Music Maker: 3D Printing and Acoustics Curriculum

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ABSTRACT

Music Maker is a free online resource that provides files for 3D printing woodwind and brass mouthpieces and tutorials for using those mouthpieces to learn about acoustics and music. The mouthpieces are designed to fit into standard plumbing and automobile parts that can be easily purchased at home improvement and automotive stores. The result is a musical tool that can be used as simply as a set of building blocks to bridge the gap between our increasingly digital world of fabrication and the real-world materials that make up our daily lives.

An increasing number of schools, libraries and community groups are purchasing 3D printers but many are still struggling to create engaging and relevant curriculum that ties into academic subjects. Making new musical instruments is a fantastic way to learn about acoustics, physics and mathematics.

Author Keywords

3D printing, rapid prototyping, acoustics, Maker Movement

ACM Classification

K.3.1 [Computing Milieux] Computer Uses in Education, H.5.5 [Information Interfaces and Presentation] Sound and Music Computing - Methodologies and techniques, J.6 [Computer Applications] Computer-aided Engineering - Computer-aided design (CAD), J.6 [Computer Applications] Computer-aided Engineering - Computer-aided manufacturing (CAM).

Figure 1. Music Maker Mouthpieces

1. INTRODUCTION

3D Printing, or additive manufacturing, has been around since the 1970's but it wasn't until 2009 when the patent for the most economical extrusion method (Fused Deposition Modeling or FDM) expired that the 3D printing market began to really ignite. A number of small companies began manufacturing 3D printers and the cost for these machines decreased dramatically. With the introduction of Fabrication Labs (FabLabs) into schools and the continuing expansion of the DIY or Maker Movement, the demand, availability and quality of 3D printers, grows each year.

In 2010, the authors began experimenting with the use of 3D printers to explore aspects of acoustics research. In 2011, the Center for Computer Research in Music and Acoustics (CCRMA) at Stanford University purchased a 3D printer for the prototyping lab. The machine became an instant attraction in the lab and one of the first experiments done was the making of a trumpet mouthpiece that conveniently fit into a discarded hose from a wet-dry vacuum. It made a lovely low growling and could be swung in the air around the player creating a Doppler effect reminiscent of a Leslie speaker. The toy-like nature of the "instrument" was quickly apparent. As computer-musicians, many of us entered this field through our love of making strange sounds. Along the way, we managed to learn quite a bit about the associated sciences of physics, acoustics, mathematics, computer science, neuroscience, music theory, audio engineering, electrical engineering, and mechanical engineering. 3D printing offered a new way to translate malleable digital models to real world objects. This has proven to be another way to share our "gateway drug" of weird sounds with the next generation of makers, musicians, and engineers.

After such ludic beginnings, the question remained how to integrate this fabrication process into engaging curricula. A critique may be leveled that the core activity of sending a file to a printer is not much different than ordering a product from a retail hub, both requiring a series of keystrokes and clicks on a laptop. Equating 3D printing with these standard modes of consumption is what many of the larger 3D printer companies promote as the future of additive manufacturing: they envision a home factory where you can print from a selection of finished products. The site of production becomes proximal, but the essential interaction remains the same. If our goal here is to facilitate making for inquiry and discovery, this is exactly what must be avoided. In Music Maker we aim to strike a balance where only the more complex geometries are printed in a way that accelerates acoustic experimentation rather than resolving it with finished products. The mouthpieces are complex and would occupy a great deal of time to fabricate otherwise. They double as bespoke adaptors that couple to otherwise disparate things. The objects are unfinished and aim to move the maker immediately into the experimentation stage that includes sound production.

2. DESIGN CRITERIA

2.1 Provide curriculum for 3D printers

Constructionism is an educational theory and method based on the premise that students learn best through building things that are tangible and can be shared with others [10]. Many of us who teach courses on new musical interfaces at the university level are aware of the powerful results of teaching courses where students are encouraged to leverage interdisciplinary knowledge to create a working device or performance [6, 7]. Martinez and Stager, in their

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book *Invent To Learn: Making, Tinkering, and Engineering,* [8] give an excellent overview of the history of researchers and thinkers who have advocated for younger students to learn through active engagement with the real world. The history and politics of educational trends are too large for this paper to address but Paulo Blikstein [1] articulates two trends that are conspiring to ignite interest in Constructionism and inspiring the creation of spaces where students can learn to both use computers and create real world "inventions" as part of their learning process. The first trend came from a recognition by university faculty and employers that engineering students were not being taught skills that would prepare them to create real-world designs and the second was the increasing availability and affordability of tools such as micro-controllers, laser cutters and 3D printers. Blikstein notes two different results of those trends – the proliferation of FabLabs spaces devoted to students learning through building (as proposed by Gershenfeld [3]), and the rise of the Maker Movement.

Researchers such as Papert, Blikstein, Martinez and Stager are clear that the issue of integrating technology in schools is not as simple as replicating traditional styles of teaching with new technology. Any successful implementation of these new technologies must give students a chance to both learn through their own experiences and encourage them to create things that integrate their experiences into creations that are both tangible and sharable.

Schools are increasingly acquiring 3D printers in their Maker Spaces and while this equipment is very exciting, there is often a struggle to find curriculum that combines their teaching goals with this new technology in a relevant way. Thornburg, Thornburg and Armstrong have written an excellent book entitled *The Invent To Learn Guide to 3D Printing in the Classroom: Recipes for Success* and many others are working to develop curriculum that relates their field of interest to the world of 3D printing. Music Maker adds to the growing body of lesson plans and activities that engage the 3D printer with a unique focus on acoustics and new musical instruments.

2.2 Teach about Acoustics

Acoustics is a branch of physics that many secondary students learn. In the proceedings for the 2013 Musical Acoustics Conference, Wolfe et. all [15], note that one of the advantages of teaching acoustics is that many of the phenomena involved can be directly sensed without the need for complex hardware. For example, if you change the length of a pipe, the human ear can immediately observe the change in resonance without needing to use test equipment such as oscilloscopes. For primary school students, the mathematics of entry-level acoustics are simple, but they allow for an incredible level of increasing complexity for more advanced students who want to explore higher level mathematics and physics concepts.

The world of musical instruments is an excellent way to engage with basic principles of acoustics. Books such as Bart Hopkin's *Making Musical Instruments with Kids: 67 Easy Projects for Adults Working with Children* [5] and older texts such as *Jug bands and handmade music: A creative approach to music theory and the instruments* [2] have addressed the learning and enjoyment that can come from children creating their own musical instruments. Both of these texts and similar work by other authors address instruments of various types (string, percussion, wind, etc) and focuses on the fun that can be had from creating your own instruments and the musical knowledge that can be gleaned from such exercises.

2.3 Engage real-world materials and tools

In addition to the valuable lessons that 3D printing can have in the digital world, there is also a need for students of all ages to engage the physical world around them. While prototyping in materials such as foam-core has value, using the materials that are part of our everyday physical world, helps students gain an intuitive understanding of the world around them. AnnMarie Thomas [13] notes that many university engineering and design students enter their advanced studies with a significant lack of experience in both building and taking apart objects in the real world.

Building things out of common, everyday items teaches valuable lessons in fine motor skills, the limitations of certain materials and structural integrity. As creators, the ideas that we have in our head, often do not work exactly as planned the first time. That process of creating, analyzing, fixing and iterating is a powerful lesson and one of the reasons that Fabrication Labs are becoming so popular. In *The Art of Tinkering*, Karen Wilkinson & Mike Petrich describe it this way: "It's fooling around directly with phenomena, tools, and materials. It's thinking with your hands and learning through doing. It's slowing down and getting curious about the mechanics and mysteries of the everyday stuff around you. It's whimsical, enjoyable, fraught with dead ends, frustrating, and ultimately about inquiry."

You can design almost anything in Computer Aided Design (CAD) software. But how does it work with the real world? By combining CAD design with real objects, students can practice moving between digital and physical modes of creation.

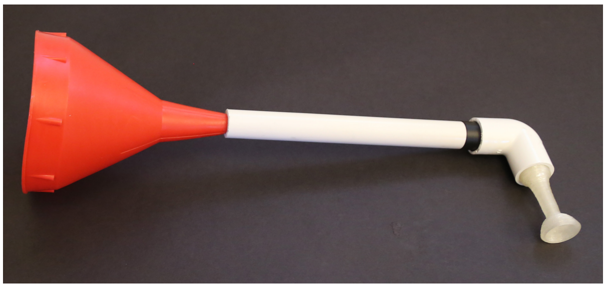

Figure 2. A "Trumpet" made with PVC middle section and a "Bell" made of an oil funnel.

3. METHODS

3.1 Multi-sized shank

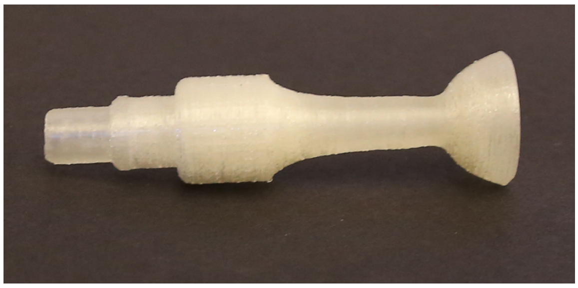

Figure 3. This trumpet mouthpiece has three stepped outer diameters.

The mouthpieces are designed to connect to materials with three different inner diameters. The shank for these mouthpieces has an oversized outer diameter that is stepped into three different widths. They can connect to ½" vinyl hose, ½" PVC pipe and the slightly larger ½" PVC pipe connectors. The enlarged outer diameters mean that materials of various thicknesses can fit onto the mouthpieces. Traditional musical instruments do not have a mouthpiece bore that opens up into a tube with a significantly larger inner diameter because it would be acoustically counterproductive. However, while some of the acoustic energy is lost in this design the resulting instruments are still quite loud and effective. Rather than numerous mouthpieces with different diameters, we determined that the flexibility of one mouthpiece that can connect to multiple materials is a superior design for acoustic inquiry.

3.2 Modularity

The advantage of the multi-sized shank is that materials can be quickly connected and disconnected. New configurations take moments to create. The pieces fit together using the natural friction of their inner and outer diameters. If the bare connection is too loose, common electrical tape can be used to form a gasket over the inner diameter that increases that friction when two pieces are pushed together. No adhesive is necessary to make a good connection and this allows for quick changes to be made. What would it sound like if we used a longer pvc pipe or a different bell shape? What would it sound like if a trumpet had two different lengths of pipe connected to one mouthpiece? Simply disconnect and reconnect the parts.

A fundamental benefit of this system is the relative ease with which different designs can be tested. If a permanent design is desired, all of the parts can of course be permanently glued together.

3.3 Safe and simple tools

One of our primary design goals was ensuring that teachers could allow students to experiment and play with materials without excessive concern for their safety. Using items such as saws power drills and other blades can be hazardous when working with younger students or rambunctious teenagers. We have chosen materials that can be cut with inexpensive, easy-to-use tools that reduce the likelihood of injuries – no saws or drills are needed.

Aside from the obvious initial investment of the 3D printer, there are only three essential tools required: PVC/Tube cutter (approx. $20USD), a Small Leather punch (approx. $8USD), a standard hammer (approx. $8USD).

The PVC/Tube cutter looks like a large pair of scissors with one blade replaced by a curved plastic jaw that holds the pipe in place. It works for cutting both the PVC pipe and the vinyl hose. It is a simple tool to use and the curved jaw makes it very difficult to lose control of the parts or injure yourself.

We struggled for quite a while trying to figure out how users could create sections that had tone holes without having to worry about drilling into a round surface. Drilling into curved surfaces is not a trivial endeavor and requires a more advanced level of skill with tools than we wanted to assume. Fortunately, the vinyl hose is ridged enough to be used in a fashion similar to the middle section of a recorder – complete with fingering holes. The finger holes can be cut using a leather punch tool and a hammer. A square dowel is inserted into the hose to act as a sacrificial surface that prevents the punch from cutting two holes across the circumference of the hose. While this might seem like a small feature, it has a big impact on creating instruments that can play multiple pitches.

3.4 Free repository of files

A conscious attempt was made to design this system so that it could be shared and developed within its community of users. To that end, each mouthpiece has both a solidworks parts file (.sldprt) and a STereoLithography (.stl) file available for download. Solidworks is one of the most commonly used CAD programs. The .stl file format is the most commonly used file format for 3D printers. If a user would like to print the parts as we have designed them, they can download the .stl file and send it to their 3D printer. However, if they would like to modify our files, they can download the .sldprt file and edit any aspect of it (shank size, trumpet cup shape, etc.) They would then need to re-export it as an .stl file to work with their printer. Our intention is to grow both the numbers of mouthpieces and the types of files we have available. In addition, we plan to add files for use in open source software such as OpenScad.

3.5 3D Printing

3D printing encompasses a wide range of additive manufacturing techniques and a full discussion of that technology and its possible application to musical interface design is beyond the scope of this paper. The two printers that we have had in the CCRMA prototyping lab have used the previously mentioned FDM (Fused Deposition Modeling) method, the most common method for entry-level printers. Prices for an entry-level printer currently range from $300 - $3000. A typical FDM printer works by having a heated "printer" head that moves back and forth in the x and y directions over a bed that can move up and down in the z direction. As the printer head moves, it pulls thermoplastic filament from a mounted spool and deposits the heated material in the appropriate place. Gradually the printer bed moves downward so that successive layers of material can be built up upon one another. There are many other methods for additive manufacturing. One of the advantages of FDM printing is its relative safety, simplicity and low-cost. There are other processes that provide more precise parts or are capable of working with a wider range of materials (metal, ceramics, even concrete) but these often involve the use of chemicals, laser technology and electronic beams. They require a higher level of skill and the cost for the machines and the materials they use is typically much higher.

One of the primary advantages to using 3D printing is the speed at which new ideas can be tested. On our printers, a mouthpiece typically takes about 1 – 3 hours to print depending on the amount of material used and the density and resolution at which we choose to print the part. This means that changes or modifications can be made and tested very quickly.

If a school does not have access to a 3D printer, there are a number of companies that provide quick turn around for 3D printed parts. Customers send them your files, their skilled team checks them for any errors or problems, and within two weeks, you have your part.

4. MOUTHPIECES

Currently, we have .stl and solidworks files for three mouthpieces on the Music Maker webpage – a trumpet, saxophone and trombone. The alto saxophone and the trumpet mouthpieces each have shanks with three decreasing outer diameters and are designed to fit into the materials mentioned above.

One small outlier in the system is the toilet roll holder trombone. This is a trombone mouthpiece that fits onto the "spring-loaded" toilet paper roll holder common in many households. The musical result is a small slide trombone effect with a surprising frequency range. Unlike the other mouthpieces, it does not fit into standard ½" plumbing. While it breaks away from one of our goals of being modular, it is so much fun that we had to share it.

Figure 4. Toilet paper roll "Trombone"

5. TUTORIALS/CURRICULUM

Currently, there are eight guided tutorials on the webpage. We cover topics such as the effect of pipe length, the effect of pipe diameter, hole patterns, the effect of adding a bell at the end of the instrument, the Doppler effect, sympathetic vibration, reed thickness and creative prompts for inspiring young instrument builders.

Our feedback from teachers so far has been that the more details and structure we can give them, the better but conversely that too many options can become overwhelming. So, for example, if we are talking about the Doppler effect, in addition to our own description of the scientific principles, it would be useful to point to links where more in depth information can be found. Additionally, they would find it useful to have a couple of different links that each pointed to material that was age-appropriate for their student group. The way you explain the Doppler effect to 10 year olds will be different than how you explain it to students who are more familiar with concepts of wavelength and frequency.

Our website is built on the WordPress content management system. This makes it is very easy to make changes on the fly as we receive feedback from teachers, students and other users. It is also easy to bring on additional collaborators who can help us create and improve content.it.

6. OTHER POSSIBILITIES

In addition to educational possibilities, the system also creates an excellent way for more experienced musicians and instrument builders to experiment with new designs. The low-cost of the materials involved in this system and the relative speed at which one can print new mouthpieces, mean that it is an excellent platform for experimentation. For example, a musician interested in different tuning systems, can quickly make tubes out of the vinyl hose to test different hole spacing configurations.

For sound artists working with found objects, our resources are a good place to start. We offer these files freely and are excited to see what people create. The mouthpieces could be attached to various mechanical devices, used in sound art installations or become building blocks for new musical instruments.

7. RESULTS

Our results so far have been very encouraging. At the 2015 Bay Area Makers Faire in San Mateo, California, approximately 600 people had a chance to test out and play with the music maker mouthpieces and an assortment of precut PVC and hose. The response was overwhelmingly positive from both adults and children.

Early discussions with educators and curriculum developers have also been encouraging. We have received a number of offers for classroom visits and are working towards scheduling those in the coming months.

8. FUTURE WORK

First on our agenda, is refining the materials to best suit teacher's needs. We would like to augment the informal feedback that we have received with more structured user testing. Currently, we are speaking with a number of organizations in our local area about plans to host teacher workshops where we can teach instructors how to use our system. This will provide invaluable feedback about improvements that we can make in how we present this information. While both of the authors are college instructors, neither of us is trained in education. We are eager to implement the feedback we get from teachers and curriculum designers.

In addition to refining our current materials, there are many ways we would like to expand this project: add additional tutorials, additional file formats and additional mouthpieces (clarinet, recorder-type fipple mouthpieces, trombone, etc.) We would like to share more examples of instruments we have made with this system. Too often, we have been caught up in the playful moment of creating new instruments and have forgotten to document an instrument before we dissemble and create another. Perhaps, eventually, we would like to make it possible for users to upload video and audio documentation of their own creations. This project has been created with a clear focus on the materials readily available in the United States. We would like to expand our models to fit the materials commonly used in other nations.

We look forward to further developing this system and sharing it with an extended community of educators and creators.

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