AC 2012-3777: MUSIC TECHNOLOGY AS AN INTRODUCTION TO STEM

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Music Technology as an Introduction to STEM

Introduction

The United States faces a problem in which too few students retain an interest in Science, Technology, Engineering, and Math (STEM) fields after graduating from high school[1]. In order to remain competitive innovators on a global scale, we need to create more interest and excitement about STEM fields at the high school level. In order to motivate students, STEM topics need to be approached in ways that are relevant and interesting to high school students. One proposed method is to connect everyday technology to scientific and mathematical concepts. This has been done before through the INFINITY Project, which pioneered collaboration between high schools, universities, and industry to create a project-based engineering curriculum[2].

Music technology, as shown by its inclusion in the INFINITY project, is a potential topic for motivating students into STEM fields. Music is an integral part of students' daily lives, and the vast majority possess large personal libraries and use digital music devices and services. Digital music curricula have been used as positive and educational gateways in public and at-risk high schools in other countries. For example, some British schools host digital music workshops combining the youth culture of musical "chatting" (British rapping) with music-creation software[3]. Even before computers were useful tools for creating music, the 1980's urban Hip-Hop movement provided ways for young people without musical training to compose and create music[4].

Howard Gardener's theory of multiple intelligences suggests that music may be one way that children relate to the world and learn from their experiences[5]. Jeanne Bamberger's research has shown that studying coherent musical structure, especially when taught through interactive media, can provide contexts for better learning of basic and intermediate math skills[6]. In spite of this obvious interest in music and its potential benefits, there has been a decrease in the amount of instructional time devoted to music and art education in public schools[7].

Over the past five years, we have developed a series of lessons designed to introduce high school students to the engineering, science, and mathematics behind modern music technology[8]. Each lesson emphasizes signal processing concepts, tools, and methods through hands-on activities that require minimal background knowledge. Developed by signal processing engineers with musical backgrounds, each activity focuses on a different aspect of music technology and has specified objectives that students should understand after completion. The inquiry-based program strives to maximize time spent engaged in activities and minimize lectures.

Additionally, the activities are designed to be portable and useful to other instructors, either individually or as a unit, and are available online for any interested instructors and organizations[*]. Current topics covered in the program include: music recording and production, transduction of signals to sound using speakers, the wave-based nature of sounds, creating new

[*] http://music.ece.drexel.edu/smt/curriculum

sounds and sound effects, musical instrument acoustics, using novel interfaces for music manipulation, digital signal representations, and music information retrieval.

Initiated in 2006 as part of an NSF CAREER award, these activities have served as the basis for our Summer Music Technology (SMT) program. SMT has enrolled over 100 high school students, primarily in 9th- and 10th- grade, and recently completed its fifth session. The program also serves to attract students from backgrounds underrepresented in the fields of engineering, math, and science who may not have previously considered further study in these fields.

The curriculum has been revised each year with new material and includes significant contributions from graduate and undergraduate engineering students. These revisions are partially based on student feedback and instructor observations during the activities. The high school students fill out surveys after each activity, providing feedback on how interesting and difficult an activity was, as well as how much students feel they learned.

In order to evaluate the activities outside of the SMT program and introduce them to more students and instructors, program activities were deployed within other organizations for the first time. Six of the activities were implemented as part of the Franklin Institute's STEM Scholars Program, which aims to prepare underserved students for college and increase matriculation into STEM fields[†]. This allowed us to test our methods on a different subset of students who did not specifically seek out a music technology program. Furthermore, the Musical Instrument Acoustics activity was successfully introduced as a lab in a traditional high school physics class. In this setting we could observe our activity with more typical high school students who may not have any prior interest in technology.

Summer Music Technology program

Each summer, a group of 20-30 students from the Philadelphia area is admitted into the program. The program consists of five six-hour days divided into four activity blocks. Throughout the week, eleven blocks are dedicated to structured activities where students get a hands-on lesson in a particular topic. An additional seven blocks are dedicated to individual student projects. These projects allow students to explore an area they find interesting in greater depth than any of the activities allow. This gives students the opportunity to experiment and come up with ideas of their own. At the end of the week, each student gives a short presentation on the results of his or her project.

Projects fall under one of four main categories, and within each grouping students are encouraged to explore a topic they find interesting. *Analysis of musical instruments* focuses on studying the differences between instruments and how these differences correspond to changes in the sound, waveform, and frequency spectra. *Music synthesis* uses computer software to simulate sounds and sound effects, such as falling rain. Students in the *musical interfaces* group explore new ways of interacting with music by configuring their own input device (such as a Wii remote) to control sounds generated by a computer. The final group builds and composes music for an *electric monochord*, a single-stringed guitar-like instrument.

[†] http://fi.edu/STEM-Scholars/

Curriculum

The guided activities are designed to be used by other instructors as part of another camp, classroom lesson, or stand-alone activity. Instructions include a list of prerequisite knowledge the students will need before beginning and a set of objectives that they should understand after completion of the activity. In order to increase portability, we use low-cost materials and open-source software whenever possible. Additionally, we have developed our own software to use with several of the activities. Most activities require one computer for every 1-2 students. However, the computational power required is relatively low; older, less expensive computers are sufficient to run the activities. They have all been tested on a 2006 MacBook with an Intel Core 2 Duo processor and 1GB of memory.

The majority of software development is done using Pure Data[‡] (Pd), an open-source real-time programming environment for audio, video, and graphical processing initially developed by Miller Puckette (creator of the similar, commercially available Max/MSP application). We chose this software primarily because of its real-time audio processing capabilities, which enables direct manipulation of algorithms and parameters and provides instantaneous feedback to students. Pd's graphical programming environment is also much easier for students to comprehend without prior programming experience. Students can visualize the signal flow within an algorithm by using Pd's graphical programs (called "patches"), shown in Fig. 1. Because it is open-source and freely available, interested and motivated students can download it to their computers at home. This allows students to continue working on their projects overnight and even after conclusion of the camp.

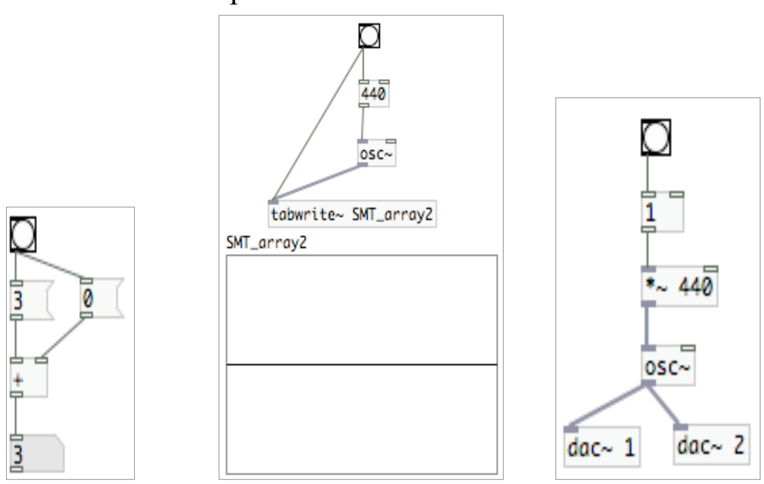

Figure 1: Example Pd patches used in SMT.

[‡] http://puredata.info

Activity Overview

Music Production

The Music Production activity introduces students to the basics of sound recording, channel mixing, and editing a song. Students use music editing software, such as GarageBand, to modify existing songs and create their own music. Songs that have separate instrument tracks available (e.g. drums, bass, guitar, vocals, etc.) are used to allow students to modify individual components of the music. They are also introduced to recording techniques and create their own sound effects (e.g. clapping or shouting), which can be added to their song as an additional track.

This activity requires no prerequisite knowledge, which makes it an excellent introduction activity for the week. Upon completion, students should understand basic music mixing concepts and be able to create their own unique song using pre-recorded tracks.

Speaker Building

In the Speaker Building activity, students learn the physical principles behind speaker operation by building one out of household materials. The most important part of the speaker is the wire coil, which is fastened to a paper plate hung loosely from a cardboard housing. This coil is connected to an amplifier, and the flow of electricity causes the plate to vibrate when a strong magnet is held near the coil.

Students require a basic understanding of electromagnetism, which can be taught immediately before the activity as a short introduction. At the end of the activity, students should understand how speakers work and what factors influence their performance. They should also have a better understanding of electromagnetism and its use in speaker design.

Waves and Sounds

Waves and Sounds allows students to explore the nature of sound. A short introduction teaches students the basic principles of sound using real-world examples. Afterwards, they learn how basic periodic signals can be created and viewed using a function generator, oscilloscope, and the Pd application. Students are also exposed to the frequency limits of human hearing and the concept of harmonics (overtones).

After this activity, students should understand that sound is made up of sinusoidal vibrations. They should also understand the basic sinusoidal equation and its parameters (period, frequency, amplitude, etc.). Finally, students should be able to understand and explain the concept of harmonic series.

Echo and Sound Design

Echo and Sound Design teaches students about the basics of echoes and digital sound design. The lesson begins by using GarageBand to experiment with shifting copies of a sound and listening to the echo-like result. They then move outside of the classroom where real-world echoes can be heard to provide students with a sense reverberation. Returning to the classroom, students use Pd to explore echo simulation.

At the conclusion of the lesson, students should understand that echoes are a combination of direct sound and delayed copies of that sound. They should also be able to simulate simple echoes on a computer.

Musical Instrument Acoustics

Musical Instrument Acoustics is divided into two activities. The first activity uses PVC tubes to explore the concept of resonant frequencies and filtering. Speakers play sounds into the tubes, and the sound at the other end of the tube is recorded for comparison to the input. The second activity looks at different musical instruments and explores how they produce sound. Similarities and differences between the different families of instruments (e.g. strings, brass, woodwind) are also explored. The two parts of this activity can be split up and used individually.

This activity requires basic knowledge of waves and sinusoidal equations. At the end of the first half of the activity, students will understand basic concepts of resonance and why different lengths of tubes resonate at certain frequencies. They will be able to calculate resonant frequencies and verify their calculations by testing with an actual tube. After the second part of the activity, students should understand the basic physics behind how musical instruments produce sound. This includes how the sound is generated and how it propagates through the instrument.

Musical Interfaces

The Musical Interfaces activity is another two-part activity exploring the use of nontraditional interfaces and computer-based instruments in music. Students discover new ways of interacting with music using the interfaces to manipulate sound in Pd. Five different interfaces (including a Nintendo Wii remote and a pressure sensitive trackpad) are available and are connected to a Pd patch. In the first part of the activity, students are given an interface and asked to experimentally determine how it controls sound generated from a computer. The controls are set up to change features such as volume, pitch, and harmonics. Each group presents their findings to the class and demonstrates how their particular device works. In the second half of the activity, students are asked to customize their own interface by manipulating the settings for their chosen device.

After the first half of the activity, students should have learned how to experiment with unknown items in a structured manner and convey their findings to others. They should also be familiar with the differences between discrete and continuous interface methods, such as buttons and sliders, and know what degrees of freedom are.

After the second half of the activity, students should understand how a signal's parameters (such as amplitude or frequency) influence the sound. They should be able to use different types of input to control this information and understand the advantages and disadvantages of each.

Analog and Digital

Analog and Digital uses a game-show format to teach students how computers store and reproduce continuous audio signals. A brief introduction explains the concept of a digital signal and why a computer cannot store continuous signals. Afterwards, students are divided into teams and the game begins. One student is asked to convey information about the shape of a waveform to the other using only discrete coordinates on a grid. The other student needs to draw the described waveform accurately.

Before this activity, students should have a basic understanding of waves. After completing the activity, they should understand the concepts of sampling and quantization, as well as what causes sound distortion. If time permits, they will also learn about common sampling frequencies and why they are used.

Music Information Retrieval

The final activity, Music Information Retrieval, introduces topics such as music recommendation and playlist selection. Students are divided into groups and asked to create playlists using methods similar to popular music recommendation services (Pandora[§], iTunes Genius[**], and Last.fm[††]).

After this activity, students should understand how math and engineering are used to organize and listen to music. Specifically, they should know how popular music recommendation services make their recommendations. Students should also understand some of the advantages and disadvantages of each method.

Incorporation into other programs

In August 2011, six activities from the SMT curriculum were incorporated into an existing summer camp for high school students. The STEM Scholars Program, hosted by the Franklin Institute in Philadelphia, PA, uses a project-based, year-long curriculum to introduce underserved 9th grade students to STEM topics. Our activities were used as half-day sessions during a single week of the summer portion of the program. The activities used were Speaker Building, Music Production, Musical Interfaces (both parts combined), Musical Instrument Acoustics (only the first half on resonant frequencies), and Analog to Digital (no data was collected after this activity).

All of the required equipment was successfully transported to the Franklin Institute using personal vehicles, no special accommodations were necessary. There were only 13 students enrolled in the program, allowing us to try our activities with a smaller group size. The students participating were younger than our typical students in SMT and were not necessarily interested in music technology.

[§] http://pandora.com

[**] http://itunes.com

[††] http://last.fm

These students were less motivated than our usual summer camp students. Some of that may have been due to a lack of a specific interest in music technology, which is typically the drawing factor to our summer camp. Another likely reason is that these students were completing week five of an intense summer camp, whereas our summer camp is only a single week. In spite of this, students still seemed to enjoy the activities. In particular, several students were excited by the music production activity and put a lot of effort into their remixed songs.

Incorporation into a high school classroom

In May 2011, we tested one of the activities in an 11th grade high school physics classroom at Central High School in Philadelphia, PA. The students were slightly older than our typical SMT students and attended a magnet school, which draws students from multiple districts and has a competitive entrance process. The first half of the activity *Musical Instrument Acoustics*, which uses tubes to explore resonant frequencies, was used during a unit on waves.

The biggest challenge when incorporating this activity in a classroom is providing the students enough time. It took students over 3 hours to finish an activity that was designed to be completed in just over an hour. The summer camp provides an uninterrupted block of time for the activity, which is generally preceded by another related activity. High school students switch subjects every 50 minutes and require set-up and cleanup time before and after every class. This leaves approximately 30 minutes of actual work time per class. Finally, when run as a summer camp there is at least one helper for each group of students, while in a classroom there were only two instructors for the entire class. While the activity can be run with fewer leaders, it runs more quickly and smoothly when students can receive more attention and feedback from instructors.

Despite these challenges, students seemed to enjoy the activity. Using Musical Instrument Acoustics as a lab helped improve the waves unit, which was not the specialty of this particular physics teacher. The unit was previously very short, lecture based, and lacked a hands-on lab for the students. This activity, or others from SMT, may also prove helpful to other teachers who are trying to cover a topic that falls outside of their particular expertise. These activities provide predefined methods and learning objectives so that instructors do not have to come up with an activity on their own.

Results

We asked the participants of the Summer Music Technology program to fill out a number of surveys to gauge the effectiveness of the modules in which they participated. A pre- and post-survey were given to the students before and after they participated in the camp. They were also given a survey after completing each module. The results of these surveys are presented in the following sections.

Pre-Survey

The participants were asked to complete a general survey as the first activity during the camp. This survey collected basic demographic information on the participants. This past summer's participants included 15 males and 9 females (24 total) ranging from 14 to 17 years of age. Most of the students had taken algebra and geometry. Only 11 had taken trigonometry and 5 had taken pre-calculus or calculus. Twenty of the students played an instrument. The survey also included questions about the technology the students used to interact with music. All students had used an internet site or service such as Pandora or iTunes to find new music.

Students were also given a section on the survey to write about what music means to them. One student wrote, “Music is almost everything to me. I can’t do anything without it.” Another wrote, “I can listen to music no matter what mood I’m in, and I feel like it’s the best way to express myself.”

Post Survey

Another survey was issued to the students at the end of the camp. This survey was used to gauge the overall perception of SMT and asked questions about which sessions were the most enjoyable as well as the success of the topics that we covered.

When asked which session students enjoyed the most, the majority chose the Music Interfaces module. Most students did not differentiate between the first and second part of the module. A few students noted that they would have liked a clearer explanation on the Speaker Building and Waves & Sounds modules.

The students were also asked about their opinion of the individual projects. They were asked to rate a statement using a 5-point Likert scale. The results are shown in Table 1.

Statement	**Rating**
Amount Of Project Options	3.04 ± 0.63
Diversity of Project Options	3.08 ± 0.66
Difficulty of Projects (in general)	3.08 ± 0.84
Enjoyment of Projects (in general)	4.43 ± 0.94
Educational Value of Your Project	4.43 ±0.66
Difficulty of Your Project	3.43 ± 0.84
How Creative You Were Feeling	4.04 ± 1.14

Table 1: Student ratings of individual projects on a scale from 1 (a little) to 5 (a lot).

Individual Modules

Surveys for each of the individual activities were given to the students asking questions about their opinion of the module. Some of the questions in the survey were rated on a 5-point Likert scale (1 = a little, 5 = a lot). The highest rating for the question “Did you learn from this activity?” was the Musical Instrument Acoustics II (4.08). The lowest rating was for Music Production (3.25). The highest rating for the question “Did you enjoy this activity?” was the Analog & Digital module (4.52). The lowest rating was for Musical Instrument Acoustics II (3.52)

The surveys for the Echo and Sound Effects, Music Information Retrieval, Music Interfaces II, and Speaker Building had additional questions about the student’s mental state. The results are shown in Table 2. Please note that a low score in the question "Were you frustrated?" is desired, as we want to reduce the amount of potential frustration in our modules.

	Musical Interfaces II	Echo & Sound Effects	Music Information Retrieval	Speaker Building
Was this activity challenging?	2.45 ± 1.10	3.13 ± 1.25	2.65 ± 1.19	3.27 ± 1.16
Did you have the ability to complete the module?	4.86 ± 0.35	4.21 ± 0.73	4.52 ± 0.73	4.27 ± 0.98
Were you succeeding?	4.54 ± 0.59	3.95 ± 0.76	3.95 ± 0.97	3.63 ± 1.13
Were you frustrated?	1.54 ± 0.67	1.86 ± 0.96	1.86 ± 0.96	2.04 ± 1.13
Were you proud?	3.40 ± 0.95	3.04 ± 1.18	3.30 ± 1.36	3.09 ± 1.26

Table 2: Student evaluations of 4 activities on a scale from 1 (a little) to 5 (a lot).

Franklin Institute Program

As previously mentioned, some of the modules were used in another program at the Franklin Institute and survey responses were also collected from these students. The results for the questions about learning and enjoyment are shown in Table 3.

	Did you learn from this activity?	Did you enjoy this activity?
Speaker Building	4.55 ± 0.52	5.00 ± 0
Music Production	3.36 ± 1.28	3.91 ± 1.13
Musical Instruments	3.71 ± 0.95	3.71 ± 1.38
Interfaces	3.25 ± 1.28	3.50 ± 1.19

Table 3: Student evaluations of activities presented at the Franklin Institute STEM Scholars Program. Responses are on a Likert scale from 1 (a little) to 5 (a lot).

For the activities that were used in both SMT and at the Franklin Institute, the results of the questions "Did you learn from this activity?" and "Did you enjoy this activity?" were compared in Figures 2 and 3. Both the Musical Instruments and Musical Interfaces modules were separated into two different activities (e.g., Musical Interfaces I and Musical Interfaces II) during SMT; therefore, we calculated the mean of all responses in both parts and use those values in the plot.

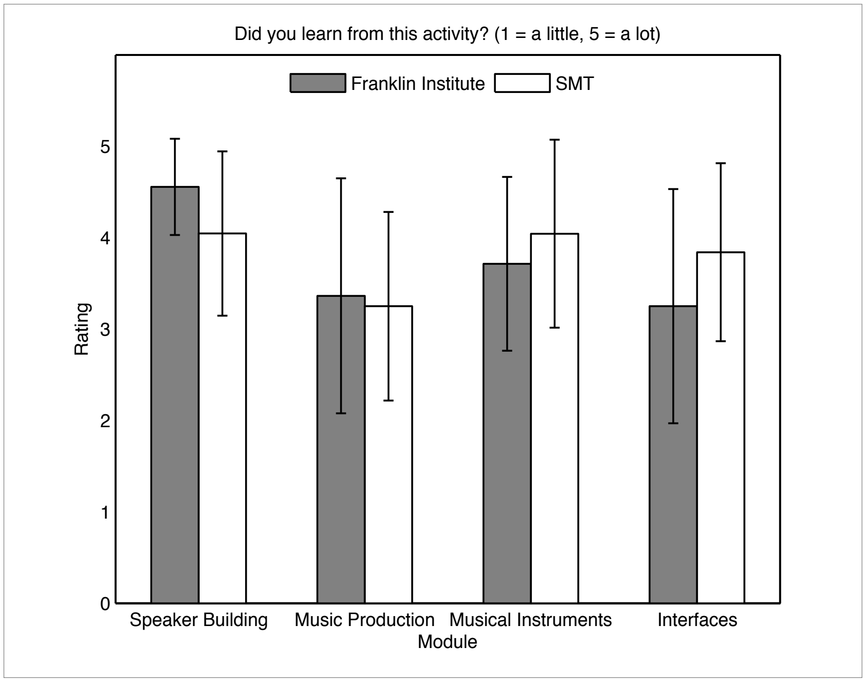

Figure 2: Comparison between SMT and Franklin Institute participants when asked, "Did you learn from this activity?"

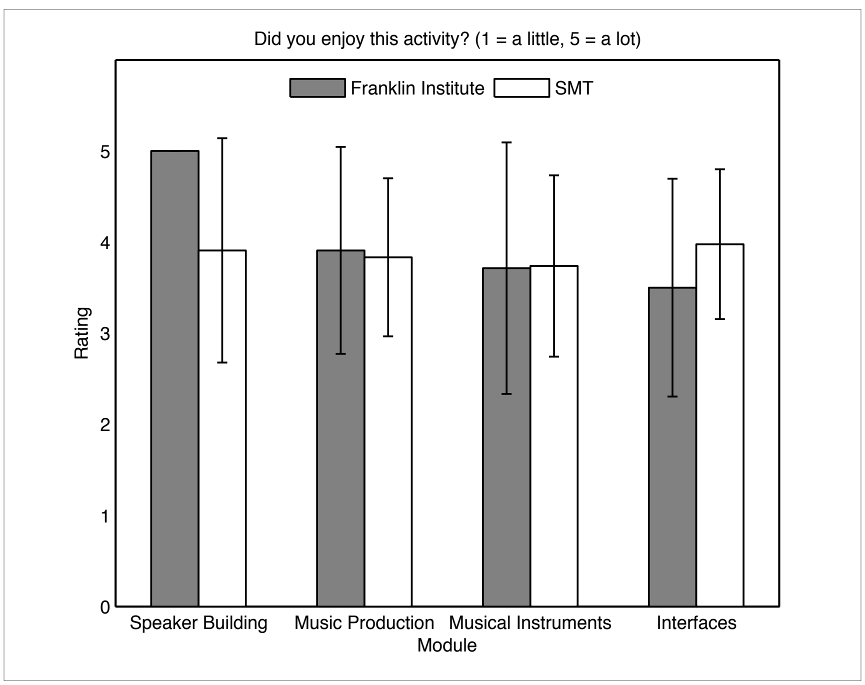

Figure 3: Comparison between SMT and Franklin Institute participants when asked, "Did you enjoy this activity?"

For both questions, the Franklin Institute participants gave the highest rankings to the Speaker Building module. They awarded the lowest rankings to the Musical Interfaces module. The students from the SMT program believed they learned the most from the Speaker Building module (4.045), however this module was ranked only slightly higher than the Musical Instruments module (4.043). The SMT students also claimed to learn the least from the Music Production module. They most enjoyed the Music Interfaces module (3.9773) but only slightly more than the Speaker Building module (3.9091). The SMT students' least enjoyable activity was the Musical Instruments module.

Conclusion

The activities presented in this paper have been used five times during our summer camp, with improvements and adjustments made each year. Anonymous survey results and comments from students, as well as observations made by instructors, have been used to improve the activities. Each activity focuses on a specific set of musical and engineering concepts and principles. Minimal background knowledge is required for the activities and any required material is covered in lesson overviews. Students have indicated through the surveys that they both learn from and enjoy the activities. Additionally, presentations and discussions between students and instructors show that they do understand the concepts being taught.

The activities are also portable enough to be used as part of another camp or in a high school curriculum. They were successfully incorporated into another summer camp and an 11th grade physics classroom. Much of the equipment is relatively inexpensive and reusable. The students' survey responses at the Franklin Institute roughly correlated with the responses from SMT, indicating that the activities were consistent at the different locations.

In the future, we will continue to improve the activities based on student feedback. In particular, we will provide clearer guidelines for presentations, which was the most common complaint among participating students. The portability of activities could also be improved by dividing them into sections or providing alternative, shorter, stopping points. This would allow them to be more effectively incorporated in classrooms or other instructional programs with shorter blocks of time.

Acknowledgments

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