Form, Function and Performances in a Musical Instrument MAKErs Camp

Blake Sawyer, Jason Forsyth, Taylor O'Connor, Brennon Bortz, Teri Finn, Liesl Baum, Ivica Ico Bukvic, Benjamin Knapp, Dane Webster
Institute for Creativity, Arts and Technology
Virginia Tech
Blacksburg, VA USA
{basawyer, jforsyth, jto2e, brennon, tfinn, licombs, ico, benknapp, webster}@vt.edu

ABSTRACT

This paper presents the planning, execution and results of a 5-day musical instrument MAKErs camp for K-12 students. Students used various hardware sensors, a graphical programming environment and different physical prototyping techniques to create musical instruments. The design of a musical instrument introduces students to the full spectrum of the design process including form factor and function. Throughout the camp, students shared and performed in front of their peers to gain feedback as they iterated through the design of a musical instrument.

Categories and Subject Descriptors

K.3.2 [**Computers and Education**]: Computer and Information Science Education—*computer science education, curriculum*

General Terms

Design

Keywords

computer science education, GUI programming, MAKEr camp, musical instrument design

1. INTRODUCTION

Our changing world is a topic of constant conversation and strife within many areas of research and education. Creativity and innovation are abundant in areas of professional design and development and it is understood that this frame of mind, which encourages flexibility, risk-taking, and openmindedness, will encourage success within industry. Yet, the question remains as to why such creative behaviors are not being fostered among students in K-12 and university. As things continue to rapidly progress, it becomes more apparent that students must be prepared to meet and match competition for success.

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The MAKEr mindset [6] is one of creative and curious people, which is typically reserved for product designers. With the movement of making, those characteristics are being used to shift the relationship between the manufacturer and the consumer. MAKErs are simply unsettled by the final product, as it is slated to be, and carry an unwillingness to accept products in a final form. MAKErs view products as partially complete and concern themselves with the hackability and seek to redesign products to meet very specific, personal needs. Some view this as a DIY culture in which MAKErs are creating their own products, often for trivial needs. A more thorough look, however, reveals that the simple process of making may lead us to a deeper understanding of personal identity. John Seely Brown states that through this culture of tinkering, our "identity is defined by what [we] have created, and [what] others have ... built on it as well" as opposed to what our parents or upbringing have simply given [1]. This same *hacker* mentality is what pushed early computer scientists and created the current state of computing and technology.

With this idea in mind, we wanted to introduce the MAKEr concept to a group of K-12 students in hope of inspiring creativity in computer programming, computer hardware and the arts. During a 5-day summer camp, we challenged students to design and build an electronic musical instrument. This paper presents the planning, execution and results. The remainder of the paper is outlined as follows, Section 2 will provide an overview of the camp preparation and schedule and discuss our rationale for using musical instruments as platform for teaching computer programming, sensors and circuitry design, and physical prototyping. In Section 3, we present six teaching modules that form the basis of the camp. We discuss our experiences with the camp in Section 4 and describe how to move our informal process towards more formal educational environments. Finally in Section 5 we conclude our paper and look towards future work.

2. MUSICAL MAKERS CAMP

Music and computation go hand and hand. And, due to music's wide applicability and interest, it is an ideal method for teaching computer science to students of all ages [12, 9, 7]. We wanted to use this same method by letting K-12 students design a musical instrument which introduces not only computer science and programming but other aspects

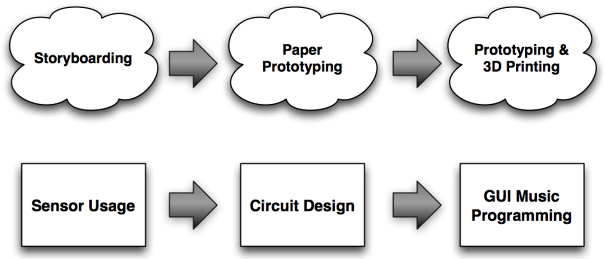

Figure 1: The design of an electronic musical instrument introduces students to the full spectrum of the design process including both form (above) and function (below).

of MAKE (e.g., creative design, physical prototyping, computer hardware, etc.)

The camp also introduced the students to the full spectrum of the design process in two ways: first, by designing the form of the instrument through storyboarding on whiteboards and constructing paper and 3D prototypes (top of Figure 1) and second, by designing the function of the instrument through sensor placement, circuitry design and using our GUI programming tool to program the music (bottom of Figure 1)

2.1 GUI Programming With PD-L2Ork

A critical component of the camp and the musical instrument design process is the conversion of sensor input into audio. Given that one of our core goals was to produce sound output, we sought a solution that provides minimal latency overhead (here we define latency as the amount of time between the sensor signal input to the computer and the resulting sound output from the speaker). In addition, in hope of fostering easy access to the platform of choice, we sought a free open-source solution. PD-L2Ork is a fork of Pure-Data [11], a real-time graphical programming environment for audio, video, and graphical processing actively developed as part of Virginia Tech's Linux Laptop Orchestra (L2Ork) project [4]. Its primary focus is to create a stable and usable environment designed specifically for music ensemble, and most recently on the development of a K12 education module. The current version is maintained exclusively on the Linux platform. For this reason, we chose to utilize the L2Ork hardware infrastructure, namely sixteen stations that include hemispherical speakers, external USB soundcard, MSI U-100 netbooks, and Wiimotes [3].

While the PD-L2Ork's K12 module was introduced as a pilot study in the spring 2012 and offered a flexible foundation, it was limited by its relatively small library of objects and its inability to store system-wide states (presets). Therefore, in preparation for the camp, the team set out to implement the global preset mechanism, and expand the system's library of coarsely-grained objects necessary for our K-12, target user population. Originally created for 4th and 5th grade students using WiiMote inputs to make music, PD-L2Ork was extended to accept inputs from an Arduino microprocessor [10] running the SARCduino firmware [8]. This firmware samples all inputs on the Arduino (12 digital and 6 analog) at 100 Hz. The new version includes over 40 new objects that allow students to seamlessly interact with each of these digital and analog signals coming from

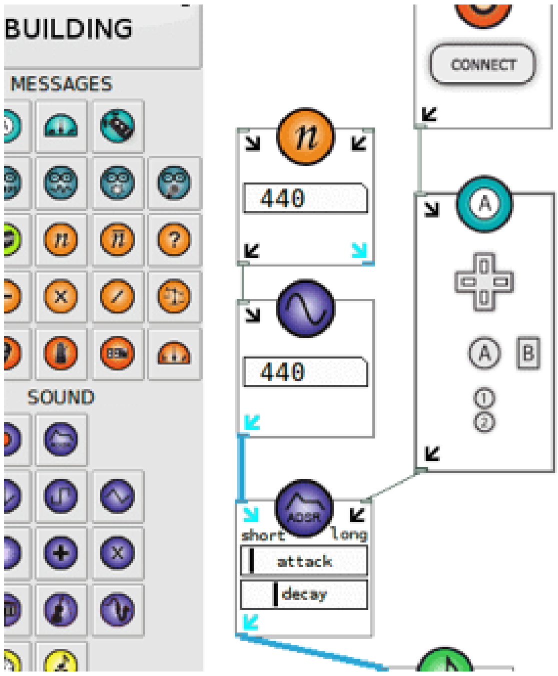

Figure 2: PD-L2Ork. The objects on the left can be dragged and connected within the workspace on the right.

sensors on their instrument. No Arduino programming was necessary, only the GUI programming in PD-L2Ork.

A screenshot of PD-L2Ork's K12 programming environment is shown in Figure 2. In PD-L2Ork K12, objects can be connected via patch cords to allow their output to be sent to other objects. Patch cords as well as object inlets and outlets are colored differently to distinguish the difference between continuous audio streams (constant streams of 48,000 samples per second) and relatively sporadic sensor data streams (variable, up to 100 data points per second). This helps to reflect the objects' function and consequently legal/possible connections. For example, the K12 module features two sets of mathematical operator objects (one for manipulating sensor data streams, and one for manipulating audio streams) which are colored accordingly.

2.2 Team and Camp Preparation

The camp team consisted of four faculty, four graduate students and one undergraduate student. Together the camp team has expertise in creative design, education, engineering and music.

Preparation for the camp took 6 weeks. As a group, we discussed different types of electronic instruments that the students could build during the week. With 32 students attending the camp, we prepared four types of instruments the students would choose from. This allowed two groups of four students for each instrument. We also pre-built a fifth instrument that would be used as an early demonstration to the students at the camp.

Aside from preparing PD-L2Ork for use with an Arduino, each instrument had to be prototyped to determine required materials. We then prepared two "kits" for each of the four instruments. These kits included electronic sensors, Arduinos, wiring and some wooden enclosures and pieces they

Day	9:00-10:30	10:45-12:15	1:00-2:30	2:45-4:00
1	Introduction to MAKE using videos	Teaching creative process through group discussions	Introduce PD-L2Ork programming	Introduce different types of sensors; Build LED flashlight
2	Demonstrate laser harp instrument's circuitry and programming	Use LED flashlight to play 1-string light harp with light sensor and PD-L2Ork	Introduce 3D printing using paper prototyping and CAD software	Introduce 4 instruments students can choose from; Create instrument groups
3	First instrument group design time; white boarding and story boarding	Create 3D component using paper prototyping	Share and gain feedback on 3D component with other groups	Begin wiring and placing sensors on instrument
4	Finish wiring instrument	Create first music with instrument using PD-L2Ork	Share and gain feedback about instrument from other groups	Take field trip to 3D printing facilities to see their parts printing
5	Iterate their instrument both in form and function	Create and practice a performance with the instrument	Performance	Outro/Discussion about what students learned

Table 1: Daily Schedule for MAKEr Camp

could incorporate. We now describe each of these instruments, including what was put in each kit:

Percussion Instrument: The drum instrument provides up to four microphone sensors that can be configured by the students (e.g., putting them in cardboard boxes or inside a wooden enclosure). The microphone sensors detect vibrations which can be thresholded and play a sound or effect in PD-L2Ork.

Wind Instrument: The wind instrument has three types of sensors: a microphone detects when the player blows into the instrument, an accelerometer allows the player to move the instrument to create sounds, and four touch sensors for detecting when the player covers a hole on the wind instrument.

String Instrument: The string instrument resembles a stand-up bass with one string. It employs two types of sensors: a joystick that detects eight directions and a resistant stretch cord that can be pulled and plucked. The stretch cord can be attached to the joystick, so the player can pull and pluck in eight directions to create sounds and effects.

Room Instrument: This instrument uses an entire room separated into quadrants. Depending on the location of the player and the gestures they make, different sounds and effects can play. The player holds a device that includes an accelerometer to pickup gestures and IR sensors for determining their location in the room.

Laser Harp: We used a laser harp for demonstration purposes. This instrument consists of a harp-shaped device with four green lasers aimed at four photocell sensors. When the player's hand breaks the line of light, a sound or effect will play.

We also prepared materials for a simple LED "flashlight" that turned on through a force sensitive resistor.

The camp schedule was iterated throughout the preparation phase of the camp. In Table 1, the planned schedule consisting of four time blocks over the five days is summarized.

3. TEACHING MODULES

In this section we outline the teaching modules that were used during the week. These include teaching a process, exploring form and function and using sharing and performance to motivate students during the camp.

3.1 Teaching A Design Process

To give students a plan for the week, as well as a design process, we wanted everyone to understand a common creative design framework of ideas, constraints, and prototypes. For any particular problem there are certain ideas that can be potential solutions, but the ideas have to be balanced against relevant constraints in the problem area. Often ideas have to be realized through prototyping and exploration to determine which ideas are best. The idea of iterating, building your own prototypes, and testing, are a core part of the MAKEr philosophy [6]. Having this framework gives the students a tool that can be used to resolve future open-ended problems, but also provides a rationale for the remainder of the week. In this way, students understand why we have them perform the activities during this week and they can appreciate the process, more than the final product.

From the outset we knew many students had their own projects and hobbies, and often followed this design process without knowing it. To help them understand the relationship between the intended design process and what they already do, we asked the students to share their own projects and discuss their own experiences making things. Many of the students shared their projects and reported that often they had to try several attempts before "getting things right."

To help reinforce the notion of iteration and prototypes, we showed several videos from animation studios where the designers are trying out new characters or studying how the characters move. Additionally, it was useful for the students to see that these grand characters did not begin fully formed, and had to be worked on several times to reach their final state.

After discussing iteration and prototypes, we conducted a few exercises to help identify ideas and constraints for a problem. In particular, we wanted to have the students consider constraints to a problem, as they are the main factors that shape a design. For this exercise we had the students consider a hypothetical trip to Mars. We felt this exercise was accessible to a majority of the students, and the constraints (such as time, distance, lack of oxygen, etc.) would be understandable to anyone.

Finally, we ran through a small design exercise where the students identified three musical instruments of interest, and then in groups, synthesized a new instrument from their ideas. Each group drew their ideas on white boards and

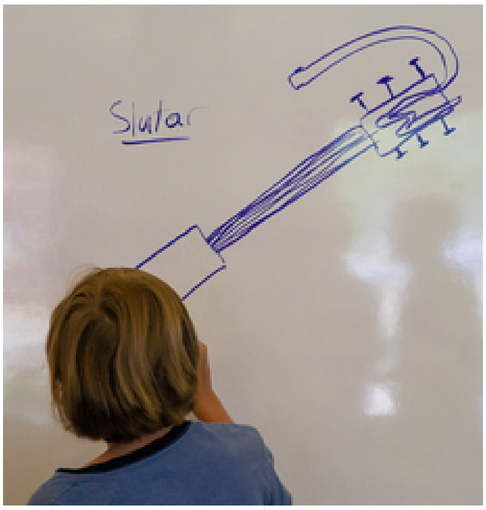

Figure 3: A student working on the whiteboard in front of the group as they discuss the design of an imaginary instrument called a "slutar".

Figure 4: Final laser harp instrument with four green lasers on the top pointed at four light sensors.

presented them to the camp group. Figure 3 shows a student presenting their imaginary "slutar" instrument.

3.2 Exploring Functionality

3.2.1 Sensors and Circuitry

The electronic sensors and their circuitry provided a bridge between the physical world (i.e., form) and the music making software (i.e., function). Sensors and their different uses were introduced to the students early, during day one. After teaching the design process, time was committed to group discussions about everyday devices that use sensors (e.g., mouse and keyboard, phones, WiiMotes, etc.) This led to a more formal presentation of different types of sensors and their uses. The group went over accelerometers, touch and light sensors, and microphones.

At the end of day one, the laser harp (seen in Figure 4) was used as a target for discussion. The group discussed how to wire the four lasers and light sensors and then they spent time programming in PD-L2Ork together to make different sounds and effects for the laser harp.

Beginning on the second day, the group discussed more types of sensors including all the sensors available in the four prepared instruments. To apply this new knowledge and give them an idea of what they would be doing the rest of the week, the students built a 9V LED flash light that turned on through a pressure sensor attached to an enclosure. They then used this LED flash light to interact with a light sensor to play music (i.e., a 1-string light instrument). The LED flash light was given to the students to take home after the camp.

3.2.2 PD-L2Ork Programming

Throughout the camp students were exposed to a series of small workshops covering the basics of creating patches in PD-L2Ork as well as one-on-one tutoring. The latter proved to be critical in tackling project-specific challenges, particularly considering time constraints. Workshops tended to only cover the most basic, overarching concepts rather than specific needs of each student group. The ensuing projects exhibited a relatively high level of complexity so each group spent one-on-one time with a camp faculty member experienced in programming with PD-L2Ork. Figure 5 shows students working in PD-L2Ork to program the music for their string instrument.

PD-L2Ork's K12 module focused on visual approach to object-oriented programming environment. Akin to Labview, students placed various objects (abstractions) onto a canvas (a.k.a. patch). The coarse-grained nature of these objects shielded users from advanced, low-level tasks (e.g., dealing with the recognition of peripheral devices and the filtering of data streams), while still exposing them to core math and science challenges (e.g., through the use of basic math operations, such as addition, subtraction, multiplication, division, etc.) [2]. Each object contained GUI elements allowing its behavior to be easily customized. For example, the object which allows access to the analog Arduino data stream offers a channel selection, while a hit detection object allows for specifying thresholds, etc.

3.3 Exploring Form

3.3.1 3D Printing

3D printers are becoming less expensive, easier to operate and, therefore, more abundant to everyday people. It has been said that 3D printers might become as ubiquitous as our paper printers at home. And we may soon see dedicated "Kinko-esque" stores [13] and kiosks [5] for 3D printing services. During the third block of the second day of camp, we introduced the 3D printing process which included paper prototyping (discussed below) and 3D modeling. The group was shown 3D printed prototypes and given an overview of how to use the software to create different 3D models.

Later in the week as the students designed one of the four instrument, each group delivered one small, paper prototyped component of their instrument to be 3D printed. One of the camp workers took these designs, created 3D models and sent them off to be printed. The students had the op-

Figure 5: Picture of a student working with the PD-L2Ork software to program a string instrument.

portunity later to see their designs being printed during a field trip to the 3D printer on the university's campus.

3.3.2 *Paper Prototyping*

Paper prototyping became a useful and concrete way for students to share their ideas throughout the camp. Students used cardboard, scissors and tape to construct paper prototypes at three points during the camp week: (1) when first introduced to 3D printing on day two, (2) when they first began designing one of the four prepared instruments during days two and three and (3) when they designed a component to be 3D printed. Some examples of different paper prototypes can be seen in Figure 6. This paper prototyping technique became an important way for students to quickly transfer their imagination from a sketch to a physical artifact. This physical artifact could easily be shared with other people to gain feedback. For example, one group of students, when designing the enclosure of their wind instrument, decided to share two paper prototype designs with all the other groups. Paper prototyping enabled them to quickly build a design and then collect votes on the best enclosure to use for their wind instrument.

3.4 Sharing and Performances

Throughout the camp, and especially leading up to the performance at the end, we encouraged and set time aside for students and groups to share their ideas with their peers and camp workers. The act of presenting their ideas and receiving honest feedback from others motivated the students to do their best. We mentioned above how paper prototyping enabled sharing and critiquing. This was also accomplished using story boarding and white boarding to share ideas within and among groups. And, once groups began making music, students performed in front of others as a way of sharing their work. On several occasions during the camp, we took 10-15 minutes of time where the whole camp visited each group's work area having students present their current designs and receive feedback. Lastly, while we already planned a culminating performance at the end of the camp, we decided to invite all the parents to this performance, not only because parents were asking to come, but also to motivate the students to work even harder on their instruments and performances.

Figure 6: Examples of student paper prototypes

4. DISCUSSION

In this Section we give an overview of the camp week, discuss how to move to more formal educational environments and how we were able to foster creativity throughout the camp week while still constrained by time.

4.1 Overview of the Week

Overall the camp was well attended with 28 students attending the full five days. Due to the many varied tasks of designing a musical instrument, most, if not all, students actively participated and collaborated in at least one or more tasks throughout the week. For example, some students spent the entire last half of the week prototyping different artifacts for the instruments while other students in their group spent the majority of their time programming in PD-L2Ork or wiring the hardware. Furthermore, during and after the camp, we received positive feedback, in the form of text messages and emails, from the students' parents, including requests to sign up for the camp next year.

When the camp week began, it became apparent that our planned schedule would need constant alteration and updating. Changes to the schedule occurred quickly as the day progressed and at the end of the day. Some major changes include: (1) spending extra time teaching and experimenting with the PD-L2Ork software, (2) using more paper prototyping to learn about 3D printing, create fantastical instrument and expand their instrument design, (3) including second field trip to a robotics lab to react to many students' interests in robotics, and (4) inviting parents to attend the final day performance.

4.2 Informal vs. Formal Education

The informal environment made the iterative nature of our camp schedule easy to manage. Since we had students for seven hours a day with no restrictions, we had the freedom to allow students a longer period of time if they seemed to require it. Similarly, if they finished a project more quickly than we anticipated, we could move on to the next portion of our day without the time constraint of a formal classroom environment.

The studio space in which we were located also lent itself well to flexibility. Student brainstorming sessions remained on the whiteboards for them to refer to all week, their projects could stay out on the work spaces without being in anyone's way, there was ample space to spread out and give each working group their own area in which to work. All of these factors led to an experience that felt effortless in many ways.

Implementing such an environment in a formal setting is not without its challenges, though. Teachers whose classroom time is confined by bell schedules or other constraints might consider teaming with other teachers who share a similar interest in encouraging a maker mindset. Such a tactic offers the potential to schedule larger blocks of time for project-based work yet still cover content from multiple disciplines. Once we, as teachers, demonstrate flexibility, openness, and willingness to invest in our own personal goals (i.e., implementing a maker project in the classroom), students will in turn be more willing to do the same.

4.3 Fostering Creativity With Time Constraints

One big challenge during the camp was allowing students to be creative with each of their designs, but also, when it came to actually building an instrument, we needed to constrain their designs so that they could finalize a design and be able to perform. This was accomplished in two ways. First we prepared partial "kits" for the four types of instruments before the camp began. These kits loosely defined each instrument by providing a set of sensors and a few physical artifacts. We were also careful in how we first presented the instruments to the students. The introduction was meant to be abstract, concentrating only on the sensors available (e.g., the stretch sensors for the string instrument or the location sensing for the room instrument). At this point, we did not want to constrain how the students would construct the instrument (i.e., form) or how it would sound musically (i.e., function).

Secondly, the paper prototyping module enabled students to stretch their creativity for designing their instruments. Most groups, when they first began, constructed very complicated instruments out of paper. As the week progressed, it was important that the students understood how they might actually build these complex instruments, but that they could only build and wire up a small part of this larger instrument.

5. CONCLUSION

As educators work to explore the potential of making within the classroom, it becomes increasingly clear that the benefits far outweigh the risks. The push for creativity, critical thinking, and innovative producers and seekers of knowledge creates a welcome environment for the MAKEr mindset and opens doors for students to play with knowledge. As students engage in making, they lead their curious minds through steps of design that are critical to creativity and innovation. Whether it is design of a new product, or hacking of an existing product, the stages of curiosity, ideation, experimenting, and iterating encourage a mindset of risk-taking, openness, and ownership.

Due to positive feedback, we plan to run this camp next summer in an informal environment and we are currently coordinating with a local high school to move to more formal educational environments.

Acknowledgments

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6. REFERENCES

[1] J. S. Brown. Tinkering as a mode of knowledge production. Carnegie Foundation of the Advancement of Teaching, October 2008.

[2] I. I. Bukvic, L. Baum, B. Layman, and K. Woodard. Granular learning objects for instrument design and collaborative performance in k-12 education. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2012.

[3] I. I. Bukvic, T. Martin, and M. Matthews. Moving beyond academia through open source solutions–introducing l2ork, virginia tech's linux laptop orchestra. *SEAMUS*, 2011.

[4] I. I. Bukvik, T. Martin, E. Standley, and M. Matthews. Introducing l2ork: Linux laptop orchestra. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, 2010.

[5] V. T. Department of Mechanical Engineering. Dreamvendor, http://www.dreams.me.vt.edu/dreamvendor/index.html, 2012.

[6] D. Dougherty. Make magazine - http://makezine.com, 2012.

[7] J. M. Heines, G. R. Greher, and S. Kuhn. Music performamatics: interdisciplinary interaction. In *Proceedings of the 40th ACM technical symposium on Computer science education*, SIGCSE '09, pages 478–482, New York, NY, USA, 2009. ACM.

[8] J. Jaimovich. Sarcduino. *MuSE: Music Sensors And Emotion*, March 2010.

[9] A. L. Meyers, M. C. Cole, E. Korth, and S. Pluta. Musicomputation: teaching computer science to teenage musicians. In *Proceedings of the seventh ACM conference on Creativity and cognition*, C&C '09, pages 29–38, New York, NY, USA, 2009. ACM.

[10] E. Naone. Arduino uno. *Technology Review*, 114(2):78–79, April 2011.

[11] M. Puckette. Pure data: another integrated computer music environment. In *Proceedings of the International Computer Music Conference*, pages 37–41, 1996.

[12] A. Ruthmann, J. M. Heines, G. R. Greher, P. Laidler, and C. Saulters, II. Teaching computational thinking through musical live coding in scratch. In *Proceedings of the 41st ACM technical symposium on Computer science education*, SIGCSE '10, pages 351–355, New York, NY, USA, 2010. ACM.

[13] VentureBeat. The future of 3d printing looks a lot like kinkos, http://venturebeat.com/2012/08/16/the-future-of-3d-printing-looks-a-lot-like-kinkos/, August 2012.