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# Personally Meaningful Design: Sound Making to Foster Engineering Practices with Artifacts from Home

**Santiago Hurtado [1,*], Teemu Leinonen [2] and Anna Keune [1,*]**

[1] Institute of Advanced Study, School of Social Sciences and Technology, Department of Educational Sciences, Technical University of Munich, 80333 Munich, Germany
[2] Department of Art and Media, Aalto University, 02150 Espoo, Finland; teemu.leinonen@aalto.fi
* Correspondence: s.hurtado@tum.de (S.H.); anna.keune@tum.de (A.K.)

**Abstract:** Early engineering experiences can provide young people with experiences that can contribute to developing longer-term interest in the field and addressing dropout issues faced in engineering internationally. One way to engage young people with engineering is through the creation of personally meaningful sound-making projects with everyday materials and electronic kits. Sound making can make it possible for people to connect to their personal experiences and to represent these personal experiences through artistic means while also performing engineering practices, like asking questions, defining and delimiting problems, and developing and optimizing solutions with physical materials that produce sounds. Such design processes are referred to as engaging in the design of personally meaningful projects. However, it remains underspecified what personally meaningful means and, therefore, what aspects to integrate into engineering educational activity and technology designs to foster personally meaningful design opportunities. Building on constructionist perspectives on learning, this qualitative research investigated engineering practices as middle-school-aged youth used electronic construction kits and personal tangible material objects to create sounds. Iterative and thematic analysis of engineering practices of semi-structured interviews and video-recorded youth workshops showed that sound making with personal objects and electronic construction kits is a context for engineering design practices. This study also showed that integrating personal tangible projects that materialize personal histories can foster engineering practices. The findings contribute to our understanding of the theoretical idea of personally meaningful design in constructionism by presenting the importance of integrating personal histories through the design of personal projects with tangible material objects of a person's life.

**Keywords:** engineering learning; constructionism; sound; construction kits



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## 1. Introduction

The STEM field faces dropout issues internationally [1–4]. Alternative approaches to STEM (Science, Technology, Engineering, and Mathematics) education are needed to counteract this trend. We focused on engineering education, which can be a pathway to STEM education [5]. Engineering education in K-12 settings is still not widely implemented, but early exposure could provide youth with positive experiences to inform their decisions to choose to continue to engage with STEM-related fields. A promising approach toward adopting early engineering education is through the design of personally meaningful projects [6]. Personal projects provide meaning beyond intended use; they evoke experiences that tie domain learning and interests [7].

One meaningful context in this area is sound making. Sound has personally meaningful properties because we experience sound in everyday life and attribute meaning to sound through memories and emotions [8]. Sound as a design material can be a quasi-object (i.e., a material we cannot touch but we can create and hear) [9] and an "object-to-think-with", which provides a link between abstract and sensory knowledge at the intersection of cultural presence, embedded knowledge, and the potential for personal identification [6], p. 11. Constructionist studies of personally meaningful learning experiences describe the personally meaningful as the possibility of learners to create the projects they want to create within the bounds of the materials and the scope of provided goals [10–13]. Yet, these studies underspecify the meaning of personally meaningful, making it difficult to know how to design for it and to understand how personally meaningful design projects might intersect with the kind, the quality, and the quantity of performed engineering practices. Investigating materials and designs that will make it possible for youth to tie their projects to personal histories, expanding our understanding of the personally meaningful in constructionist designs is needed to guide learning activity and technology design in targeted ways. Therefore, we asked:

Research Question:

*How does designing for personally meaningful learning using tangible artifacts from home foster engineering design practices in a sound-making workshop?*

To address the research question, we investigated the engineering design practices that youth performed as they engaged in sound making using electronic construction kits (e.g., Squishy Circuits and Playtronica Playtron) combined with personal tangible objects that youth brought to the workshop from home settings. We explored conductive and non-conductive materials that could be combined with the sound-making electronic construction kits. We conducted two workshop sessions (70 min each) with two groups of 10-year-old middle school students (approximately 4.5 h total), and we conducted semi-structured interviews during the sessions (approximately 2 h total). We analyzed the data using iterative and thematic coding to capture the interactions with kits, materials, and a tangible artifact from homes, as well as coding of performed engineering design practices based on the Next Generation Science Standards (NGSS). The analysis showed that designing with personally meaningful through using tangible artifacts from home can engage young learners to develop personal projects that foster engineering design practices. Expanding the definition of personally meaningful could help better design for learning in the STEM field, and, therefore, lead to a more sustainable approach to early STEM education. We share thoughts on possible implications of the work on social, economical, and ecological sustainability through the use of low tech and low-cost tools and materials along with possible impacts that early access to engineering educational opportunities might have on young people.

### *1.1. The Importance of Engineering Education*

The STEM field faces dropout issues internationally [1,2]. The European Union (EU) is on a downward trend in STEM graduates [14], despite an overall increase in enrollment and graduation rates in non-STEM disciplines [3]. One example of this are the dropout rates in Germany in Engineering, which are around 50% in majors like electrical engineering [4]. Alternative approaches to STEM education are needed to counteract this trend [15].

Standards like the Next Generation Science Standards (NGSS) [16] provide guidance for designing curricula and activities, and encourage interdisciplinary connections across STEM domains that may address the challenges related to people turning away from the field. The importance of STEM education lies in the potential impact that STEM graduates can have on advancing new technologies, such as those related to renewable energy and sustainability [17]. In this study, we focused on engineering education, which can improve knowledge in related areas, including mathematics and science [5]. While engineering education is not widely implemented in K-12 education, early exposure could provide youth with positive experiences to inform their decisions to choose to continue with STEM. Thus, there is a need to better understand how to design interventions that foster engineering practices among young people.

*1.2. Constructionism as an Approach to Early Engineering Education*

One perspective for generating contexts that foster opportunities for young people to engage with engineering is constructionism [6]. Papert developed constructionism based on constructivist approaches that state that knowledge is constructed actively in the mind of the learner through the construction of artifacts, positioning the learner as an active agent [18]. In constructionism, learning involves developing connections between old and new knowledge through interaction with others and creating artifacts [19].

Within constructionist interventions, including those focused on engineering learning, the theoretical idea of personally meaningful describes projects where learners can bridge personal interests and abstract knowledge, arguing that learning is most effective when learners work on design projects to build meaningful outcomes [6]. Personally meaningful projects have been investigated in creating virtual worlds [10], in motivating learning opportunities within a juvenile detention center [20], in learning computational skills through bug creation [12], learning about machine learning through personalized stuffed toys [21], or developing understanding of computation thinking in pre-service teachers [11]. These studies showcase some examples of personally meaningful projects in different populations for a variety of learning themes, using different materials. For example, using stuffed animals to inspire youth to learn about machine learning by coding movements of sensors and training them [21], or using personalized e-textiles projects to design bugs and learning computational skills [12]. Additionally, materials can also be personally meaningful. Pahl and Rowsell argue that personal artifacts can connect personal histories to the learning experience of learners by incorporating them into their learning process (e.g., using family artifacts to aid the development of literacies) [22]. Yet, we can see that it remains underspecified what personally meaningful is, which aspects are productive for engineering learning, and how to support it.

Papert also argues that the materials used for the construction of the projects allow learners to explore complex systems and concepts using objects-to-think-with (OTTW) [6]. OTTW are objects that enable learners to connect personal creations and theoretical knowledge. The personal projects facilitated by OTTW focus on objects that have meaning that goes beyond their intended use and provide learners with experiences that are tied to their interests and learning experiences [7]. Specifically, Papert states that OTTW should meet the three criteria of "an intersection of cultural presence, embedded knowledge, and the possibility for personal identification" [6] (p. 11). Therefore, materials that enable learners to explore and create are essential for developing personally meaningful projects and, by extension, learning experiences. Materials that only allow for binary right or wrong outcomes may not be suitable for constructionist designs, as they leave little room for personal design. OTTW have been studied extensively, with research showing the potential learning experiences that can occur with various materials as OTTW, such as video games [23], e-books [24], construction kits to create OTTW for physical education [25], and robotics construction kits [26]. In makerspace contexts, OTTW have also been explored as materials-to-develop-with, which encompass materials and co-development over longer periods of time and across spaces [27].

In this study, we looked at materials and design that can expand our understanding of personally meaningful for learners. We used tangible artifacts from home of the participants to guide their personal project. These artifacts are objects that they brought from their personal lives, and represent stories and connections to their histories. We used tangible artifacts from home to create personally meaningful projects and foster engineering design practices. We aim to look at the gap of understanding personally meaningful projects as more than just projects that involve personal interest, and take from literacies research that ties tangible artifacts from home to connect personal histories with personal projects for meaningful learning experiences.

This study focuses specifically on engineering learning. Hernandez-De-Menendez et al. state that engineers need to be prepared for the challenges of today's world, where pedagogical strategies across curriculums need to evolve to implement approaches that include active learning, research-based learning, and experiment-based learning, to name a few [28]. Constructionist approaches to engineering education may help young learners to understand engineering concepts through personally meaningful projects and materials that allow them to construct their learning experiences. One of the contexts where constructionist approaches to engineering education could be used is using sound as a material in making activities.

### *1.3. Sound as a Personally Meaningful Context for Engineering Education*

For this study, we considered sound making as a personally meaningful context for engaging with engineering. Sound is connected to material things, like by tapping fingernails on the table, by talking, by singing, or playing an instrument. At the same time, sounds cannot fully be touched like other "more physical" objects. For this reason, Wargo describes sound as a quasi-object, an object that carries meaning [29]. Sound and auditory sensing are familiar to many people as something that surrounds hearing people and that impacts hearing-impaired people through sound wave vibration. Sounds can tell and narrate a story, just like other artifacts. The alarm clock, the shuffling of sheets, birds chirping, coffee brewing, the shower running, a cat meowing. Some sounds can connect us with deep-rooted memories and experiences and, therefore, be deeply personally meaningful.

Beyond the physical sense of sound as personally meaningful, researchers have also considered sound as a design element that connects to a person's experiences. For example, Cambrón explored the methodology of sound postcards, in which a written letter is replaced by a sound message and the postcard creator must think about what sounds to include that represent a place [8]. Rodríguez-Sánchez et al. implemented this methodology with victims of armed conflict in Colombia and concluded that sound can be a powerful tool for recalling and telling a life story because we can connect these sounds to meaningful moments of our life, as they bring our personal histories to the present [5]. In the medical field, patients with Alzheimer's Disease have been treated with Music Therapy to regulate emotions and enhance cognitive capacity [30], because they are able to preserve songs connected to memories and emotions [31]. This suggests the potential of sound as a personally meaningful material that we can use in education.

Within educational contexts, sound has a wide array of implementations ranging from simple mnemonic devices to understanding the deconstruction of classical musical pieces with mathematical models [32], and the explanation of mathematical concepts through musical representations of a pangolin's armor [33]. Efforts are now being made to implement music, not only as a learning tool for STEM disciplines but also to combine it, encouraging learning in music and STEM, and fostering creative outcomes. Projects such as EarSketch, developed by researchers at Georgia Tech, allow people to create songs through programming, teaching basic Python skills, and engaging participants to create songs with samples from known artists and their own samples [34]. Another example is the Algorave movement, which uses programming software that aims to have live performances, with code projected on a screen to show how the music is being made in real time [35]. The Cinderella software has also been used to teach mathematics using programming for MIDI and algorithms as music outputs [36]. Additionally, noise is being researched as an alternative approach to traditional Western music making by bringing in cultural histories and embodiment of the learners through noise [37,38]. Sound is also being researched as a way to deepen understanding of pedagogical approaches or disrupt understanding of educational inquiry through sound [39].

In the present study, we consider sound as an OTTW, a material that connects learners to personally meaningful experiences through representations of their own tangible artifacts from home.

## 2. Materials and Methods

This qualitative study aimed to identify and test a design for youth to perform engineering design practices as they crafted personally meaningful sound projects with electronic construction materials. We facilitated sound making with a range of conductive and nonconductive materials inspired by tangible artifacts that participants brought to the research from their homes.

### *2.1. Research Setting and Participants*

#### 2.1.1. Research Setting

The research took place in a Junior Maker Space at an international private school with International Baccalaureate (IB) curriculum in Bavaria, Germany. Students with 65 different national backgrounds, covering a total of 48 spoken languages, were enrolled at the school through open enrollment, so prospective students could start any time during the school year. The Junior School Maker Space (Figure 1) was established in 2017 and, at the time of the present study, was equipped with tools and materials for Science, Technology, Engineering, Arts, and Mathematics (STEAM) educational activities, including floor and table workspaces, a variety of items to add or modify student creations (e.g., glue sticks, paint, glue guns), software (e.g., Adobe Creative Suite), and electronic kits or tools (e.g., MakeyMakey or 3D printer). Students had varying levels of experience with these tools and materials, as the space was used for students to work on particular projects. Teachers could reserve the space for particular occasions and students could create personal projects during a student-run after-school club focused on technology-related projects, such as digital media production.

**Figure 1.** Junior Maker Space panoramic picture.

#### 2.1.2. Workshop

To design a workshop that could support us in better understanding which aspects of personally meaningful could support engineering practices, we conducted three iterative design cycles: (1) *material and artifact inquiries* to identify the affordances and constraints of different sound-making materials, (2) a *pilot workshop with adults* with the materials identified in the first cycle, and, finally, (3) a *sound-making workshop* at the Junior Maker Space with two groups of 10-year-old students, which is the focus of the data collection and analysis.

*Material and artifact inquiries.* We investigated the sound-making possibilities at the intersection of engineering practices with three kits (Figure 2): (1) littleBits KORG Synth kit, an electronic construction kit with magnetically connecting modules to quickly create and manipulate electronic sounds [40], (2) Playtronica Playtron, a MIDI controller that connects to a computer or smartphone to play instruments like a piano by connecting 16 outputs to conductive materials to create sounds [41], and (3) Squishy Circuits kit, which utilizes conductive playdough to build circuits with buzzers and motors with possibilities to create sounds [21,42,43]. During the material inquiry, we investigated whether and how different conductive materials could be used with the kits to expand engagement with engineering practices, such as considering multiple solutions for creating circuits while tinkering with the affordances and constraints of different conductive materials. We used (a) conductive thread, a silverized thread that can sew and knot components together [44], (b) copper tape, a highly conductive solid metal that can tape components together [45], (c) conductive playdough, a clay that can connect different parts [42], and (d) graphite-based paint and pencils (i.e., 10B) for drawing conductive images that components could be laid on top of.

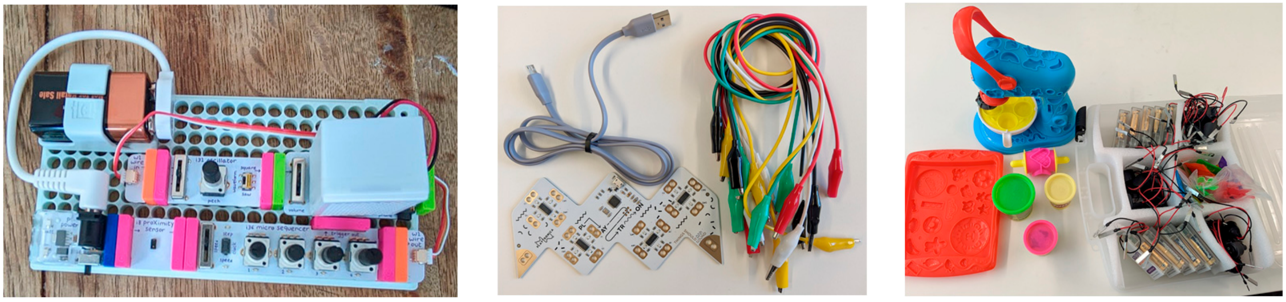


**Figure 2.** littleBits KORG Synth Kit (**left**), Playtronica Playtron (**center**), and Squishy Circuits kit (**right**).

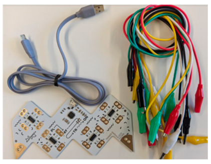
*Pilot workshop with adults.* We tested the kits with adults (four women, two men; self-identified; 22–32 years old) whom we recruited through personal networks. During the pilot workshop, the participants created sound with the kits to represent a tangible artifact from home, which we asked each of the participants to bring along. Feedback discussions revealed two key themes: (1) the importance of incorporating tangible artifacts from home to direct and deepen the experience and (2) the significance of offering a diverse range of conductive and non-conductive materials to enhance project construction and engineering design practices. Thus, we excluded the littleBits kit from the subsequent youth sound-making workshop, as it could not easily connect to a range of conductive materials.

*Youth sound-making workshop.* We conducted the sound-making workshop with youth at the Junior Maker Space. Similar to the pilot workshop, we asked participants to bring a tangible artifact from home to the workshop. During the workshop, participants used conductive materials (e.g., conductive thread, copper tape, playdough, conductive paint, and 10B pencils) and non-conductive materials (e.g., paper, tape, and cardboard) together with the materials that the electronic kits came with (e.g., Playtronica Playtron and Squishy Circuits kit, see Table 1) to create a sound inspired by their tangible artifact from home. Each sound-making workshop included two sessions that were 70 min long and we conducted the workshop with two cohorts (i.e., 70 min $\times$ 2 sessions $\times$ 2 groups). The youth worked at tables in the space, organized in a round table formation so participants could see each other's progress and creations. Author 1 facilitated the workshop and, throughout, asked questions about the participants' previous crafting and engineering experiences and their design process. At the end of the workshop, participants presented their projects, explained the meaning of their tangible artifacts from home, and talked about how their project represented their artifacts.

#### 2.1.3. Participants

Two groups of ten-year-old students participated in the sound-making workshop in two sessions each over the course of two days. The first group included 10 students (five girls, five boys), and one of the participants did not participate in the second session. The second group included 11 students (seven girls, four boys) and three of the participants did not participate in the second session. The two groups were assigned by teachers at the school based on student interest and willingness to participate in the study. Additionally, the age range was selected as research suggests elementary and middle school is when learners begin to form conceptions about engineering and interest toward the field [46]. All participants visited the Junior Maker Space at least once and most had some engineering experiences prior to joining the workshop. For example, 15 participants mentioned having designed an engineering-related project, such as building Rube Goldberg machines, at school or at home before. However, five participants did not mention any experience related to engineering. Of all participants, 12 mentioned playing or having played an instrument and six said they had no formal sound-making experience.

**Table 1.** Sound-making kits, materials, and number of participants that used the kits per workshop group.

| Sound-Making Kit | Number of Participants Who Used Kit in Group 1 | Number of Participants Who Used Kit during Group 2 |
| --- | --- | --- |
| Playtron  | $n = 2$ | $n = 2$ |
| Squishy Circuits  | $n = 8$ | $n = 9$ |

### 2.2. Data Sources

#### 2.2.1. Sound-Making Workshop Video Recordings

Video recordings were captured of the workshop using three GoPro Hero 10 Black cameras, resulting in a total of 280 min of video data. Figure 3 shows the point of view (above) and location (below) of the cameras as they were set up to capture the workshop. The cameras captured the participants while designing their projects from different angles so we could observe the table groups individually as the participants interacted with each other and with materials in the space. This data captured the artifact-building process and the conversations and non-verbal expressions of participants from three angles, which made it possible to analyze the participants that used their tangible artifacts from home as part of their projects and how this intersected with performed engineering practices.


**Figure 3.** Arrangement of the three cameras highlighted with a red square in the space (**top row**) and screenshots of the cameras' view (**bottom row**).

#### 2.2.2. Semi-Structured Interviews

We used a mobile camera to record the participants' project presentations at the end of the workshop as well as semi-structured interviews throughout the workshop. This resulted in a total of 123 min of video data. The interviews included questions about their prior experiences with crafting, engineering, and music, what their projects were about, the objects they brought with them, and the sounds they were making

We created verbatim transcriptions of the semi-structured interviews, which provided insights into the participants' experiences with crafting, engineering, and sound, their projects, their design processes, and how their tangible artifacts from home were integrated into their projects.

### *2.3. Analytical Techniques*

#### 2.3.1. Sound-Making Workshop Video Recordings

We conducted iterative thematic analysis of the sound-making workshop video data. We generated narrative summaries to describe how the participants approached their designs, how they interacted with the kits, their tangible artifacts from home, and with each other. Then, we coded the data using the NGSS Middle School Engineering Design standards to identify instances of engineering design practices (see Table 2). We selected these standards after reviewing the overall standards for this age group and identifying which standards could be present in the sound-making workshop. We counted the instances of engineering standards to see the differences in how participants used their tangible artifacts from home and the electronic kits to develop their personal projects. Through the analysis, we deepened our understanding of how the tangible artifacts from home intersected with the personal sound-making designs in relation to the electronic construction kit the participants used.

**Table 2.** Next Generation Science Standards codes selected to observe engineering design practices.

| NGSS Standard | Definition |
|---|---|
| MS-ETS1-1<br>Engineering Design | Define the problem's criteria and constraints precisely, considering scientific principles and potential impacts on people and the environment to limit possible solutions. |
| ETS1.A<br>Defining and Delimiting Engineering Problems | Clear criteria and constraints in a design task increase the likelihood of a successful solution. This includes considering scientific principles and relevant knowledge that limit possible solutions. |
| ETS1.B<br>Developing Possible Solutions | In order to enhance a solution, it is necessary to test it and make modifications based on the test results. |
| ETS1.C<br>Optimizing the Design Solution | Iteratively testing solutions and modifying based on test results leads to refinement. |
| MS-ETS 1-1 Asking Questions and Defining Problems | Create a design problem that requires developing an object, tool, process, or system, considering multiple criteria, constraints, and scientific knowledge that may limit solutions. |
| MS-PS3-3<br>Constructing Explanations and Designing Solutions | Building on experiences from K-5, the process of constructing explanations and designing solutions in grades 6–8 advances by incorporating multiple sources of evidence that align with scientific ideas, principles, and theories. |
| MS-PS3-4<br>Planning and carrying out investigations | Advancing from grades K-5, the process of planning and conducting investigations in grades 6–8 includes exploring inquiries with multiple variables to provide evidence supporting explanations or solutions. |
| MS-PS3.C<br>Relationship Between Energy and Forces | Models serve as representations of systems and their interactions, including inputs, processes, and outputs. They also depict the flows of energy and matter within these systems. |

2.3.2. Semi-Structured Interviews

We generated verbatim transcriptions of the semi-structured interview recordings to deepen our understanding of how the participants developed their projects and the design decisions they took. The interviews also added to the narrative summaries of the session recordings, because the interviews provided a close-up view of the participants' projects. The interviews provided additional information about the participants' tangible artifacts from home as participants described what the artifacts meant to them, showed it up close, and elaborated how they built on the artifact to create their sound. Further, the semi-structured interviews provided information about the participants' backgrounds with engineering, crafting, and sound making. Lastly, the semi-structured interviews also showed the participants showcasing their progress with explanations about their design decisions, how well they worked, and what challenges they faced during the process. This allowed us to investigate how the tangible artifacts from home related to the observed engineering practices in the context of the sound-making workshop.

## 3. Findings

In the following, we present four cases of youth engaging with engineering practices while creating sound-making projects to better understand how to design for personally meaningful design that supports engineering engagement.

### *3.1. Everyday Personal Tangible Objects to Support Engineering Practices*

As a tangible artifact from home, Ben brought in a pop fidget toy (Figure 4), a small plastic toy with three hollow half-spheres made of soft rubber that made a popping sound when the soft half-spheres were pushed. When asked about why he chose the artifact, Ben said:

**Figure 4.** Pop fidget toy.

> "*Because it was in my bag. Because I forgot it was the day. And I thought it was going to be easier to, like, duplicate it with this stuff. It was proving to be more difficult than I thought.*"

Ben chose the pop fidget toy as he had been carrying it around. It seemed to be an everyday object for Ben. Its personally meaningful attributes came from the daily routine. This type of toy can help keep one's hands occupied while doing other activities (e.g., listening, reading, thinking) while giving a satisfying popping sound and haptic feeling, like endlessly bursting bubble wrap. One of the sounds this object makes is a popping sound, and which Ben chose to make with the materials throughout the sessions.

Ben built up his design by trying different approaches to sound making, iteratively gathering materials from around the space and bringing them to the project table for his sound production. He looked through different boxes in the space to test the different sound approaches. Figure 5 shows the four main iterations Ben performed: (1) squeaking sounds with a buzzer powered by a playdough-based circuit, (2) a propeller on a running motor hitting a xylophone, (3) a propeller hitting against the inside walls of a plastic bottle, and (4) reproducing the sound of a lid being removed from a metal can.

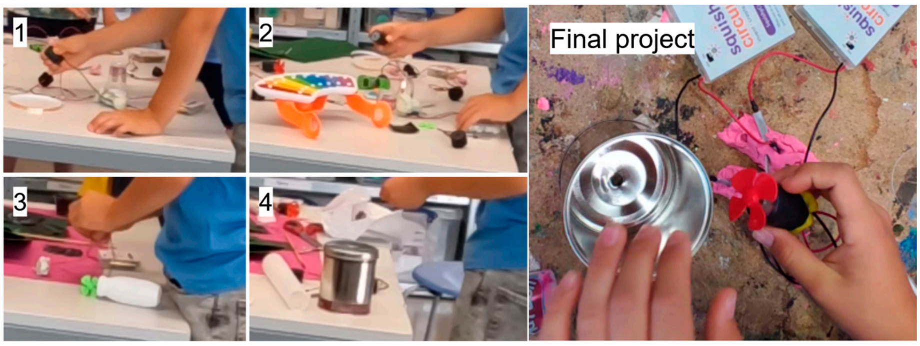



**Figure 5.** Ben's sound design iterations (**left**) and final project (**right**).

The multiple iterations and finally settling to refine one solution is similar to the engineering design practice of *defining and delimiting engineering problems.* To generate the sound of a lid being removed from a can, Ben drilled a hole into the bottom of a container and inserted one propeller. He then worked to try to use more than one propeller and more than one battery pack as part of the can. Then, he tried out different lids to achieve the sound. This helped him iteratively refine his solution while also *developing a set of possible solutions.* Additionally, Ben talked with his peers and instructor about his plans and possible solutions, and improved his design throughout the process, which is representative of the engineering design practices of *optimizing design solutions.* Even though his final design (Figure 5, right) could not complete his objective of removing the lid off the can using circuitry, he explained how he developed his design, showing evidence of the engineering design practices of *developing and testing hypotheses*. Ben said:

> "*Well, first of all, I drilled a hole [in the can] with experimenting, putting the fan in. But I thought I was going to make a popping sound with air pressure. But then I realized it was going to be harder with a not very powerful fan inside this [can]. And then so that I just thought if it was tapping on the side, it would work better than the lid popping.*"

He concluded that he could not generate enough pressure from inside of the can to make the lid pop off. After trying alternatives he noticed that his design would not achieve enough pressure due to not being airtight, the lid being too heavy, and the propellers not having enough force. Ben's reflections about why his design did not turn out as expected evidences a developing explanation of the relationship between air pressure and force, which evidences connections to engineering design practices of *constructing explanations and design solutions* as well as *relationships between energy and force.* He reflected on the reasons why his design did not have the outcome he expected, and developed an explanation on the relationship between air pressure and force. Ben finished his project by tapping the side of the can with the propeller powered by the Squishy Circuits motor (Figure 5, right).

Ben's case shows a range of engineering design practices that were made possible through the exploration of a range of materials as part of a circuitry project set out to create a sound of an everyday object and a personal routine. The sound he chose allowed him to iterate and fine tune his designs, because it was a sound that he likely knew from his daily routine and had heard over and over again. To approach this sound-making task, the Squishy Circuit supported various approaches (i.e., making sound with a buzzer or with physical moving objects) and materials (i.e., using the motor to create air or to hit surfaces). This combination of both a meaningful personal tangible object with a kit that supported various design approaches intersected with a range of performed engineering design practices.

### *3.2. Personal Historical Artifacts to Support Engineering Practices*

Hewett's tangible artifact from home was a small green toy car (see Figure 6). Hewett mentioned: "*(. . .) it was my first present ever. Cause the paper said, bring in a personal object. So I brought the personal object. My first object I ever got.*" As the first present he received in his life, the toy car had a particular personal meaning for Hewett. The toy showed marks of extensive use, including chipped paint. Especially relevant for the present study, the car also made a soft screeching sound when it rolled across a surface.

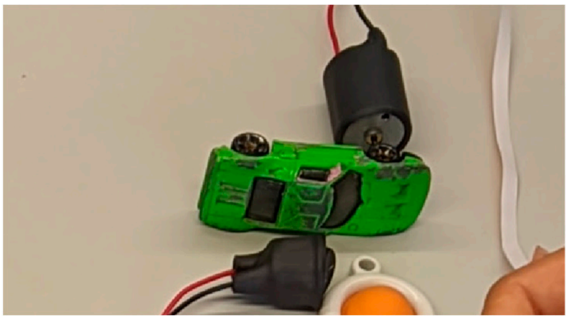


**Figure 6.** Hewett's personal tangible object.

Hewett decided to replicate the soft screeching sound of the toy car using the Squishy Circuits kit. He started by creating circuits with several buzzers and said: "*This [buzzer], it's really annoying*." Rather than abandoning the buzzers, he tinkered with them. Hewett decided that several buzzers created a screeching sound that was too loud for the kind of sound he aimed for. So, he opted to use one buzzer at a lower volume. To lower the buzzer's volume even further, Hewett layered different materials on top of the buzzer, first playdough, then paper, demonstrating the engineering design practice of *developing possible solutions*. He found a sound he thought was similar to the toy car and continued to iterate his design to identify the best possible arrangement of materials that would generate a sound similar to the screeching car, showcasing the engineering design practice of *defining and delimiting engineering problems*. Hewett referenced his iterations throughout the sessions. For instance, he said: "*I failed a lot at it. I just kept trying. It was hard, but eventually I did it. Yeah.*" Hewett also developed additional solutions for generating sounds that were inspired by the toy car as he tinkered with a plastic bottle that he cut open and placed on top of a propeller that was attached to a running motor powered by playdough wires and a battery pack, demonstrating the engineering design practice of *developing possible solutions* (Figure 7).

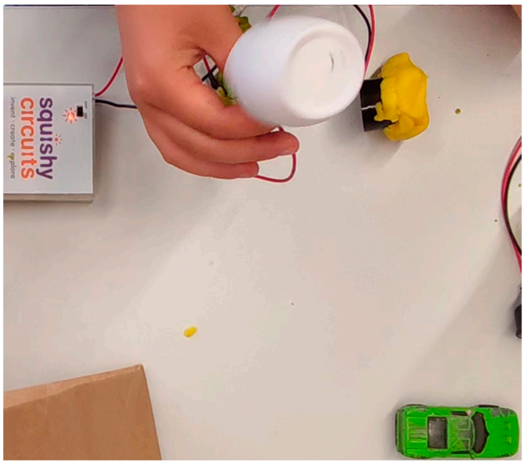



**Figure 7.** Hewett's final project.

The soft screeching of the car rolling on a surface was a personally meaningful sound that Hewett not only had heard many times but also connected to a personal history. The playdough circuits kit provided various sound creation opportunities through material explorations with electronic and non-electronic parts that Hewett used to recreate the screeching sound. He used the buzzer combined with a spinning bottle as an electronic/non-electronic sound output. Propelled by the personal screeching sound and his goal to recreate it, Hewett had to consider two different sound sources working together and fine tuning the material arrangement to achieve his desired sound, which we call tangible sound making. This level of interaction was likely fostered by his personal tangible object, as he brought something that is very meaningful to him to the activity. Through the process, the materials' possibilities and openness of the kit along with the object of deep personal history made it possible to engage with engineering design practices in sustained and diverse ways.

### *3.3. Grounding and Binary Material Explorations with a Tangible Artifact from Home*

Sara brought a small purple stuffed cat (see Figure 8) to the workshop. She shared her affinity with cats through the tangible artifact from home that was soft and showed signs of frequent use as the plush seemed to have been washed several times. This toy connected her interest in cats to the sound making activity and engineering design practices. Building on the tangible artifact from home, she aimed to create a meowing sound with the electronic and non-electronic tools and materials available.

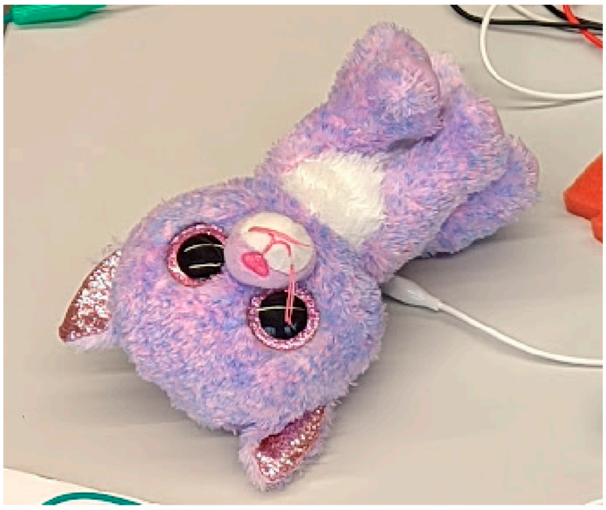


**Figure 8.** Sara's tangible artifact from home: a purple stuffed cat toy.

Sara started by using alligator clips with the Playtronica Playtron, which work as the main input conductive material to activate the output sounds suggested by the kit. To activate the outputs, one of the alligator clips must be connected to the 'ground' output to complete the circuit. Then, she tried to integrate playdough as a possible additional conductive material, likely because other youth worked with playdough circuits. However, Sara noticed that the playdough she used was non-conductive and she moved on to try out other possibilities with the kit, showcasing connections to the engineering design practice of *constructing explanations and designing solutions* as she designed alternatives. Next, to test different materials, Sara experimented with sticking copper tape on cardboard and attaching the alligator clips to the tape and the Playtronica Playtron. By touching the tape, Sara activated the Playtronica Playtron, which produces a sound through the interface in the connected laptop, in this case, a piano note. As Sara wanted to integrate her tangible artifact from home in her design, but did not want to feature the stuffed toy in the project directly, she wrote the word 'cat' with high graphite (and therefore conductive) pencil on the cardboard (see Figure 9). The implementation across copper tape and graphite pencil demonstrated the engineering design practice of *developing possible solutions*, because she tried different conductive materials and explored how they could work with her design until she settled for one possible option.

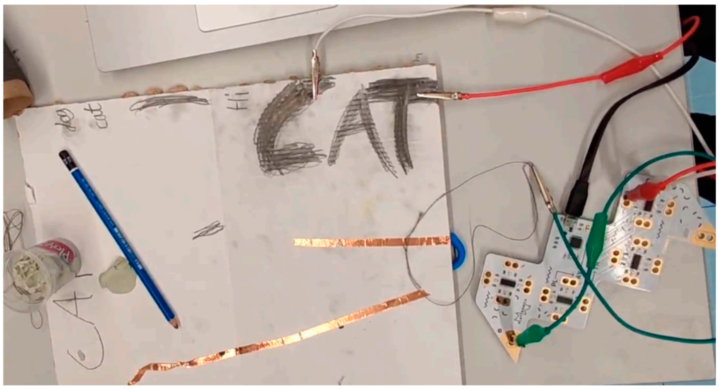



**Figure 9.** Sara using the word 'cat' with 10B pencils.

Sara's idea was that rubbing the letters would activate the Playtronica Playtron and play the sound at different notes depending on her finger's location on the word (see Figure 9, red alligator clip). With her design, she was able to play one note, but could not explore volumes because of the binary input/output mechanism, which meant that Sara could not explore sound beyond the on and off functionality. Thus, she changed her goal and decided to tinker with different solutions for how to ground herself in an easier way. She wanted to avoid holding the 'ground' alligator clip with one hand. To achieve this, Sara iterated several times with a range of different materials to achieve volume ranges through differences in resistance. She experimented with a conductive thread that was attached to the ground alligator clip. First, she used a short piece of conductive thread attached to the 'ground' alligator clip; then, she combined conductive thread with copper tape to extend the 'ground' link and strengthen the conductivity, and, lastly, she used a longer piece of conductive thread with a couple of loops in the alligator clip to securely attach the chain of materials to the 'ground' alligator clip (Figure 10, green alligator clip). Finally, she landed on a design with three main parts: (1) the conductive thread for the ground output, (2) the 10B pencils to draw the word 'cat', and (3) the alligator clips connected to the Playtronica Playtron. Figure 10 shows Sara's hand on her final design along with her previous iterations, including the design with the playdough (left), the design with the copper tape, and the design with graphite pencil. The range of iterations demonstrate the engineering design practice of *optimizing the design solution*, because she iterated until she completed a design that worked as intended.

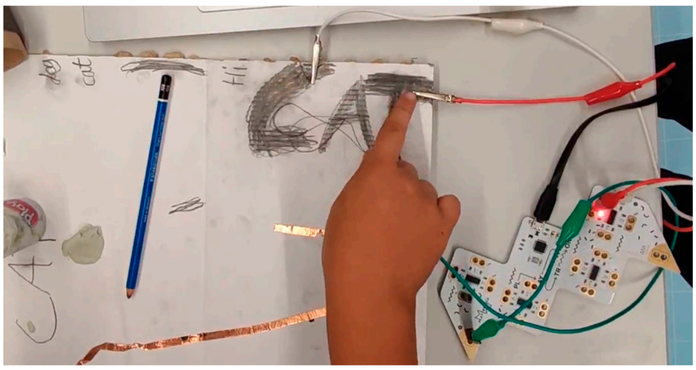


**Figure 10.** Sara showcasing her project.

Sara's case displays a variety of engineering design practices that were part of creating sound related to a tangible artifact from home, including tinkering with materials and the kit, iterating for troubleshooting and combinations, and optimization of approaches to achieve a desired outcome. The process involved engineering similar to the other two cases. What is interesting here is that the Playtronica Playtron presented limitations for sound creativity with its binary input/output mechanisms. When a conductive material was connected with the Playtronica Playtron, it would emit one signal, switching between on/off states, which led to limited possibilities to explore resistance and modulate sound that way. Sara wanted to replicate a cat meow at a range of pitches, but ended up using one note from the preset Playtronica Playtron in her final design. Her iterations focused on trying a range of conductive materials rather than creating a range of sound solutions that integrated non-conductive materials.

### *3.4. Material Explorations without a Tangible Artifact from Home*

Nathan's tangible artifact from home was a small toy that bounced back with a loud noise when thrown to the ground called a Bouncy Bowl Fidget Toy. He seemed to play with it often during the first workshop session, and likely used it as an everyday toy. Despite this, he did not use the personal tangible object to guide his project, rather he focused on the kit and the materials available to design. Nathan started by playing with the laptop and digital tools that come with the Playtron. He went around the space looking at other participants' projects and asking questions about them, possibly to investigate others' kits and designs. After 20 min into session one, Author 1 approached his table to demonstrate how to use different materials to create sounds. Nathan decided to develop a cardboard piano using the default piano sounds of the Playtronica Playtron.

He cut a cardboard rectangle to use as a keyboard and drew small rectangles with the high graphite and conductive pencil to represent the piano's keys. Nathan then connected a large number of alligator clips to the cardboard and the Playtronica Playtron to get his piano to function. Troubleshooting all connections, he found out that his initial set up lacked the 'ground' cable that would complete the circuit and fixed that (Figure 11, left). These explorations showcase connections to the engineering design practice of *optimizing the design solution*, because he tried several approaches to make his design work as intended. For the rest of the session and the next one, he focused on expanding his design, starting with 8 connections and moving to the full 16 possible connections that the Playtronica Playtron offered (Figure 11, right). As Nathan identified that he would always have to have one hand touching the 'ground' cable, he experimented and developed a bracelet using both conductive tape and conductive thread, which would allow him to have both hands free. Again, this demonstrates connections to the engineering design principle of *optimizing the design solution*, because he fine-tuned his design by using additional alligator clips and added graphite piano keys to refine his project.

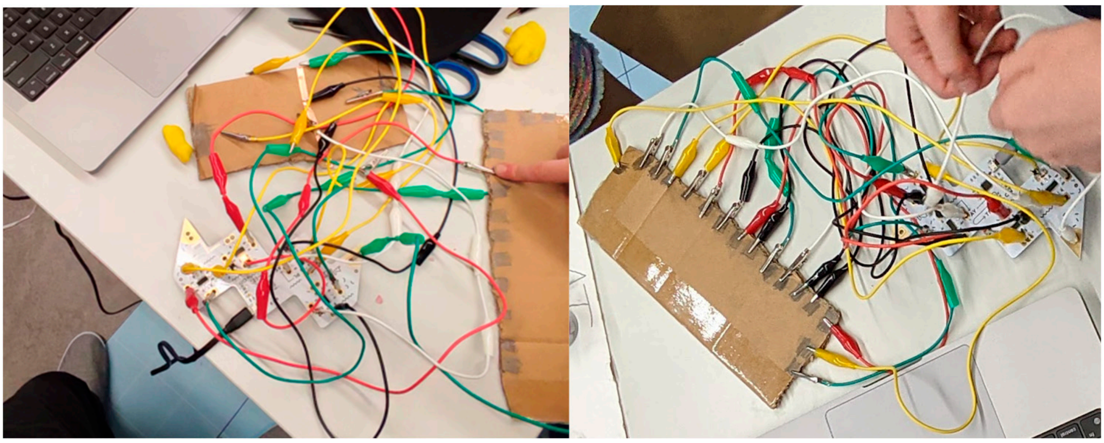


**Figure 11.** Nathan's initial (**left**) and final (**right**) designs.

Nathan focused on creating a project with preset sounds and did not engage in tangible sound making. He also did not work with the personal tangible object to guide his design. The Bouncy Bowl Fidget Toy that he brought to the workshop was untouched throughout the workshop. Of all the cases we viewed, Nathan's included the least number of engineering practices and the lowest diversity of engineering practices. We consider that this was because he did not build on his personal artifact to create a personally meaningful sound project. This seemed to have limited the directions that the project could go to the pre-set affordances and project examples of the Playtronica Playtron compared to exploring different conductive and non-conductive materials toward tangible sound making.

## 4. Discussion

This study shows that tangible sound making with electronic and non-electronic materials based on a tangible artifact from home can support engineering design practices. The study also sheds light on how to support personally meaningful design in ways that are supportive of engineering design practices. The tangible artifacts from home played a key role in the design activity, and the youths' personal tangible objects guided their work throughout. Whenever they arrived at a solution, they went back to their object, compared, and made decisions to modify their sound outcomes to better fit their goals. Whether a mundane everyday object of routine use of a present connected to one's personal history or a deep personal historical artifact, the personal objects provided those youth who continued to work with them a meaningful context for design. This personally meaningful context fostered a design space that invited multiple engineering design practices. For example, Ben developed his tangible sound making by representing the popping sound his artifact made, which encouraged him to engage in iterative design through material explorations and continuous optimizations to achieve his desired representation. Youth brought more than just their interests into their designs. Their tangible artifacts from home brought personal stories within them, from the everyday toy in a bag (Ben), to the idea of a first ever gift (Hewett). The tangible artifacts from home guided the personal projects of the participants, inspired their own ideas, and motivated them to continue working on their projects. This allowed participants to engage in engineering design practices through the sessions while they designed their personally meaningful projects. The sound that these objects made, their connections to personal experiences, and the possibility to represent the sounds with a range of electronic and non-electronic materials turned their design engagement into an opportunity to perform a range of engineering design practices. The study suggests that personally meaningful can mean building on everyday objects and on objects that are historically meaningful. Bringing tangible artifacts from home and creating sounds based on them seemed conductive of engineering design practices.

The study also suggested that the integration of personal tangible objects for sound making may lead to multiple interpretations related to which sound to represent and defining the relationship of the sound to the object. A common question asked throughout the various sessions was, "*How does [participant's object] sound*?" To some, it evoked sounds immediately through sounds that the objects themselves made (such as the screeching sound in Hewett's case). For others, the tangible artifact from home reminded them of sounds around the object. However, for others, it was not clear how their object could be represented by sound (e.g., one participant brought a plant and wondered how it could sound). As Wargo [29] mentions, sound may exist as a quasi-object, and this can be complex to understand for some, at least as a design element for learning activities. Personally meaningful can have multiple meanings. We consider that it is important to facilitate making explicit connections between the tangible artifact from home and the created sound so youth can return to this connection throughout the making process.

Additionally, we also consider the possibility of engaging with tangible sound making through multiple conductive, non-conductive, electronic, and non-electronic materials as an important aspect of personally meaningful design because it fostered tangible sound making and a range of engineering design practices. For example, Hewett and Sara experimented with different conductive materials that could connect with their kits, and decided to use what they found most appropriate to make their soundscapes. Additionally, the openness of the playdough-based circuitry kit supported engineering practices by making it possible for the youth to add their own materials in ways that supported the making and refining of a range of sounds, which encouraged them to continue to perform engineering design practices throughout the workshop. For instance, Hewett modulated the buzzer's sound by layering materials on top of the buzzer or turning it upside down, which showed engagement in engineering design practices. Hewett was able to manipulate his sound and therefore was able to tinker and optimize his designs, which resulted in him engaging in engineering design practices. Facilitating activities that included a range of conductive, non-conductive, electronic, and non-electronic materials that could be integrated into one project fostered the creation of sound based on tangible artifacts from home.

### *4.1. How Is this Study Related to Sustainability?*

This study shows that engineering design practices in educational settings can be supported by using low-tech, low-cost, and everyday materials. The study has implications for sustainability in relation to social, economic, and ecological sustainable education. Using tangible artifacts from home as a starting point for creating personal sound projects with a range of materials, this study considers social sustainability as expanding engineering educational approaches to integrate the personal interests and histories of all students. We consider that the activities presented in the article and in particular the use of everyday and historical tangible objects can diversify entry points into engineering, making it possible to connect one's personal life-histories and cultural practices with engineering. Facilitating engineering design practices through personally meaningful projects that connect to a person's personal history and cultural context can lead to opportunities for fostering multiple design solutions and considering design challenges that are connected to diverse groups of people, teaching from the ground up about diverse technological solutions. Additionally, such early learning opportunities are an important part of fostering sustained interest in engineering, which is part of a larger effort to develop a more diverse force, able to tackle a range of future societal challenges. Beyond that, this study has implications for economic and ecological sustainability in education. The study showed that especially the low-tech and low-cost materials fostered engineering design practices. This included tools and toys that children own that are commonly available in classrooms and are recyclables and reusable (e.g., gathered from old toys and household appliances/waste). This makes it possible to facilitate such experiences to a larger number of learners using a low number of resources and considering ways to repurpose and reuse materials. This points toward the utility of designing economically sustainable educational kits and resources that also hold promise for ecological sustainability in the form of upcycling for educational purposes.

### *4.2. Future Directions*

This study aimed to look into an underexplored topic to evidence relevant pathways in the field. The small number of participants gave us an opportunity to investigate, in depth, this underexposed space through a detailed analysis of the participants' interaction during the workshop. The study showed that there is a possibility for more targeted follow-up research studies with higher numbers of participants toward mixed methods across contexts. Further research in sound as a material could bring about engineering practices in K-12 education, where other strategies in sound-making activity design could be looked into as well as the use of the plethora of sound-making materials and kits. Other differently purposed kits could support sound making in different ways by expanding conductive (e.g., pressure sensors) and non-conductive material interactions for sound manipulation. Additionally, researching materials like sound, where personally meaningful histories can contribute to the learning experience, could point to developing novel educational technologies that take the everyday and historical artifacts of a person as a core part of STEM learning. This promises to lead to ways of learning that expand STEM cultural practices by teaching the value and purpose of inclusive design solutions.

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**Informed Consent Statement:** Legal guardian consent and informed consent was obtained from all participants involved in the study. School approval was obtained. Data management protocols were developed and followed for this study.

**Data Availability Statement:** Data are not openly available because the data can only be anonymized to ensure the privacy of the participants with very extensive effort.

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