Board 309: Improving Teachers' Attitudes Toward Sound and Waves Through the Connections with Music

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Improving teachers' attitudes toward sound and waves through the connections with music

Abstract: Children can feel disengaged from STEM subjects taught in schools, which are often presented in ways that are not connected to their interests and everyday experiences. The subject of waves is fundamental for understanding a variety of scientific and engineering processes, from gravitation to telecommunications. Furthermore, the subject of waves presents an excellent opportunity to bring to the school activities connected to one of children's deepest interests: music. For this, we created Listening to Waves, a program that has been developing web applications and curricular activities that allows users to connect with the science of waves by playfully exploring and creating sound and music. Previous work by our team has shown that these types of activities can be powerful for engaging children in science, especially those typically underrepresented in STEM domains. However, a fundamental step for their spreading is that they are also engaging for teachers. To disseminate the program and evaluate its potential to engage teachers, we created a three-day professional development workshop for teachers serving underserved communities. We administered quantitative and qualitative surveys before the workshop, immediately after the workshop, and after the teachers implemented the materials in their classrooms. The surveys indicate that the experience improved teachers' attitudes toward the subject, including their comfort in teaching the subject, their enjoyment, and their perception of the children's enjoyment. This effect was particularly relevant for teachers who were not initially engaged, either because of a lack of experience or lack of knowledge. Taken together, these results indicate that activities connecting music and STEM have the potential to spread throughout the formal educational system by engaging teachers, and that they can be instrumental in engaging children in STEM. This research is funded by NSF's ITEST award "Increasing Students' Interest in STEM through the Science of Music."

1. Introduction

Music and STEM have been deeply intertwined over centuries, as evidenced in the mathematical formulations attributed to Pythagoras, describing musical harmony and the music of spheres, and in the investigations of Kepler, who explored the fundamental principles that unify music, mathematics, and the structure of the known universe [1]. These early natural philosophers perceived parallels between science, mathematics, astronomy, and music that offered means to think about these disciplines in integrative ways. The parallels were highlighted with the rise of acoustical research in the 19th century, which led to the creation of laboratory-generated sounds for experimental purposes [2]. These sounds, neatly described with mathematical formulas, allowed a systematic exploration of human acoustic perception. To study hearing, scientists took to using sounds like electronically generated sinusoids, acoustically resonating tuning forks, and electronic sirens [2]. This line of scientific inquiry on the effects of music and sound continues to interest psychologists and neuroscientists in their studies on musical acoustics and its relationship with human memory, emotion, and language, among others [3], [4], [5]. Similarly, this experimentation and technological advancements provided musicians, and non-musicians, with new ways of creating, exploring, and programming music, as evidenced by the electronic music explosion in the 80s [6].

A key motivation for science, technology, engineering, and math (STEM) education is to help students make connections between practical applications of various disciplines [7]. The domain of musical acoustics rests squarely at the intersection of music, science, mathematics, and technology, and can provide an environment to make these connections interesting and motivating for students. Prior research on introducing such courses in basic physics, for instance, that discussed musical waves and sound, served to motivate students and give them a broader understanding of the related concepts, and were also instrumental in increasing teachers' understanding [8], [9], [10], [11], [12]. Preparing such interdisciplinary lessons drawing on the deep historical lineage of integrative scientific pursuit can help broaden and contextualize topics better for the learners, and can offer an engaging learning experience in the classroom.

In this context, music integration offers a path for what has been called Thickly Authentic STEAM experiences, characterized by having a) personally meaningful learning experiences; b) learning that relates to the world outside of the learning context; c) learning that encourages thinking within a particular discipline (for example sound production); and d) allowing for assessment that reflects the learning process [13], [14], [15]. Although the potential for STEM and music integration has long been recognized, the idea has been slow to become popular with mainstream audiences, such as school children in their classrooms. A previous experience by this team, supported by the National Science Foundation's grant *"Connecting STEM to Music and the Physics of Sound Waves"*, developed and implemented a set of activities geared towards engaging underserved children in STEM through the connections with music. In it, members of this team visited 8th-grade classrooms and worked together with teachers, helping children explore how physical objects and digital tools vibrate and create sound. The experience proved to greatly improve the children's attitudes toward science, including their interest in the subject of science and their intention to pursue a science career [9]. The experience benefited from the direct participation of subject domain experts: a neuroscientist specializing in music, and an accomplished musician and ethnomusicologist, who provided direct instruction and physical materials, and spent time installing specialized software and hardware in the school's computers. For music and STEM integration to make a large impact in the educational system, however, it must be able to reach students, which it can only do if it is meaningful for teachers.

To facilitate a large-scale expansion of the music and STEM integration activities, and sponsored by NSF's grant *"Increasing Students' Interest in STEM through the Science of Music"*, this team has been a) developing web applications that formalize the most important aspects of the classroom experience mentioned above; b) developing a standards-aligned curriculum; and c) training teachers in their implementation.

For the web applications, this team has developed a spectrogram, a signal generator, and an oscilloscope. These are common tools found in STEM laboratories and are used to visualize and generate signals, including sonic signals. This team has made them available online and has simplified their interfaces so they can be easily used by novices. Furthermore, it has modified them so they can be used to playfully create sound [16].

For the curriculum, this team has partnered with the San Diego County Office of Education and with the San Diego Science Project to create a series of lesson plans centered on the web applications, incorporating playful activities that explore how everyday objects create sound. The

current version of the curriculum can be accessed for free through this team's website www.listeningtowaves.com.

All these activities have been carried out in an iterative manner: evaluating how children interact with the curriculum and applications and how teachers respond to the training. This paper examines how teachers' attitudes toward the teaching of waves change as they participate in the professional development.

2. Methods

Twenty-four science teachers from 19 schools across 10 districts in California participated in the study. In the summer of 2022, teachers engaged in a three-day professional development workshop. The workshop was facilitated by Dr. Minces, the creator of the program; by Dr. Barron, leader of the San Diego Science Project; and by John Spiegel, then science coordinator at the San Diego County Office of Education. The workshop was divided into two types of activities: the "dance floor", in which teachers went through the curricular activities as students, and the "balcony", in which they received additional expert instruction and reflected on their experiences. The curricular activities included physical exploration of how objects make sound -- for example grabbing a coffee stirrer between the teeth and plucking it, an exploration of the web applications -- for example using the online oscilloscope to visualize and transform sound waves, and the creation of a personal musical instrument or sound-making object. Most activities were carried out in groups of three or four, and teachers were allowed time to explore freely before moving into a systematic discussion.

During the school year, teachers were expected to implement the activities in their classroom, if they considered them appropriate, and to meet three times for office hours. Teachers were compensated for participating whether or not they implemented the activities. They were surveyed before the workshop (pre-workshop), after the workshop (post-workshop), and after teaching (post-teaching). The data was collected by the team at the University of California San Diego and analyzed by the co-authors and evaluators team at WestEd.

We conducted a survey study to evaluate whether there were changes in teachers' attitudes toward waves and to what extent the changes vary by teachers' prior knowledge of and experience with the concept of waves. Teachers completed the surveys before the workshop, after the workshop, and after teaching waves and sounds. The survey included 8 six-point Likert scale items (1-strongly disagree; 2- disagree; 3- somewhat disagree; 4-somewhat agree; 5-agree; and 6-strongly agree), designed to measure teachers' enjoyment of teaching waves and sounds, their perception of their students' enjoyment of learning waves and sounds, and their comfort in teaching waves and sounds. The items were as follows:

Enjoyment Teaching Waves (Survey Item #1):

- Before PD: In my past experiences, I have enjoyed teaching waves.
- After PD: After participation in the Science of Sound and Music Workshop, I am looking forward to teaching waves.
- After Teaching: This school year, I enjoyed teaching waves.

Enjoyment Teaching Sound (Survey Item #2):

- Before PD: In my past experiences, I have enjoyed teaching sound.
- After PD: After participation in the Science of Sound and Music Workshop, I am looking forward to teaching sound.
- After Teaching: This school year, I enjoyed teaching sound.

Students' Enjoyment Learning About Waves (Survey Item #3):

- Before PD: In my past experience, students have enjoyed learning about waves.
- After PD: After participation in the Science of Sound and Music Workshop, I think my students will enjoy learning about waves.
- After Teaching: This school year, students enjoyed learning about waves.

Students' Enjoyment Learning About Sound (Survey Item #4):

- Before PD: In my past experience, students have enjoyed learning about sound.
- After PD: After participation in the Science of Sound and Music Workshop, I think my students will enjoy learning about sound.
- After Teaching: This school year, students enjoyed learning about sound.

Preference for Teaching Waves vs. Other Topics (Survey Item #5):

- Before PD: In my past experience, I have enjoyed teaching waves more than teaching other science topics.
- After PD: After participating in the Science of Sound and Music Workshop, I am looking forward to teaching waves more than teaching other science topics.
- After Teaching: This school year, I enjoyed teaching waves more than teaching other topics.

Preference for Teaching Sound vs. Other Topics (Survey Item #6):

- Before PD: In my past experience, I have enjoyed teaching sound more than teaching other science topics.
- After PD: After participating in the Science of Sound and Music Workshop, I am looking forward to teaching sound more than teaching other science topics.
- After Teaching: This school year, I enjoyed teaching sound more than teaching other topics.

Comfort in Teaching Waves (Survey Item #7):

- Before PD: In my past experience, I have felt comfortable teaching about waves.
- After PD: After participating in the Science of Sound and Music Workshop, I feel comfortable teaching about waves.
- After Teaching: This school year, I felt comfortable about teaching waves.

Comfort in Teaching Sound (Survey Item #8):

- Before PD: In my past experience, I have felt comfortable teaching about sound.
- After PD: After participating in the Science of Sound and Music Workshop, I feel comfortable teaching about sound.
- After Teaching: This school year, I felt comfortable about teaching sound.

After each pair of Likert items (for waves and for sound), surveys included open-ended questions asking them to justify their responses.

The survey also included a section inquiring about the teachers' educational background and teaching experiences, their satisfaction with the workshop, if they thought other teachers should take the workshop, if they would continue using the materials, and if they shared or were planning to share the resources with other teachers.

3. Results

3.1. Quantitative Results

All 24 teachers answered the pre- and post-workshop surveys. Five teachers had never taught waves before. The nineteen teachers who had taught the subject of waves and sounds also answered pre- and post-workshop questions related to their attitudes toward the subject. Of the 19 teachers, 13 completed the post-teaching surveys. Compared to pre-workshop responses, teachers' attitudes toward waves and sound significantly improved after the workshop. Teachers also maintained a high level of enjoyment and comfort in teaching waves and sounds when they applied what they learned from the workshop in their science classrooms. Figure 1 shows the average results and statistical significance for the teachers who completed all three surveys on items related to attitudes toward waves and sounds.

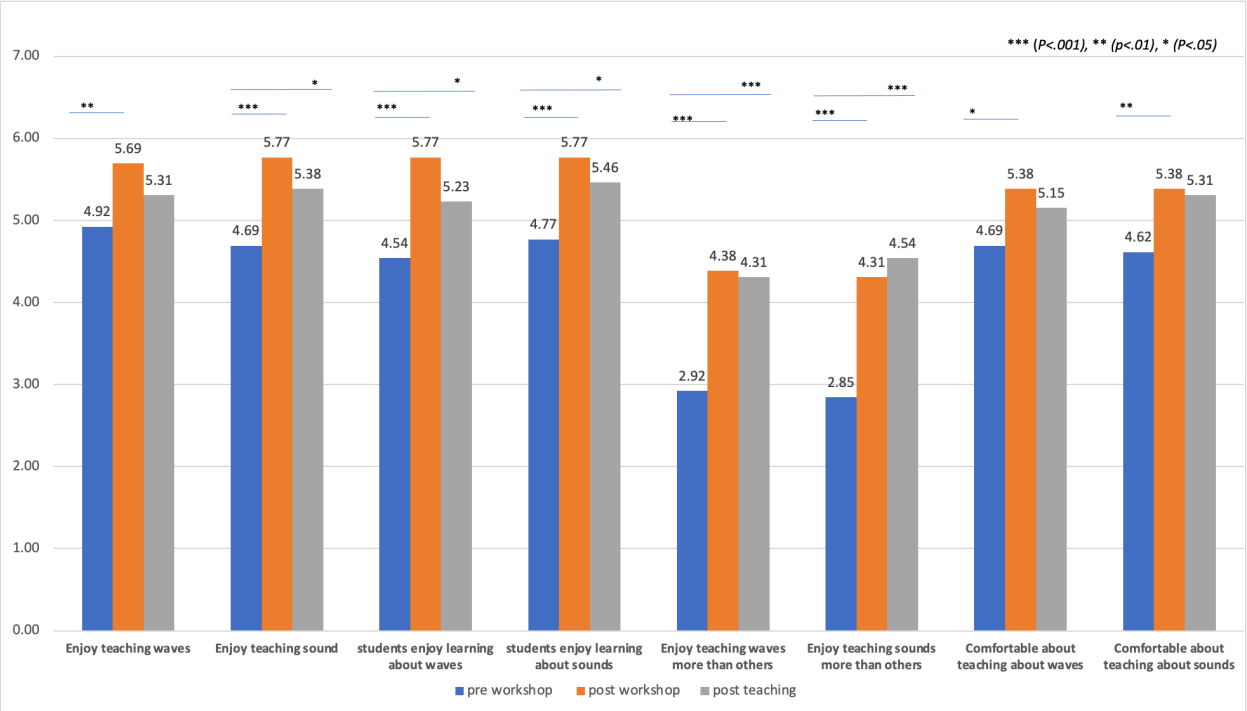

Figure 1. Participating in the workshop connecting music with the science of sound and waves improves teachers' attitudes toward the subject: Average survey scores across three measuring points, before the workshop, after the workshop, and after teaching the materials in their classrooms.

Before participating in the workshop, teachers had an average score of 4.25 (SD=0.90) on their attitude survey. Their average attitude survey score increased to 5.39 (SD=0.39, $p<.001$) after the workshop. The increase was sustained after they taught waves and sounds using the content provided in the workshop 5.09 (SD=0.70, $p<.001$).

Most saliently, teachers enjoyed teaching waves (pre-mean= 2.93, post-workshop mean =4.38, and post teaching mean=4.31) and sounds (pre-mean=2.85, post-workshop mean =4.31, and post

teaching mean=4.54) more than other science topics. The results also showed that teachers became more interested in teaching sound and perceived that their students were more interested in learning about waves.

After the workshop, teachers tended to show a very strong agreement (5.80) with the statement that “other teachers should participate in the workshop” and a very strong agreement (5.54) that in comparison with other workshops, this was one of their favorites.

After teaching, they tended to strongly agree that they would implement the activities again in the future (5.84), and 75% expressed that they shared or were planning to share the materials with other teachers.

3.2. Qualitative Results

Qualitative analysis of teachers’ open-ended survey responses involved a systematic examination to identify emergent themes. Through repeated readings, initial loose codes were generated to capture meaningful concepts, which were then organized into potential themes. The resulting emergent themes were described and supported with teacher quotations, offering a comprehensive understanding of qualitative insights derived from the survey responses. In the following section we present the themes emerging from before the workshop, after the workshop, and after teaching.

3.2.1. Comfort and Knowledge

Pre-workshop Comfort and Knowledge

A qualitative analysis of pre-survey responses revealed a common trend among educators regarding the teaching of topics related to sounds or waves. Many teachers either had not previously covered these subjects or, if they had, exhibited varying degrees of confidence in their ability to teach the material effectively. Moreover, teachers' perceptions of student responsiveness towards these topics varied considerably.

Among those who had not previously taught sounds or waves, the reasons were predominantly attributed to challenges such as time constraints, a limited grasp of the subject matter, and inadequate resources. One teacher highlighted these challenges by stating:

> *"I understand waves and wavelengths, but the sound part is tricky for me. We also end up losing a lot of time because we have outside enrichment for our students, so we have less time to teach that."*

Conversely, educators with prior experience teaching these subjects expressed a positive inclination towards these units. They appreciated the engaging and enjoyable nature of these topics, emphasizing the potential for hands-on activities and real-world applications. For instance, one teacher emphasized the interdisciplinary aspect, stating:

"The understanding of waves is applicable to life in a number of ways, including how we perceive them in nature. By tying the idea of waves to natural phenomena, this unit can transition or even overlap with environmental science. As a multidisciplinary science educator, I try to look for connections between subjects as a means of creating seamless learning experiences between lessons and units."

Educators who felt less confident in teaching these topics attributed their discomfort to limitations in their own content knowledge or methods to effectively engage students, with one teacher expressing, *"[my] lack of complete knowledge about [the] topic makes it more difficult to impart to students."*

Post-workshop Comfort and Knowledge

Teachers also completed a post-survey upon completion of the workshop. A qualitative analysis of post-survey responses revealed that after the workshop, teachers expressed positive excitement about their newly acquired content knowledge and online resources; and that teachers find the topics enjoyable and are confident that they could relay the topic to their students.

Post-survey responses indicated that teachers were enthusiastic about teaching the units due to how they perceived they gained knowledge in what to teach, along with skills on how to teach it, overall expressing a better understanding of content. For example, one teacher said:

> *"I am looking forward to teaching sound and waves now because I have a better understand[ing], more resources to use, and many exciting hands-on activities to do with the students."*

Furthermore, teachers also felt positively about the new resources and tools that were afforded them through the program, and generally felt an increased confidence in their instructional capabilities as a result. For example, one teacher expressed enthusiasm about the program's tools:

> *"I love the new tools, like the spectrogram and signal generator and ways to get students to think about the relationships between frequency and amplitude, and how this connects to the source and the receiver of sound."*

Another teacher similarly shared that the new resources they gained help them to connect the topic to measuring sound:

> *"I have a lot of physical objects and activities, but now I have a better teaching resource to help demonstrate the actual science of what is happening by using the different tools to measure sound."*

Teachers reflected that the materials, curriculum, and resources from the workshop helped teachers to feel increased excitement and preparation around teaching the topics. For example, one teacher shared:

> *"We have curriculum for teaching waves, but this workshop has given me many additional resources I can use with my students. I know my students will be excited to learn using the online tools you have provided."*

These findings highlight the importance of foundational content matter knowledge and adequate equipping in bolstering teachers' confidence when teaching the subject matter.

Post-teaching Comfort and Knowledge

Similar themes were sustained throughout the year when post-teaching survey responses, completed by teachers at the end of the year, were analyzed.

At the end of the year, teachers similarly reported increased comfort in teaching the topics of sound and waves. Teachers again primarily cited the additional understanding, experience, and materials afforded by the workshop as primary reasons that they felt comfortable teaching those topics this year. One teacher elaborated, "I feel the workshop prepared me well to teach the unit. Going through the workshop as a student helped me understand how to teach the unit better." Another teacher similarly noted, "I had access to lots of resources to help me with teaching this in a fun way. It was my first time teaching waves so now I have all of these resources."

However, a subset of the teachers felt that they needed additional practice or experience with the workshop resources, expressed a desire for additional practice or familiarity with the workshop resources, despite their enhanced comfort and confidence in teaching these specific subjects. For example, one teacher shared:

> *"I still want to practice the web apps for this unit, the MusicScope in particular. I would also like more practice building the instruments. But I was very comfortable with what I did convey to students."*

Overall, the analysis of post-teaching survey responses reveals a consistent and positive impact of the workshop on teachers' proficiency in instructing sound and waves throughout the academic year.

3.2.2. Teacher Enjoyment and Student Engagement

Pre-workshop Teacher Enjoyment and Student Engagement

Regardless of prior background experience, many teachers' pre-survey responses cited personal perceived limitations as obstacles impacting both their own teaching enjoyment and student engagement. For example, one teacher noted that they did not feel they taught the material in a way that was engaging for students, remarking, "I don't think I teach it in a way that is interesting or fun…YET." Another teacher also observed varying levels of student engagement to the content material, prior to teacher participation in the program. This teacher elaborates:

"Student reception to lesson material is usually varied. Multiple points of entry to understand the subject provide students different ways of enjoying the experience. In the past, nearly everyone has enjoyed making homemade speakers."

Post-workshop Teacher Enjoyment and Student Engagement

After the workshop, teacher post-survey responses indicated that teachers felt students would be excited about the topics, due to the real-world application and hands-on nature of the subject matter. One teacher highlighted this shift in perspective, stating, "This part of science was not one I enjoyed personally [previously], and [the workshop] made me want to learn more and I found it interesting. I found ways it applied to parts of science that I do enjoy like animals. I think it has lots of ways for students to apply the information to their life so that they care about learning waves."

Teachers also stated that due to the subject matters' connections with music in the real-world, they believe their students will find the topics especially engaging. For example, one teacher explained:

"I think using the initial Soundscape will be an excellent introduction for the students as they explore sounds in their home environments. The culmination of an original exploration of a musical instrument in a group presentation will bring satisfaction and learning to the whole class as they learn together."

Along a similar vein, another teacher shared:

"The activities are very hands-on, and music is something that most students enjoy (and something we don't really talk about in school). I love all the mini demonstrations that are fun and easy and demonstrate different concepts. Teaching about sound and waves can be bland so this will help make it all a little less theoretical."

Another educator shared how the workshop's curriculum and tools transformed their approach and enjoyment of the subject, stating, "The unit is well laid out and has great tools. I myself enjoyed learning about waves and sounds, so I am hoping I can relay that emotion and passion to my students." This teacher reflects directly that an increased enjoyment on her part leads to a motivation to relay the same enthusiasm to her students.

Reflecting on the workshop's impact, another teacher identified a transformation in her understanding of the subject matter which directly enables her to impart enthusiasm to her own students as well. She noted:

"My understanding of waves has definitely changed. The way I was using a virtual oscilloscope in the past was just to view the waveform. But with the knowledge this workshop provided, I feel as though I, as well as my students, will be able to really break it down into what we are seeing and WHY."

Another teacher similarly shared about increased enthusiasm for teaching the topic, due to this teacher's belief that the topic would be extremely interesting to students because of its connection to music. This teacher states:

> "*I am excited because this curriculum and the way the concepts are presented is so very high interest for students . . . they all have favorite songs, musicians, genres, or play instruments, so this makes teaching waves palatable to students."*

Teachers also emphasized the collaborative aspect of the workshop, expressing gratitude for the opportunity to engage with fellow participants, colleagues, and instructors. They acknowledged that this collaborative environment provided valuable additional support, contributing overall to their enhanced learning experience.

By and large, the qualitative analysis highlighted a spectrum of experiences and challenges faced by educators in teaching subjects related to waves and sound, underscoring the need for diverse teaching approaches and continuous professional development to further equip teachers and improve content accessibility for students.

Post-teaching Teacher Enjoyment and Student Engagement

Post-teaching teacher responses likewise revealed a similar theme as the post-workshop surveys. Overall, teachers enjoyed teaching the topics of sound and waves when reflecting on the past year, which contrasts with teacher responses from the beginning of the year. Teachers primarily cited increased student enjoyment and/or engagement during the unit this year, especially due to the interactive and hands-on aspects of the material, as a reason that increased their enjoyment of teaching the subject. One teacher shared that "[the students] really enjoyed the collaboration part of this project, and the hands-on labs… [and that for them], exploring sound is super hands-on so it was fun."

Teachers also appreciated teaching the topics more this year because they were able to rely on the materials and resources that they gleaned from the workshop. They stated that they appreciated not having to develop their own curriculum:

> *"It's always so much easier and more enjoyable when I don't have to develop curriculum from scratch. I loved how the website already has so many resources available so all I have to do is add to it if I want."*

Lastly, teachers expressed gaining an increased understanding of the content matter, saying that "this year, [teaching the content] was better since I had gained a deeper understanding of sound waves and had more resources to teach. "

Notably, teachers also expressed that they felt their students enjoyed learning about the topics of sound and waves. Teachers especially noted that students enjoyed the hands-on and interactive tools which allowed them to connect to real-world applications, and that the music aspects were especially engaging. For example, one teacher reported that students "learned information that was new to them and applied it to creating their own instruments, which they truly enjoyed."

Similarly, other teachers shared about how the musical aspect of the topics impacted student engagement positively:

> *"The modules were fun for the students and engaging. Students loved the different web apps for waves and sound and especially enjoyed creating their instruments and playing them with their group."*

> *"Students particularly enjoyed the interactive tools within the Listening to Waves website. By having a tool with which students can visualize and manipulate waveforms, the concept became more accessible and engaging. In the sound unit, students were eager to connect scientific principles to their personal interests. The activities within the lesson plan helped connect the physics of sound to their daily lives and personal experiences, such as understanding why musical instruments create unique sounds."*

Teachers also noted that students found modules fun and engaging, especially enjoying the musical aspects of the units and being able to create instruments. Importantly, many teachers agreed that they enjoyed teaching these topics more this year than in prior years due to their feeling more equipped. One teacher specifically mentioned:

> *"Waves is already one of my favorite topics, and with the added supplies, knowledge and lessons, I enjoyed it even more!"*

Overall, the sentiment expressed by educators reflected an enhanced enthusiasm for teaching sound and waves in teachers and an enhanced engagement in the topics in students due to the hands-on elements of the topics and the practical applications of these topics in real-world contexts, particularly in relation to musical connections.

General Themes

When asked whether teachers would share the workshop with their colleagues, teacher response varied, but some teachers cited appreciation of the curricular resources and materials. Several teachers also expressed that other teachers would benefit from this workshop and find it needed or valuable, therefore they would recommend it to their colleagues. One teacher articulated:

> *"Other teachers need to understand how to present information in a way that is an experience for students and this workshop has given us ... many ways to make it more interesting for students. It also taught us so much more about sound than what we already knew... we didn't know what we didn't know and now we know so we weren't looking for resources to use that will help."*

In addition, the survey responses generally revealed some perceived strengths of the workshop that teachers appreciated. Generally, teachers cited that they appreciated opportunities to collaborate with other participants, colleagues, and instructors; the pacing and appropriate balance of activities during the workshop; the workshop resources and instructors specifically, and the musical aspect of the curriculum. For instance, one teacher noted that they appreciated the "relaxed pace, [that they had] plenty of time to explore the tools, [and the] lack of

time-wasting activities that are often found in workshops.” Another teacher specifically noted that they appreciated the "collaboration between participants [and] being given enough time to go through the curriculum on our own and ask questions."

Survey results also highlighted some suggestions from teachers on how to continue to improve the program. Some teachers suggested that lessons could be potentially shortened in order to cover all material, modifying the slides and materials to include more direct instruction on the vocabulary terms, and including lesson objectives and NGSS.

4. Conclusions and Future Directions

Learning about the science of sound and waves allowed teachers who had never taught the subject to start teaching it. For those who had taught the subject before, participating in the workshop increased their enjoyment of and comfort with it.

A limitation of this study is that, although teachers report an increased enjoyment by their students, it is not clear that this perception is accurate, nor that this enjoyment will translate into an increased student appreciation for STEM or a STEM career. Thus, we are currently evaluating the effect of the approach on the students of teachers who participated in our latest workshops. For this, we are administering surveys for students in which we inquire about their engagement with the activities, and how the activities translate to their engagement with STEM. These surveys also allow us to evaluate what activities they find most engaging and meaningful, and which are more problematic; and to use this information to improve the resources. We are also conducting personal interviews with teachers after they taught the materials in order to evaluate what features they thought were most meaningful, what didn’t work out, and what needed more guidance. This information will allow us to streamline the activities and improve the clarity of the resources, so they are easier to implement. For example, our evaluation of the teacher’s understanding informs the creation of “science-explained” videos, which are teacher-facing videos embedded in the teacher slides, in which we explain the phenomena explored in each lesson.

We hope that by making the resources ever clearer and self-contained, teachers from diverse geographical regions will be able to use them with minimal or no training, or with some help from their peers. Given that teachers report that they will continue to use this knowledge and tools and that they shared or will share the resources with other teachers, it can be expected that the approach will spread. This is supported by the fact that the web applications and website resources created by our team are being used nationwide, approximately 300,000 times per year, mostly on school days. In combination with our previous finding [9] that similar science of sound activities engage children in science, the results reported here indicate that the approach has the potential to reach and engage many children in their classrooms.

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References

[1] G. L. Rogers, "Interdisciplinary lessons in musical acoustics: The science-math-music connection," *Music Educ. J.*, vol. 91, no. 1, pp. 25–30, 2004.
[2] O. Mattis, "Varèse's Multimedia Conception of" Déserts"," *Music. Q.*, pp. 557–583, 1992.
[3] C. J. Darwin and A. D. Baddeley, "Acoustic memory and the perception of speech," *Cognit. Psychol.*, vol. 6, no. 1, pp. 41–60, 1974.
[4] M. Joos, "Acoustic phonetics," *Language*, vol. 24, no. 2, pp. 5–136, 1948.
[5] F. Weninger, F. Eyben, B. W. Schuller, M. Mortillaro, and K. R. Scherer, "On the acoustics of emotion in audio: what speech, music, and sound have in common," *Front. Psychol.*, vol. 4, p. 292, 2013.
[6] P. Sheeky and C. Wilson, "A History of Electronic Music. Podcast.," https://ahoem.org/.
[7] J. M. Breiner, S. S. Harkness, C. C. Johnson, and C. M. Koehler, "What Is STEM? A Discussion About Conceptions of STEM in Education and Partnerships," *Sch. Sci. Math.*, vol. 112, no. 1, pp. 3–11, Jan. 2012, doi: 10.1111/j.1949-8594.2011.00109.x.
[8] A. N. Booker and V. Minces, "Harmonized mutual development through exploring and creating sound," in *Proceedings of the 16th International Conference of the Learning Sciences-ICLS 2022, pp. 871-878*, 2022.
[9] V. Minces, A. Khalil, and A. Booker, "Listening to Waves: Engaging Underrepresented Students Through the Science of Sound and Music," *Connect. Sci. Learn.*, vol. 3, no. 4, Jul. 2021.
[10] G. Ramsey, "The physics of music course as an introduction to science," in *Proceedings of Meetings on Acoustics*, 2012.
[11] G. P. Ramsey, "Teaching physics with music," *Phys. Teach.*, vol. 53, no. 7, pp. 415–418, 2015.
[12] A. M. Batula *et al.*, "Music technology as an introduction to STEM," *ASEE Annu. Conf. Expo. Conf. Proc.*, 2012.
[13] J. Freeman *et al.*, "Engaging underrepresented groups in high school introductory computing through computational remixing with EarSketch," *SIGCSE 2014 - Proc. 45th ACM Tech. Symp. Comput. Sci. Educ.*, pp. 85–90, 2014, doi: 10.1145/2538862.2538906.
[14] H.-S. Lee and N. Butler, "Making authentic science accessible to students," *Int. J. Sci. Educ.*, vol. 25, no. 8, pp. 923–948, Aug. 2003, doi: 10.1080/09500690305023.
[15] D. Shaffer and M. Resnick, "'Thick' Authenticity: New Media and Authentic Learning," *J. Interact. Learn. Res.*, vol. 10, Jan. 1999.
[16] V. H. Minces, "Developing and Popularizing STEM Online Tools: The Case of 'Listening to Waves' Tools for the Science of Music," in *2021 ASEE Virtual Annual Conference Content Access*, 2021.