Listening to Waves: Engaging Underrepresented Students Through the Science of Sound and Music

Satisfaction with the program. After participation, 99% of students agreed or strongly agreed that the program should be implemented in the following years. When asked to write a sentence describing why, 73% used words connoting positive emotions such as *fun, cool,* or *excited*, and 62% used words connoting intellectual engagement such as *curious, interesting,* or *learn*. The two categories frequently overlapped; for example, a student answered: *"I agree because it's such a great experience and lots of fun. I wasn't very into science at first but now I really like it and find it more interesting."*

Student achievements and engagement. All groups of students finished their sound compositions, including many layers of sound and signal transformations, found nodes on the pipes, chose musical scales with the spectrogram, and successfully built their musical instrument. The students participated in the modules playfully and attentively, exploring and sharing their "discoveries" with their peers, very often using expressions of wonder. For example, after they explored how pipes vibrate, we visualized their sound using the oscilloscope tool. When the students saw the waveform appear on the screen, many of them yelled "Ooohhhh!" Such expressions of wonder were repeated frequently throughout the program. Students often related the activities to everyday encounters with sound. Students

also appeared to value the musical instrument they created, as they often argued to see who in the working group would take the instrument home, and teachers reported that they kept playing with the instrument during breaks throughout the day.

Discussion

The survey results indicate that program participation improves students' attitudes toward science in several ways. Students indicated that they were considerably more engaged in the science of sound activities than in a generic science activity (question A) or in their typical science classes (question E). Significantly, they were much more likely to agree or strongly agree that while the science of sound was taking place (E-post), science was one of their favorite subjects (71%), their preference for science at other times (E-pre) was much lower (42%). It is remarkable that for so many students the science class becomes a favorite. Assuming that the students' appreciation for non-science subjects did not decline during this period, this dramatic change indicates that the students' overall appreciation of classes—and therefore their daily school experience—increased. Further, the effect goes beyond the specific time spent in the program, extending into students' science self-efficacy (question C) and students' intentions to pursue a science career (question B).

The program design intentionally builds on prior knowledge across modules. For example, the experience with the *signal generator* allows the students to arrive at the *object vibrations lab* with an understanding of the relationship between frequency and pitch, which allows them to reflect that longer pipes vibrate slower than shorter pipes (because they have a lower pitch).

LTW contains several design features organized to respond to challenges of underrepresentation in science learning pathways and careers among students and families contending with low-income circumstances and marginalization along lines of racial/ethnic heritage, immigrant, and refugee positions/status. Focusing on musical sound allows the program to build on the students' experiences and abundant *strengths* and incorporate several dimensions that foster equity and diversity in STEM education, as identified in the *Framework for K–12 Science Education* (National Research Council 2012). LTW targets those dimensions in that it

(1) Approaches science learning as a cultural accomplishment, in the sense that participation allows science and science understanding to grow out of the students' lived experiences of sound and music.

(2) Builds on prior interest and identity, where the prior interest is in music, and the identity relates to their music interests, which they often re-engage as they record and transform their favorite songs or their voices. Nearly all (95%) of LTW students strongly agreed with the statement "I like music."

(3) Connects science with students' cultural funds of knowledge as they relate to music. Students were persistently invited to draw on their lived experiences, peer and family experiences of sharing music and sound, and social worlds for generating playful and logical inquiry practices. These links were supportive when visualizing and manipulating sound waves (creating loops, changing the speed) to construct scientific understanding.

(4) Makes diversity visible, by connecting the subjects that the students are learning with the science and life experiences of underrepresented near peers, through the *Wavemakers* docuseries that explored lived experiences of featured young scientists.

(5) *Values multiple forms of expression,* in the sense that students can express their understanding not by taking tests, but by the products they create, such as the sound compositions and musical instruments.

Conclusion

Whereas the potential for integrating music and science has been recognized (Emdin 2010), few have studied the issue quantitatively (Freeman et al. 2014), particularly as it relates to underrepresented students. Furthermore, many experiences have focused on students participating in out-of-school, after-school, or elective classes, which often attract students that already have an interest in the subject matter. The results presented here indicate that music-science integration can be a powerful tool for engaging underrepresented students in their own classrooms, thereby reaching all students, including those who may have poor attitudes toward science.

LTW's web applications provide students and teachers easy access to engaging tools that were once rare and expensive. This ease of accessibility makes some of these activities highly scalable. To facilitate this scaling and the use of the online tools, LTW collaborated with the San Diego County Office of Education (SDCOE) to create an associated curriculum aligned with the science standards, focusing on the core idea of waves (PS4) and including various crosscutting concepts and science and engineering practices. The curriculum builds on activities 1 and 2, and embeds them into a larger learning sequence that requires only materials available online. The collaboration followed a teacher action research model, in which *teacher-leaders*—practicing teachers who are experts in curriculum development—work with subject-domain experts to create relevant learning modules; they implement those modules in their classrooms and meet again with the subject-domain experts to discuss the results and iterate the learning modules accordingly.

Since the creation of the curriculum, LTW has been working with teachers, training them to use the online tools and learn the basics of the physics of waves and sound; LTW has trained more than 100 teachers throughout the country via teleconference, in professional development sessions ranging from 2 to 15 hours. The tools and curriculum have been accessed more than 80,000 times this year to date. A future direction of LTW is to further develop this scale-up model, to work with SDCOE to add learning modules based on the

activities described above, and to evaluate the effectiveness of the professional development and the teacher-led implementations. We suggest that future research, by this and other groups, should focus on understanding how music-integrated STEM programs can be designed for broad reach and accessibility.

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Further Information/Acknowledgments

The publically available materials described in this article, as well as lesson plans associated with the web applications, can be accessed freely here. The reader is welcome and encouraged to reach LTW through its website for suggestions, questions, and free training opportunities. This work was supported by NSF Innovative Technology Experiences for Students and Teachers (ITEST) ID 1657366. Connecting STEM to Music and the Physics of Sound Waves.

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