book [24]. Material experimentation was integrated with an exploration of the functional and aesthetic qualities of computational media. For example, the makers constructed a book by building individual interactive pop-up cards using various materials (copper tape, conductive fabric, LEDs, and circuitry with other components) and used a variety of techniques to attach these materials together. The constraints of having to create an object with a certain aesthetic forced the makers to confront engineering challenges and led them to discover new material affordances and interactive possibilities. By integrating interaction design with an exploration of physical materials, the makers were enabled to create prototypes of computation that looked, felt, and functioned differently than what they were accustomed to before [24].

Materials Help Explore New Forms of Human-Machine Interactions:

In Being the Machine, by Laura Devendorf and Kimiko Ryokai, a system is presented that guides users in building 3D models from everyday materials by following instructions typically given to 3D printers. This aimed to elicit active and personal reflections on human-machine relationships by reconfiguring the expected roles of humans and machines in the hybrid making, exposing tensions between agency and control [7]. Users were also engaged with a wide range of materials and reflected on the interplay of low-tech material practices and high-tech mechanical processes. These interactions between the participants, the 3D printer, and the materials provided insight for the design of our guidebook, where low-cost materials were used for experiments requiring a particular structure in order to be successful.

design probe

DESIGN PROBE

We created a design probe to be used in our study for participants to observe and reflect on their experiences by documenting the experiments that would be conducted.

Design probes are objects that are generally small in scale which are designed to relate to a particular question and context. They pose a question and offer the participant ways to interpret the question by forming a response through completing the probe creatively [36].

Our design probe consisted of two things: a collection of found objects that can be used to generate small amounts of electricity and a guidebook that provided students with some sample experiments for generating electricity and prompted them to think about the materials being used by posing questions. The question posed in our design probe was how we could encourage novice makers to explicitly focus on the materials in their making process and consciously learn from them.

Materials Chosen

While creating our probe, materials were tested through DIY means for generating electricity that would be replicable for the participants to follow. Low-tech materials that could be easily found were to be worked with natural materials readily available. The natural materials themselves consisted of lemons, potatoes, water, salt, and self-made conductive dough. These materials were often used in examples that were found in videos on Youtube, or in books e.g. The Art Of Tinkering [37].

Using natural materials when conducting an output such as electricity (which required a set of rules to be followed) highlighted the fidelity of the materials themselves during the experimentation process. For example, no two lemons are identical. Each may possess similar properties, however, the exact amount of potential electrical energy varies. One attempt while working with the lemons to turn on an LED included a particular lemon not having enough juice to allow the charged particles to flow within the citric acid. Lemons contain citric acid which breaks up into charged anions and cations. Lemons conduct electricity because the charged particles are able to flow within the citric acid. However, a lemon might dry out while the copper and zinc nails are inserted, and the poles are going to get rusted. This will propel the voltage to drop to zero. It is similar to what happens to a battery when you connect two ends together and they short circuit. The difference here is that the voltage and current within the lemon are so small that it won't cause any harm (i.e. spark, fire). This led to the need to swap out that particular lemon with another one and then testing once again to see if these materials were able to conduct any source of electricity.

Another example of the fidelity of materials at play during prototyping includes attempting to generate electricity with a potato. Potatoes act as a "salt bridge" between two copper and zinc metals, which allows electrons to move freely, generating electricity. Potatoes are considered good electrical conductors due to being rich in both water and acid (80% water, rich in potassium) [23]. However, the potatoes we used during the experimentation phase weren't generating any electricity. While the potatoes did contain enough voltage for an LED to light up, the resistance within the potatoes we bought from our local grocery store was too high for electricity to be conducted. This is due to Ohm's Law [22], where the electric current is the result of voltage divided by resistance ($I = E/R$). Although potatoes are known for being the staple DIY electricity generator, our potatoes (due to the unique properties of their own), did not produce enough current to light an LED.

While experimenting, we categorized the materials into two groups: the first group, input, included the materials that had the potential to generate electricity (e.g., lemons, potatoes, blow dryers, oxidized copper coil and nails, copper, aluminum cans, empty container, copper coil, zinc nails, copper sticks, lemons, plastic fans, salt, wheels, gearboxes, LEDs, alligator clips, insulated wires,

Figure 2. Input materials.

Figure 3. Output materials.

homemade conductive play-dough, and one blow dryer).

The second group, output (Figure 3), included materials that would be required to create the applications that would be powered by the electricity generated (arts and crafts materials, i.e. construction paper, popsicle sticks, and dowels, scissors).

These materials were chosen due to the nature of these objects being readily found and available at a low cost. By using materials that weren't difficult to acquire, a larger audience is able to partake in a making-based activity whose parts can be replaced if broken, damaged, or lost. The electronic-based materials are able to be found amongst old toys or electronics or even at local hardware stores, while the natural materials, i.e lemons, potatoes, are able to be found at local grocery stores alongside the aluminum soda cans. Not only are these materials readily available, but they are also interacted with on a frequent basis. Using materials that may be used for different purposes, and then highlighting other potential uses from the same source, allows users to view other materials that they might interact with on a daily basis in a newer light. Repurposing these items can lead to a change in their identity while tinkering and can lead to further material exploration.

Guidebook Design

The guidebook consisted of three subsections. These subsections were drawn from the process of experimenting with the materials from various sources to the potential to conduct electrical energy.

Section 1 (Figure 4) contained an introduction and a pre-questionnaire were students were asked to fill out prior to the workshop to gather data on the demographic that would be participating in the study. Obtaining the depth of the knowledge (on the topic of electrical energy) students had prior to the workshop, would add to understanding the relationship they developed with the materials during the workshop itself. The introduction following the questionnaire provided a quick summary of what the following workshop would entail. This section highlighted for the students what would be expected from them in the workshop, preparing them mentally for the activities to be worked through. In times of confusion, seeking particular information, students would be able to flip to certain sections for references from the Table of Contents.

Section 2 (Figure 5) contained information the participant might need to refer to while conducting or replicating experiments. This section contained basic foundational information related to the topic of electrical energy (such as voltage, current, resistance, power, etc). As a learner with little experience with understanding electrical energy, references are ideal for quick recaps of knowledge. This section additionally contained a materials page where objects were diagrammatically identified as the various material resources

Figure 4. Section 1 Guidebook

introduction

In the following activities, you will be using a number of everyday objects found around you to generate electricity from different sources of energy.

Using the electricity that you have generated, you will build simple mechanisms/devices to serve an application you have in mind.

1

table of contents

2

1. How old are you?
   a. 12
   b. 13
   c. 14
   d. 15

2. How often have you engaged in hands-on classroom activities?
   a. always
   b. very often
   c. sometimes
   d. rarely
   e. never

3. Do you know what voltage is?
   a. yes
   b. no
   c. not sure

4. Do you know what current is?
   a. yes
   b. no

5. Do you know what resistance is?
   a. yes
   b. no

Q&As

3

6. Do you know what power is?
   a. yes
   b. no

7. Have you worked with a multi-meter before?
   a. yes
   b. no

8. Have you worked on projects where you have generated electricity?
   a. yes
   b. no

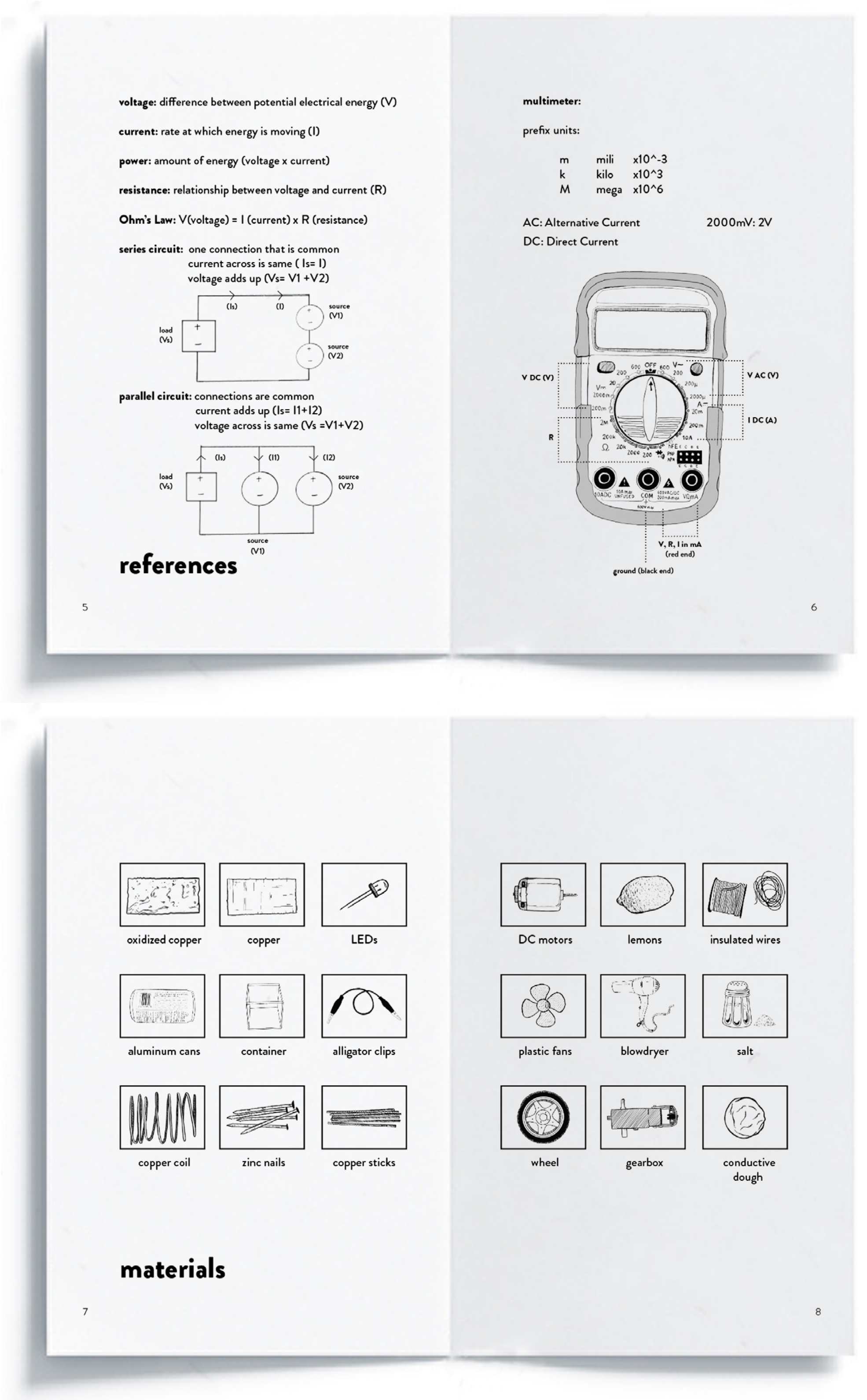
9. If yes to question 8, tell us about how you generated electricity:

10. How comfortable do you feel working on hands-on projects by yourself?
    a. extremely
    b. moderately
    b. not at all

11. How enjoyable do you find working on hands-on projects by yourself? (ex.)
    a. extremely
    b. moderately
    b. not at all

4

Figure 5. Section 2 Guidebook


voltage: difference between potential electrical energy (V)

current: rate at which energy is moving (I)

power: amount of energy (voltage x current)

resistance: relationship between voltage and current (R)

Ohm's Law: V(voltage) = I (current) x R (resistance)

series circuit: one connection that is common
current across is same (Is= I)
voltage adds up (Vs= V1 +V2)

parallel circuit: connections are common
current adds up (Is= I1+I2)
voltage across is same (Vs =V1+V2)

references

5

multimeter:

prefix units:

m	mili	x10^-3
k	kilo	x10^3
M	mega	x10^6

AC: Alternative Current 2000mV: 2V

DC: Direct Current

6

oxidized copper
copper
LEDs
aluminum cans
container
alligator clips
copper coil
zinc nails
copper sticks

materials

7

DC motors
lemons
insulated wires
plastic fans
blowdryer
salt
wheel
gearbox
conductive dough

8

made available during the workshop. The materials section contained visual references for faster comprehension to find particular items. This section was drawn from the need for the organization of materials while prototyping.

The final section of the guide, Section 3, consisted of two subsections labeled, Activity 1 and 2. Activity 1 (Figure 6) was a collection of examples for experimentation including chemical, wind, solar and kinetic sources. Activity 2 (Figure 7) contained a project template for the creation and organization of built upon applications (following the previous examples. Activity 1 served as a starting point for makers to familiarize and understand the roles and properties of the materials being used in the project. Activity 2 built upon that knowledge to help participants plan and prototype an application of their choice. Section 3 also included open-ended questions for students to note down their findings, jot down any notes they have, and organize the information regarding their prototypes. This section also served as the area for comprehension and exploration for the participants.

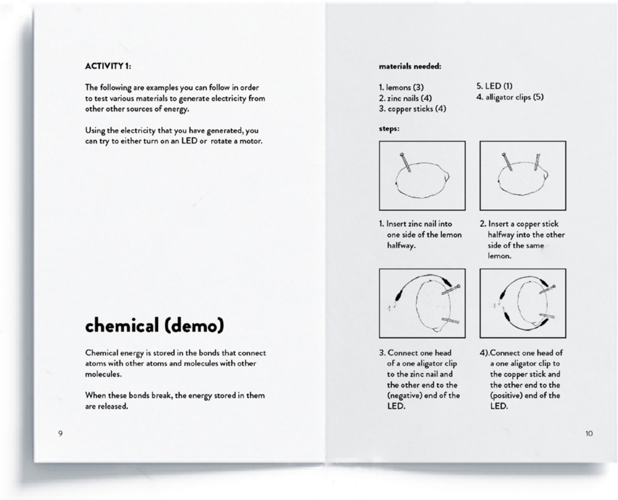
Within the Activity 1 subsection, an experiment that used lemons, zinc nails, and copper sticks and to generate electricity was included [6,21]. This activity was selected to be demonstrated at the start of the workshop by the facilitators. Due to this activity being demonstrated, an additional chemical source (using saltwater, copper coil, and an aluminum can) experiment was added for the participants to try on their own. The additional chemical activity does not yield any physical results, due to not producing enough current to turn on the LED. The activity was included as a way for the learners to comprehend the process of failure. We hoped that when the learners experimented with the material and filled in the voltage and current information that it would help them understand why the activity did not work.

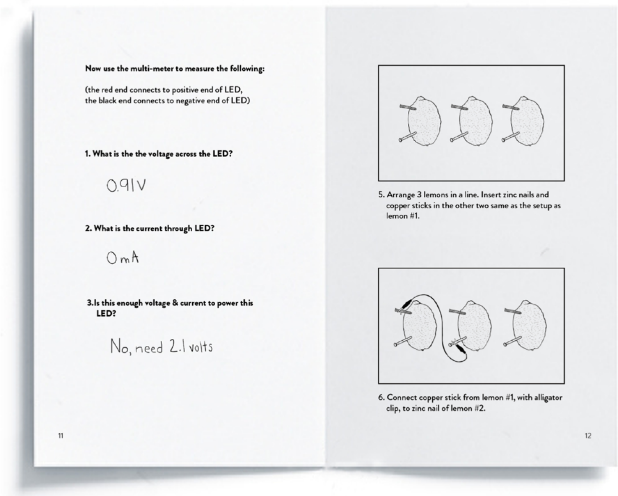
In the process of creating the guidebook, several varying experiments were tested. Some of these experiments were able to generate electricity while others failed to do so. During the process of testing, the failing experiments helped in the understanding of the composition and identity of the materials at hand during the making process.

An example of a "failed" experiment included attempting to generate enough electrical energy from a solar source. Although a small current was able to be measured with a multimeter, the amount would need to be exponentially scaled up in order to turn on a small LED (Figure 8). By incorporating an experiment drawn from existing technologies (solar panels), learners would understand the fundamentals of how solar cells are formed, and the scale needed from them in order to be functional.

The wind energy source was another example of a "successful" experiment; generating electricity to turn on an LED, while also being able to rotate a kinetic application of rotating a wheel. The blow dryer was also able to be combined with other materials (lemon, a chemical source) for a higher ceiling of experimentation [4] to be possible. Higher ceilings entail learners being able to build upon the basic tools so that different alternatives and a wide range of exploration is possible [26].

Figure 6. Section 3 Guidebook : Activity 1





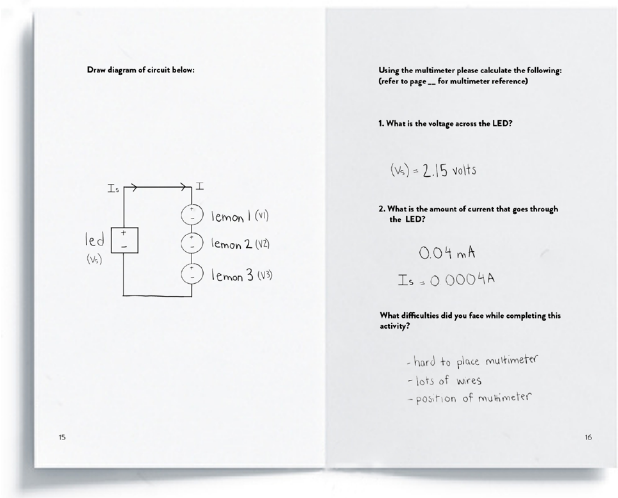


Figure 7. Section 3 Guidebook : Activity 2

Kinectic energy as a source was also an example of high ceiling experimentation in the guidebook. For generating kinetic energy, rotating a gearbox was used.

By incorporating examples that generated enough electrical energy to make something happen (turn on a LED, rotate a wheel) and those that failed to produce any visual result (besides numerical values on the multimeter), the participants are left to explore what experiments might be "successful" in the aspect of being able to generate enough electrical energy for a visible application. Participants may experience moments of failure (in this context of turning a LED on) but will have the opportunity to define the reasoning behind that failure.

Section 3 also includes the second activity which clarifies for the learners that they are moving on to a different stage of the workshop. The learners are now asked to start experimenting and find combinations of materials to generate electrical energy (using the knowledge they have gained in the previous activities). The second activity template mimics the templates previously used for activity one. The template includes space for learners to brainstorm ideas (e.g., draw concept sketches), designated sections where the students fill out the materials needed, step-by-step procedure, voltage, and current generated in their circuit and a final prototype sketch of their prototype. The students would be asked targeted questions regarding challenges faced during the activity, solutions developed, and any additional thoughts to show the growth from starting the activity.

Design Elements

The guidebook was designed to be accessible and appealing to the intended demographic (age group from 12-14) in the following ways.

A sans serif font was chosen for the text due to aiming for a friendlier, less intimidating feel for the students when working through the guide. Sans serif fonts are also used more often for accessibility and are considered more legible [32,10]. Handwritten examples are provided in the "demo" section of the first activity so learners can identify and refer to examples of what is expected of them in the activities that follow.

The open white space between the text encouraged note-taking, sketching, and reflection for students to partake in while conducting the activities. This is drawn from the journaling aspect of experimentation, where note-taking is key for knowledge to be built upon and analyzed.

Simple and efficient line illustrations were used to demonstrate the activities instead of photographs. Illustrations were an easy and cost-efficient way to reproduce the document since they were able to be printed in black and white. Creating an accessible document would benefit a wider audience.

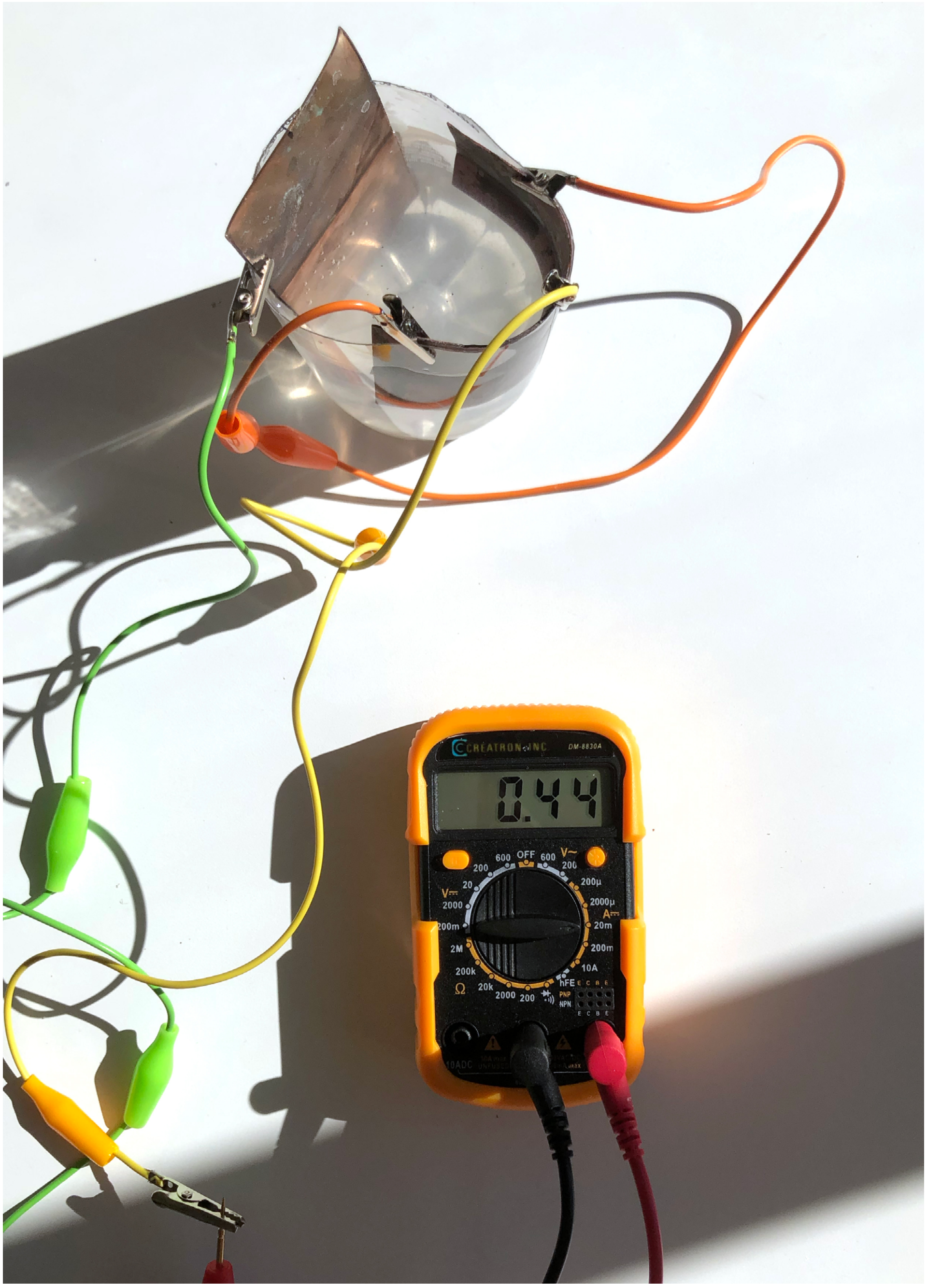


Figure 8. Multimeter reading of solar cell.

STUDY

Methodology

The overarching goal of our work is to create a design probe which enables makers to learn informally by focusing on the materials they use for making. In this specific project, we created an instantiation of our goal and built a toolkit to help students to learn concepts about electrical energy using a number of found objects such as potatoes, lemons, water, wind, copper wires, homemade conductive playdough, and art and craft materials. During the workshop, participants were encouraged to share insights based on their personal experience as it relates to the project objectives. The workshop sought to gain a clearer understanding of the relationship learners have with the materials they experiment with and how they learn informally through the process.

stu dy

School Context

We conducted our workshop study at the Tree school (a pseudonym) in Mexico City. This school was chosen because their academic structure already facilitated components of making-based learning such as; a) small class sizes which promote educational experiences to be individualized, b) child-centered curriculum that is flexible, and c) they teach students using vivid and real experiences and teamwork. At the Tree school, they practice a Project-Based curriculum, which is designed to maintain student's interest by ensuring that learning prepares them for application in a setting outside of school while encouraging them to be resourceful and use divergent thinking by looking for more than one solution to a given problem.

Tree school was interested in our goal and methodology and gave us permission to use three class periods for conducting our workshop. By working with the students at Tree school we had the opportunity to understand how our specific design was being perceived and understood by students who had already gained some exposure to learning similar to the ideas discussed in the feminist maker pedagogy [5]. Feedback from the school teachers and students also allowed us to gain input for further refining our prototype in the future.

Participants

Twelve students participated in our workshop (ages 13-15, 8 males and 4 females), Out of the total participants, P8 was the only student who stated that they had rarely engaged in hands-on classroom activities prior to the workshop. While questioning the students on their previous knowledge concerning the topic of generating electrical energy, ten students stated that they understood what the terms voltage, current, resistance, and power meant. P2 was unsure about voltage, and both P2 and P6 stated no when asked about resistance. Only 3 of 12 participants had worked with a multimeter prior to the workshop (P3, P8, and P11). Seven participants stated that they have not worked on projects where they have generated electricity, while the five who had, stated that they had experimented with generating electricity using lemons, potatoes, motors, electronics, and LEGO wheels. Ten students stated that they were either moderately or extremely comfortable with working on hands-on projects by themselves, while only six out of those ten found it enjoyable.

Study Procedure

We conducted a two hour and fifteen minutes (intended three hours) workshop hosted at the Tree (pseudonym for anonymity) school.

<u>Setup</u>

Conducting a collaborative learning workshop required students to work in four groups of three, formed by self-selection.

The workshop was broken down into five parts: a) introductory presentation and Q&A session, b) identification of material resources, c) testing of simple mechanisms, d) building applications and e) show and tell. The presentation and Q&A happened during the first thirty minutes of the workshop and covered some fundamental concepts (such as voltage, current, power, resistance, series and parallel circuits, and how to use a multimeter), introduced the students to the toolkit, and went over the safety protocol. We demonstrated to the students one simple activity of turning on an LED with lemons. Any questions the students had were also answered during this time.

The workshop was spread across three 45 minute time sessions with a lunch break after the first. There were also three isolated stations for students to progress one by one.

At the first station (Figure 9), the students were asked to play with a variety of materials (such as lemons, potatoes, copper wire, water, and hairdryer as a source of wind) and identify those that they could use as a source for generating electricity. Students would experiment with the materials and a multimeter to measure the output current and voltage. All students were provided with a guidebook to enter their findings from the experiment as well as write down their subjective thoughts about the experience. Students had to be reminded to continue filling out the guidebooks. Students resorted to filling out one guidebook per team.

Next, students arrived at station two (Figure 10) where they used their selected material sources for generating electricity to activate simple output mechanisms such as turning on/off LED and rotating a servo. We asked students to continue journaling the experience as done at the previous station.

Lastly, students arrived at station three where they used the knowledge they gained from experimenting at workstations one and two to create a prototype application of a higher fidelity (e.g., a controllable night lamp). Throughout the workshop, students were free to go back and forth between the workstations as they saw fit. Due to time restrictions, some groups were only able to interact with workstations 1 and 2.

The workshop ended with the groups presenting their projects to the rest of the class wherein they discussed what they built, how they built it, any challenges faced, how they overcame the challenges and things they learned and enjoyed. After the workshop, we conducted one-on-one interviews with the students to gain further insights into their experiences in the workshop. This also helped us get feedback from all students and not just the more extroverted participants.

Data Collection

To understand the students' experiences we collected data through a variety of sources (listed below). The data collection was done by the researcher and two workshop facilitators. One facilitator was a faculty member from the Tree school and the second facilitator was another student from our university who was fluent in Spanish.

1) Pre-questionnaire

We asked demographic information and questions regarding prior experience with understanding electrical energy concepts and maker-based activities.

2) Video Recording

An ongoing video-recording was made where all the participants were shown working throughout the workshop.

3) Group-interviews

We audio-recorded interviews with the individual teams (three in total; one team had to leave due to time running out) at the end of the workshop.

4) Fieldnotes

Notes were taken throughout the workshop concerning the behavior and attitude the students had while they worked and their work process itself from an external point of view.

5) Presentation Audio

We audio-recorded the students while they were presenting their final projects at the end of the workshop and while they discussed what they learned during the session.

6) Guidebook

The students wrote in the guidebooks that were passed around (which included the pre-questionnaire) at the beginning of the workshop. This guidebook contained prompts which they followed along for activity one and an open-ended section to be filled out for activity two.

Workshop

The social dynamics in the classroom became evident once it was announced that teams could be chosen on their own. The groups were broken down into four teams, identified in the following as T1, T2, T3, and T4. Each team had three participants, being identified as P1, P2, and P3.

The interactions the students had with the toolkit were hesitant at first since they had to recall previously learned concepts and now needing to understand them enough to apply externally. However, when asked if they found the guide helpful at all, P1 of Team 2 stated, "Yes, because if I had a doubt of what I am missing, I can go to the book."

Figure 9. Station 1

Figure 10. Station 2

RESULTS

The feedback we received post-workshop from the students included an overall sense of enjoyment of the time spent. Out of twelve, nine students gave a score out of 5 of their experience. Three students gave a 4 rating, three gave a 4.5 rating, and three gave a 5 rating.

The insights drawn from this study are presented in the following examples.

re sults

Substitution of Materials

In circumstances where participants were faced with a shortage of materials, T2 demonstrated abductive reasoning with substituting materials with the ones available to them. By analyzing the properties of the lemon (from the demonstration at the beginning of the workshop), T2 were able to identify that lemons shared similar properties as a plastic container filled with saltwater (Figure 12). T2 learned that the materials around them were available to use and replaced the materials that were prescribed for the experiment's structure with them. This method of quickly adapting to the situation when faced with an obstacle showcased how creativity was born when faced with a lack of resources. Facing adversity became the catalyst for solutions that might not have been apparent when working otherwise, to inspire alternate experiments. Understanding the components and properties of the materials at hand equipped participants for various unseen or predicted circumstances.

Identifying Materials in Experiment Structure

During the entirety of the workshop, the participants learned about the roles materials play in the experimentation structure. T3 showcased how interpreting the role of the materials was necessary in order to witness any success in exploring outside the structure of the guide book. By starting off with choosing an experiment that T3 were already familiar with (conducting electrical energy from lemons), T3 decided to experiment with adding additional materials to the given structure of that particular experiment. In the original structure of converting chemical energy into electrical energy experiment, a minimum of three lemons, four zinc nails, four copper sticks, five alligator clips, and one LED is required.

When T3 decided that they wanted to build upon this experiment, the team started adding more lemons, eventually taking all the lemons available. However, instead of duplicating the number of zinc nails and copper sticks as well, T3 spotted a copper coil and decided to replace the copper sticks with the coil. T3 then proceeded to add the lemons onto the coil, "connecting" them to each other that way (Figure 11). When the team failed to produce any electrical outcome, they realized that simply adding similar materials was not enough to reach their goal. Each material in the experiment's structure had a particular role and placement that was necessary for a successful outcome. When experimenting in a controlled environment, the role materials play is essential to understand due to how the materials interact with each other and influence the flow of the experiment. Although T3's experiment was not functional, it still propelled them to continue their exploration of what materials the team could add to their prototype. At the end of the workshop, T3 had learned that replacing one material (copper sticks) with another similar material (copper coil) changed the structure of the experiment; therefore not showing a predicted outcome.

Instigating Social Commentary

A certain amount of materials were available for the participants to interact with across the various stations set up in the workshop. The constraints of these materials influenced negotiation and creativity towards other resources (i.e. time, management of people, alternative sources). Some unintended outcomes included having team dynamics influence other teams to adapt to the lack of available materials. If one team wanted to use the blow dryer to mimic wind in their setup, the other teams had to wait for their turn or chose to spend their time building an experiment with alternative sources.

T3 had taken all the remaining lemons to build their experiment which led to a lemon deficit for the rest of the teams to experiment with. T2 decided to work on another chemical source demo which required water to be mixed with salt. However, there was also a lack of salt available. T2 then decided to take one of the discarded lemons from the facilitated demonstration which failed to conduct any voltage and squeeze out the juice within into their water so they could mimic the properties of the citric acid within. By understanding the components and properties of the materials T2 had access to, they quickly adapted to proceed with their chosen experiment.

T4 consisted of members who showed blatant frustration towards their experimentation methods, and comparative nature towards their classmates as well. Following the demonstration conducted by the facilitator, T4 immediately asked for help in recreating experiments from the guide. When told to look at the reference manual for assistance instead of relying on the facilitator heavily, T4 would express reluctance. The team decided to reuse examples given by the facilitator while prototyping and expressed distaste when realizing T2 had used similar source materials as them (blow dryer to replicate wind). This led T4 to incorporate a combination of an additional source (chemical energy from lemons). T4 was the only team who had attempted combining various sources (lemons and plastic fan, chemical and wind sources) in their prototype (which was to be explored in section 3) within the given time frame, and following T2's presentation at the end of the workshop stated, "We have practically the same [experiment as T2], except we have less power from the hairdryer and more from the lemons".

Non-Prompted Experimentation

The guidebook accompanying the workshop contained examples of worked out experiments. Some of these experiments were able to generate the amount of electrical energy required to turn on an LED or to turn a motor. However, some of these experiments did not manage to produce the necessary output needed to power anything. These experiments contained various materials that produced various sources of energy, i.e. solar, chemical, kinetic, and wind. One source that wasn't listed however was water or a hydropower source. T1(a team containing participants who already displayed knowledge of the material prior to the workshop, and had immediately isolated and worked on their own while asking for no assistance from the workshop facilitator) quickly recognized that this was a source that wasn't prompted in the guidebook after flipping through (Figure 12). Whether T1 were motivated by exploring the unknown, or due to a predetermined choice of the material they wanted to experiment with, T1 re-assessed parameters of the workshop environment as the apparatus to test their future prototype.

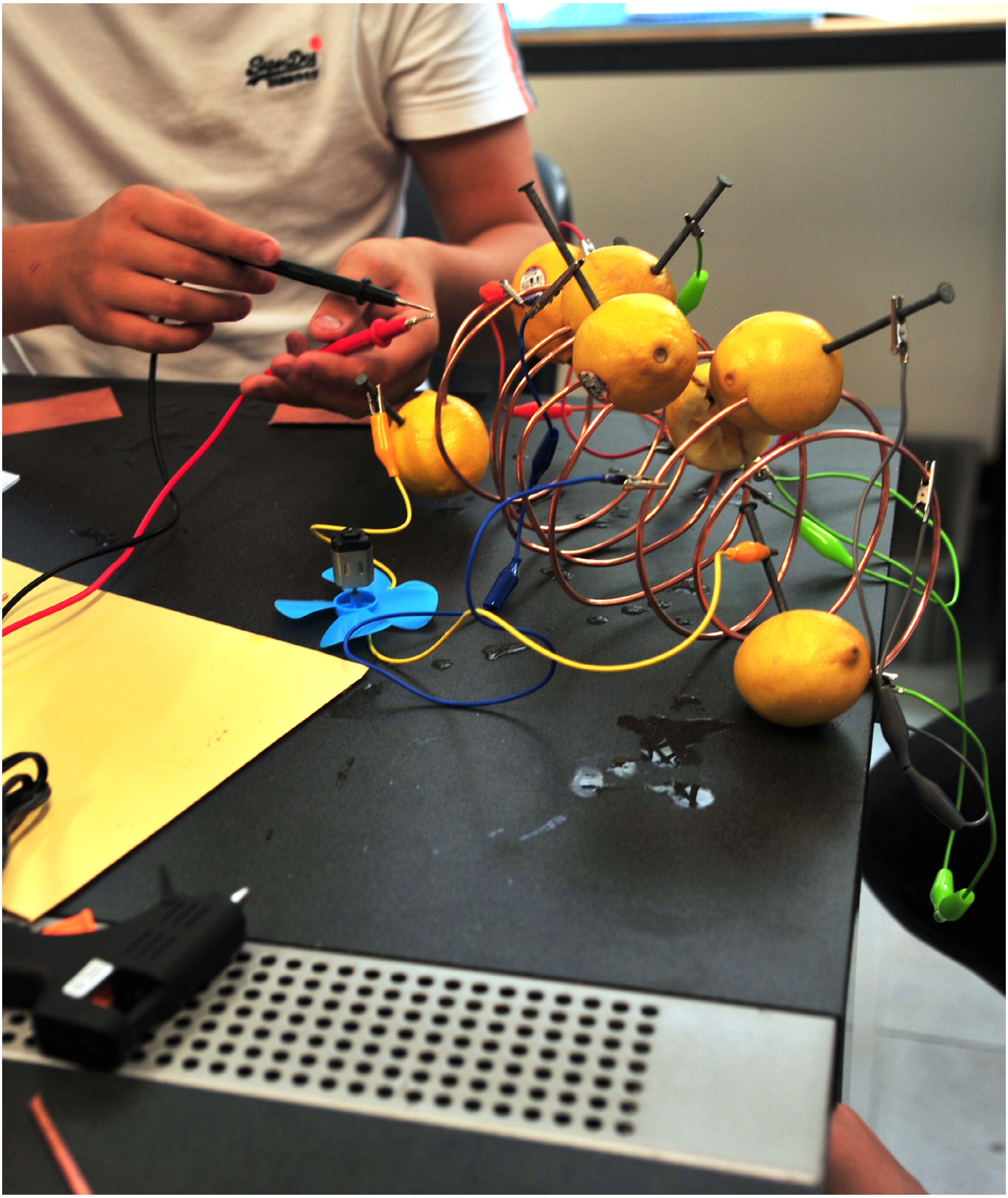


Figure 11. Copper coil replacement.

Interaction With Failure

Some intended outcomes of the study included witnessing the students' reaction to the failure of certain experiments failing to produce any electricity to power the LEDs. Asking participants to write down the voltage and current values of each experiment allowed them to understand why that particular experiment "didn't work" (generate enough electrical energy to turn on the LED). This softened the amount of frustration the participants might have felt otherwise. T2's first replicated experiment was an example that didn't work (second chemical source example), yet since T2 used the multimeter to document the voltage and current that was conducted, the team understood where the hindrance occurred and moved on to test out another experiment. The team members possessed a positive attitude despite an outcome of supposed "failure".

Figure 12. Material substitution.

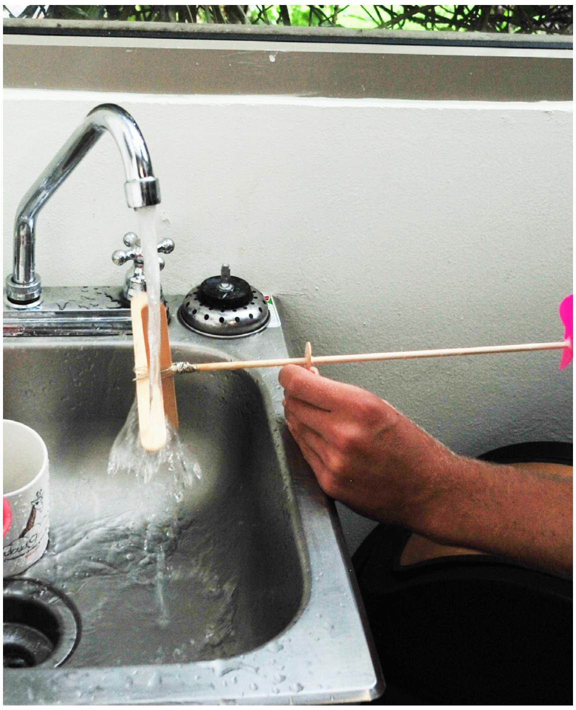


Figure 13. Alternate hydropower source.

dis
cussion

DISCUSSION

Tim Ingold (an anthropologist who has investigated the relationship between materials and the making process), argues that making is often incorrectly understood as the translation of an idea in the mind to material form. This stems from the hylomorphic view of making where Aristotle contends that every physical object is a compound of matter and form [16]. Ingold calls for a non-hylomorphic view of making where the maker "joins forces" with "active materials" and works with them "in anticipation of what may emerge" [17]. He describes making as correspondence [16,17] between the desires of the maker and the desires of the materials. Form ultimately emerges from the interplay of human and material forces. In correspondence, the maker "grows with a set of materials and practices, becoming attuned to their properties or forces and generating knowledge that carries through their practice" [8].

Our study aimed to explore how one can enable novice makers to explicitly focus on the materials in their making process and consciously learn from them. As stated in the results, while prepping for the workshop, various materials were tested in order to understand their roles in the structure of the experiment. Copper had to be heated and cooled in order to be able to convert solar energy into electrical energy once interacting with saltwater. Multiple attempts were made working with the copper to understand how much time, heat, and cooling were needed in order for it to "work". This is parallel with Ingold's view of "following the materials" [14] while making. The participant follows the flow of the material as it evolves [16]. This itinerant process brings the form of their work into existing, rather than forcing the material to arrive at a fixed destination as a preconceived product.

The guidebook presented the participants of a template to follow, outlined with activities to prototype with given materials. However, it was up to the participants to discover the identities and properties these materials possessed in order to work with them in their experiments. The building blocks were at the disposal of the students (from the learnings of Activity 1) yet the final outcome of their prototype was not outlined for them (in Activity 2 of the workshop). Students were asked explicitly not to repeat any of the previous experiments listed in the guidebook for the completion of the second activity; to enable applications of their own creation.

Ingold emphasizes that itineration is still being followed even if the practitioner is following directions laid down in a plan, score, or recipe. Planned action and itineration are not alternative procedures, the practitioner does not have to pick one or the other, or find some way to combine them [24]. The participants in our study followed the directions of the guide book to direct them from one material to the next. However, they had to find their own way, attentively and responsively, of working with the materials, to understand the process to generate electrical energy. Instead of going through the replicating explicit details while proceeding through the activities in a metronomic manner, the participants followed the guide in order to find their own rhythm of experimenting. Participants referred to the guide only when necessary to document their observations or to refer for clarification when feeling lost.

Our study also displayed the guidebook acting as the mentor guided by the theory of ZPD, or zone of proximal development [20]. The theory of ZPD suggests that in the beginning, the learner should be guided and assisted to help attain the necessary minimum skills. To allow students to ease into the DIY process and to encourage novice participants, methods should be employed that start simple and slowly move towards open-ended activities [8]. Our guide started off with experiments where students would learn about the materials they would come in contact with in order to progress and build upon that knowledge to work with the materials in a more open-ended setting. The role of the facilitator is also rooted in ZPD theory. In our study, the facilitator was responsible for the level of aid they assisted the students within situations where the students felt frustrated or lost. This was done so without leading the students explicitly to a destination, but guiding them to various possible directions the students would choose to explore. The facilitator was also responsible for creating a relationship with the students of transparency and trust, in order to witness the creative process each student would go through.

Limitations

Although participants followed the guide to attempt experiments, some students expressed that writing down information slowed them down (especially since time was already a bit shortened). P1 and P3 from Team 1 both stated that they did not have time to fill out their guide books while prototyping. Not all participants were able to interview the facilitator following the study due to time constraints as well. Three out of the twelve participants (all members of T4) had to leave due to not being able to stay overtime after class had ended. The time constraints impeded several aspects of the workshop. Unforeseen circumstances included not being able to set up the workshop materials before the students had arrived, therefore resulting in a delay for surveys to be completed at the beginning of the workshop. This delay caused students to lose focus, causing delays in the live demonstration to begin. These time constraints and classroom environment procedures (not being able to enter a classroom prior to the workshop) led to an overall loss of time for all students to partake in Activity 2.

conclusion + future work

CONCLUSION + FUTURE WORK

This paper has contributed to the understanding of how a structure where participants can explore the roles materials play while experimenting is beneficial for makers to learn from materials. Our study at the Tree School in Mexico City shows when a guideline is presented where failures are a possibility (without the knowledge of the participant prior to encountering), participants are forced to access the individual identities the materials possess in order to understand how to overcome presented adversities. Based on the results, we discussed how our study incorporated design principles, such as Ingold's, in a setting where participants were engaged in science-related topics. A possible desired outcome for this study includes helping novice learners be able to go around their own homes and identify materials for new inventions based on their surroundings.

We have several directions for future work. One direction is realizing that our study would be better observed in a setting outside a classroom or school. Participants would truly have to use found objects that were accessible for them and understand and identify their properties in order to experiment. Second, is to study the applications of our guide towards demographics with less opportunity or access to community maker workshops. In the future, for an alternative point of view from a different demographic, we would aim to work in an environment with a lower SES setting. Lastly, it would be interesting to see what other materials could be incorporated into the guidebook, and build upon the materials participants would learn from.

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