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TEACHING PHYSICS THROUGH SOUND: IMPACTS OF A PROFESSIONAL DEVELOPMENT WORKSHOP INTEGRATING MUSIC AND WAVE SCIENCE

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Abstract

Physics concepts such as waves, vibration, and frequency are foundational to science and engineering, yet they are frequently taught by teachers whose formal preparation lies outside physics. Prior work by our team has shown that sound and music can support middle school science teachers and students in learning wave physics. The present study extends that work to a more heterogeneous professional development context, including teachers across grade levels and subject areas. We examine whether a sound-based approach can support teachers with limited physics preparation by making wave phenomena perceptible, concrete, and instructionally usable.

Teachers participated in a Listening to Waves professional development workshop centered on hands-on sound exploration, browser-based visualizations, and classroom-ready activities. Pre- and post-surveys were matched at the teacher level. Likert items were scored on a seven-point scale and analyzed with Wilcoxon signed-rank tests and effect sizes. Open-ended responses were reviewed to identify recurring themes in teachers' explanations of why the workshop was useful, engaging, or relevant to their classroom practice.

The analytic sample included 39 matched teachers. Teacher background data indicate that the workshop served a substantially out-of-field population: among all teachers reporting undergraduate majors, 38 of 44 (86%) did not report physics or an engineering-related major; among teachers included in the paired analyses, 36 of 40 (90%) lacked such preparation. Paired results showed significant increases in confidence teaching sound (Mpre = 5.64, Mpost = 6.56, $p < .001$, dz = 1.10), content knowledge for teaching sound (Mpre = 5.28, Mpost = 6.56, $p < .001$, dz = 1.28), confidence teaching physics (Mpre = 5.97, Mpost = 6.33, $p = .016$, dz = .41), and content knowledge for teaching physics (Mpre = 5.82, Mpost = 6.26, $p = .003$, dz = .51). Qualitative responses explained these changes by emphasizing hands-on phenomena, visualizations that make sound visible, student-centered exploration, and ready-to-use resources. The findings suggest that sound-based professional development can support out-of-field teachers by providing embodied entry points into physics and pedagogically structured materials for classroom implementation.

Keywords: Physics education, professional development, out-of-field teaching, sound, waves, music, teacher confidence.

1 INTRODUCTION

Physics provides a foundation for understanding the technological and material world. Concepts such as waves, vibration, energy transfer, frequency, and resonance underlie communication systems, imaging technologies, musical acoustics, sensing devices, and many areas of engineering. Yet physics remains one of the more difficult areas of science education to implement broadly and confidently in schools. The challenge is not only that physics concepts can be abstract; it is also that they are often taught by teachers whose formal preparation is in another field.

Out-of-field teaching is a persistent structural challenge in science education. National surveys and teacher workforce studies have shown that physics and physical science are among the areas most affected by shortages of teachers with disciplinary preparation [1], [2]. This issue is especially important because strong physics teaching requires more than familiarity with vocabulary or equations. Teachers must be able to coordinate phenomena, representations, models, and classroom discourse in ways that help students construct qualitative understanding before formal abstraction. This type of pedagogical content knowledge is difficult to develop when teachers have had limited preparation in the subject [3].

Professional development (PD) is therefore essential, but the form of PD matters. For out-of-field teachers, professional development cannot simply transmit additional content. It must also provide

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accessible representations, coherent instructional sequences, classroom-ready materials, and experiences that teachers can translate into their own settings. Educative curriculum materials can support teacher learning by embedding explanations, pedagogical guidance, and implementation structures directly into resources teachers can use with students [4]. This design aligns with broader research on effective teacher professional development, which emphasizes content focus, active learning, coherence, and opportunities for teachers to connect new ideas to classroom practice [5], [6]. Physics education research similarly argues that teachers need opportunities to reason with phenomena and representations, not only formal equations [7], [8].

The Listening to Waves (LTW) program was developed around the idea that sound and music provide a powerful entry point into physics. Sound is a wave phenomenon that students and teachers can hear, feel, produce, manipulate, and visualize. It makes abstract concepts such as frequency, amplitude, waveform, and resonance immediately perceptible. Prior LTW work has shown that sound-based science activities can improve students' attitudes toward science and support middle school teachers in teaching waves and sound [9]-[12]. Those studies focused primarily on middle school science contexts. The present study asks whether the same general approach can support a broader and more heterogeneous teacher population, including elementary, middle school, high school, music, general science, biology, and physical science teachers. This approach also reflects arguments from STEAM scholarship that arts integration is strongest when artistic practice and disciplinary learning are mutually authentic rather than decorative [13]-[15].

This extension is important because the real ecology of physics teaching is heterogeneous. Teachers who encounter physics-related standards may not identify as physics teachers. Some teach integrated science; others teach biology or general science; others teach across grade levels or provide interdisciplinary instruction. In these contexts, the goal of professional development is not only to increase content knowledge. It is also to provide teachers with a pathway for making physics meaningful, teachable, and adaptable across classrooms.

The present paper analyzes a PD workshop offered to teachers from two school districts in Northern California. The workshop introduced the LTW curriculum and web applications, emphasizing sound as a phenomenon through which teachers can explore wave physics. We focus on three questions: (1) What was the disciplinary and instructional background of the participating teachers? (2) How did teachers' confidence, content knowledge, affect, and expectations of student enjoyment change after the workshop? (3) How do teachers' open-ended responses explain the observed quantitative results?

2 METHODOLOGY

2.1 Workshop context and design

The professional development workshop introduced teachers to LTW resources for teaching sound and wave physics. The workshop combined hands-on activities with browser-based tools that visualize and manipulate sound. These tools include a signal generator, an oscilloscope, and a spectrogram, which allow users to create sounds, observe waveforms, and analyze frequency content. The instructional design followed the LTW approach used in earlier studies: teachers experienced activities as learners, discussed the scientific content behind the activities, and considered how to implement the materials in their own classrooms.

Activities emphasized direct experience with phenomena. Rather than beginning with formal definitions of waves, the workshop invited teachers to observe, hear, feel, and manipulate sound. This design is particularly relevant for out-of-field teachers because it gives them accessible phenomena around which to build explanations. The workshop also provided teacher-facing resources, including lesson slides, simulations, explanatory notes, and implementation suggestions. Open-ended responses indicate that teachers noticed and valued this structure.

2.2 Participants

The pre-survey included 47 respondents before exclusions. Four teachers who reported prior use of LTW resources were excluded from the paired analyses. The final quantitative paired analysis included 39 teachers matched across pre- and post-surveys. The post-workshop survey included 44 respondents for post-only items. Teacher background data were also analyzed descriptively to characterize the instructional population reached by the workshop.

The participants were not a narrow group of physics specialists. Undergraduate major responses included biology, liberal studies, ecology, physiology, finance, speech pathology and audiology, music, chemistry, geology, math, classics, and only a small number of physics-related majors. Among 44 teachers who reported undergraduate majors, 38 (86%) did not report physics or a closely related engineering field. After excluding prior LTW users, 36 of 40 teachers reporting a major (90%) lacked physics-related preparation. This out-of-field profile is central to the interpretation of the results.

Table 1. Participant and background summary.

Measure	Value
Respondents excluded from paired analyses because they reported prior LTW resource use	4
Unique pre-survey respondents with names after exclusion	40
Unique post-survey respondents with names	44
Matched paired sample	39
Teachers reporting undergraduate majors	44
Teachers without physics/engineering-related undergraduate major	38 / 44 (86%)
Teachers without physics/engineering-related major after exclusion	36 / 40 (90%)

Table 2. Teaching contexts represented in the pre-survey sample after excluding teachers who reported prior LTW resource use. Counts are based on available responses.

Context category	Count
Middle school only	18
High school only	9
Multiple levels	7
Physical science mixed with other science	19
General or integrated science	11
Physics / physical science	8
Other / unclear	1
Music	1

2.3 Survey instruments and quantitative analysis

Teachers completed pre- and post-workshop surveys. The surveys included seven-point Likert items ranging from 1 = Strongly disagree to 7 = Strongly agree. Items measured affect toward teaching science, physics, life science, and sound; confidence teaching those domains; perceived content knowledge; expected student enjoyment; and workshop evaluation. Items were matched at the construct level. For example, pre-workshop items such as "I feel confident teaching about physics" were matched to post-workshop items such as "After this workshop, I feel confident teaching about physics."

Because the same teachers responded before and after the workshop, analyses used paired statistics. Likert responses were quantized on a seven-point scale and several response distributions were asymmetric, with many values concentrated near the upper end of the scale. For that reason, Wilcoxon signed-rank tests were used as the primary tests of pre-post change. Paired t-tests were also computed as sensitivity analyses and led to the same substantive interpretation. Effect sizes are reported as Cohen's dz to support interpretation of the magnitude of change.

2.4 Qualitative and semantic analysis

Open-ended survey responses were analyzed to interpret the quantitative findings. We used the responses to identify the reasons teachers gave for finding the workshop useful, engaging, and feasible to implement. Responses were read thematically, with attention to comments about student engagement, hands-on learning, conceptual accessibility, classroom materials, and teacher confidence. Representative quotations are used below to illustrate how teachers explained their quantitative ratings.

3 RESULTS

3.1 A heterogeneous and largely out-of-field teacher population

A major finding is that the workshop reached teachers with varied instructional roles and limited formal physics preparation. Teachers reported teaching middle school integrated science, high school physics, physical science, life science, biology, media and technology, music-related courses, and other mixed assignments. Grade-level responses included middle school, high school, elementary, and multi-level teaching. This heterogeneity distinguishes the present study from our prior work focused more directly on middle school science teachers.

The out-of-field nature of the population is especially important. The majority of teachers did not have undergraduate preparation in physics. This means the workshop should not be interpreted as serving an already specialized physics audience. Rather, it served teachers who often need to teach physical science concepts despite being trained in other disciplines. This context provides a rigorous test of whether sound-based PD can support teachers for whom physics is not their home discipline.

3.2 Paired quantitative results

Table 3 shows the full paired analysis for the 16 matched quantitative constructs. The pattern is clear: the largest and most reliable gains occurred in domains closest to the workshop content. Teachers showed significant increases in confidence teaching sound, content knowledge for teaching sound, confidence teaching physics, content knowledge for teaching physics, expected student enjoyment of sound and physics, and evaluation of the workshop as enjoyable and useful. Because the response distributions were quantized and often concentrated near the top of the scale, the table reports Wilcoxon p values; paired t-tests produced similar substantive conclusions.

Table 3. Paired pre-post results for matched Likert items. Scale: 1 = Strongly disagree, 7 = Strongly agree.

Construct	*Domain*	*n*	*Pre M*	*Post M*	*Change*	*Wilcoxon p*	*dz*
Affect: cheerful teaching	life science	39	5.72	5.56	-0.15	.467	-0.11
Affect: cheerful teaching	physics	39	6.36	6.49	0.13	.275	0.18
Affect: cheerful teaching	science	39	6.72	6.54	-0.18	.052	-0.32
Affect: cheerful teaching	sound	33	6.12	6.72	0.61	< .001	0.73
Confidence teaching	life science	39	5.77	5.56	-0.21	.321	-0.14
Confidence teaching	physics	39	5.97	6.33	0.36	.016	0.41
Confidence teaching	science	39	6.38	6.56	0.18	.090	0.28
Confidence teaching	sound	39	5.64	6.56	0.92	< .001	1.10
Content knowledge	life science	39	5.56	5.77	0.21	.284	0.20
Content knowledge	physics	39	5.82	6.26	0.44	.003	0.51
Content knowledge	science	39	6.13	6.46	0.33	.027	0.37
Content knowledge	sound	39	5.28	6.56	1.28	< .001	1.28
Expected student enjoyment	physics	39	5.79	6.41	0.62	< .001	0.73
Expected student enjoyment	sound	33	5.94	6.72	0.79	< .001	0.88
Workshop evaluation	enjoyable	39	5.74	6.51	0.77	< .001	0.69
Workshop evaluation	useful	39	5.62	6.62	1.00	< .001	0.95

The strongest effect was observed for content knowledge related to sound. Teachers increased from M = 5.28 to M = 6.56, a mean gain of 1.28 points on the seven-point scale (Wilcoxon $p < .001$, dz = 1.28). Confidence teaching sound also increased substantially, from M = 5.64 to M = 6.56 (Wilcoxon $p < .001$, dz = 1.10). These results indicate that the workshop most strongly affected the content area most directly targeted by LTW.

Physics-related items also improved. Confidence teaching physics increased from M = 5.97 to M = 6.33 (Wilcoxon p = .016, dz = .41), and perceived content knowledge for teaching physics increased from M = 5.82 to M = 6.26 (Wilcoxon p = .003, dz = .51). These gains are smaller than the sound-specific gains, which is expected: the workshop directly centered sound and waves, while physics is the broader disciplinary category into which sound-based learning fits.

Expected student enjoyment also increased. Teachers reported stronger post-workshop agreement that students would enjoy learning about physics ($M_{pre} = 5.79$, $M_{post} = 6.41$, Wilcoxon $p < .001$, $d_z = .73$) and sound ($M_{pre} = 5.94$, $M_{post} = 6.72$, Wilcoxon $p < .001$, $d_z = .88$). These items matter because teacher adoption depends not only on teacher confidence, but also on whether teachers believe students will respond positively to the instructional approach.

Workshop evaluation items showed near-ceiling results. The item matched to workshop enjoyment increased from $M = 5.74$ to $M = 6.51$ (Wilcoxon $p < .001$, $d_z = .69$), and usefulness increased from $M = 5.62$ to $M = 6.62$ (Wilcoxon $p < .001$, $d_z = .95$). Post-only items were similarly strong: teachers reported that they would recommend the workshop to other teachers ($M = 6.59$, $SD = .50$) and share the resources with colleagues ($M = 6.48$, $SD = .66$).

Table 4. Post-only quantitative items. These were not used as primary paired outcomes.

Item	*n*	*M*	*SD*	*Median*	*Min*	*Max*
Recommend workshop to other teachers	44	6.59	0.50	7	6	7
Share resources with other teachers	44	6.48	0.66	7	4	7
Future direction: interest in AI through sound	44	5.91	1.46	6	1	7
Future direction: interest in electricity and magnetism through microphones/ speakers	44	6.61	0.72	7	3	7

3.3 Open-response themes explaining the quantitative results

The open responses help explain why teachers appreciated the workshop and why the quantitative ratings were strong. Teachers did not describe the workshop only as enjoyable; they repeatedly pointed to concrete reasons that the activities would work in classrooms: students' interest in sound and music, hands-on exploration, visualizations that make waves visible, and ready-to-use instructional materials.

A frequent theme centered on students, music, learning, hands-on activity, and sound. This theme helps explain the strong increases in expected student enjoyment. Teachers repeatedly described sound as a medium that students would find accessible and motivating. One teacher wrote that "students love anything that is hands-on," while another explained that music can "tap into one of their passions." These comments suggest that the affective appeal of sound is not incidental; teachers see it as a pedagogical resource for making physics more approachable.

A second theme concerned the workshop's practical value. Teachers emphasized ready-to-use resources, lesson slides, simulations, and scaffolds. Representative comments included "The slides I can use in my classroom," "The explanations and the resources to use in my class," and "The online sources to make learning sound visible." These responses help explain the high usefulness rating. Teachers were not only entertained by the workshop; they saw concrete materials that could reduce planning burden and support implementation.

A third theme concerned conceptual accessibility. Teachers described sound and waves as topics that can be difficult because they involve microscopic or invisible mechanisms, but they also noted that the workshop made these ideas more visible and teachable. One response stated that "sound and waves are topics that are hard to teach especially at the microscopic level" but that the simulations would make them easier to address. Another teacher wrote, "I love the tools that make learning sound visible." This theme explains why content knowledge and confidence improved, especially for sound and physics.

A fourth theme involved shifts toward student-centered pedagogy. A teacher wrote that, instead of being teacher-centered, the lessons position students to learn by doing while the teacher serves as a facilitator. This response is important because it indicates that the workshop affected not only what teachers know, but how they imagine instruction. For out-of-field teachers, activity structures that support facilitation can be especially valuable, since they reduce the need to lecture from expert authority while still supporting disciplinary learning.

3.4 Relationship between qualitative and quantitative findings

The qualitative results explain the quantitative results in three ways. First, high scores on enjoyment and usefulness are supported by teachers' descriptions of the workshop as resource-rich, hands-on, and immediately applicable. Second, increases in confidence and content knowledge are supported by comments about simulations, visible representations, and clearer explanations of sound phenomena. Third, increases in expected student enjoyment are supported by teachers' emphasis on music, hands-on learning, and student curiosity. The qualitative data therefore strengthen the interpretation that the workshop was not merely enjoyable; it provided teachers with a usable representational system for teaching physics.

4 DISCUSSION

4.1 Sound as an accessible representation for out-of-field physics teaching

The central contribution of this study is that sound-based professional development appears to support teachers who are not formally prepared in physics. The results do not come from a group of physics specialists; they come from a population in which most teachers lacked physics-related undergraduate preparation. This matters because the needs of out-of-field teachers differ from those of specialists. They need not only more content knowledge, but also ways to experience, organize, explain, and teach concepts that may feel abstract or outside their area of expertise.

Sound provides such a pathway. It is physical, perceptible, and culturally familiar. Teachers can hear changes in frequency, feel vibration, record sound, visualize waveforms, and compare perceptual changes to graphical representations. This makes sound useful as a bridge between everyday experience and formal physics. For teachers, that bridge can support confidence because it gives them phenomena around which instruction can be organized. For students, the same bridge can support engagement because it connects physics to music, voice, technology, and everyday sonic experience.

4.2 Differentiation from prior LTW work

This study extends prior LTW research in an important way. Earlier studies demonstrated that sound and music can support middle school science teachers and students in learning wave physics and developing more positive attitudes toward science [9]-[12]. The present study shows that the same pedagogical framework can be meaningful for a broader instructional population. The teachers in this workshop included multiple grade levels and subject areas, and many did not identify as physics specialists. Thus, the paper contributes evidence about the adaptability of sound-based physics PD across teacher contexts.

This extension is not a trivial scale-up. Heterogeneous professional development settings require materials that can function across classrooms with different standards, pacing constraints, teacher identities, and disciplinary preparation. The qualitative responses suggest that the workshop met this challenge through a combination of phenomena, ready-to-use materials, visualizations, and flexible activity structures. Teachers could see how to adapt the resources rather than merely appreciate them in the workshop setting.

4.3 Affect, usefulness, and confidence as separate outcomes

The results also show the importance of distinguishing affective, instrumental, and confidence-related outcomes. A workshop can be enjoyable without being useful, and useful without increasing teacher confidence. In this study, all three dimensions moved in the desired direction. Teachers found the workshop enjoyable, perceived it as useful, and reported increased confidence and content knowledge in the relevant domains. This combination is important for implementation because teachers are more likely to adopt materials when they perceive them as engaging, feasible, and instructionally meaningful.

The largest gains were not in general science affect, which was already high, but in sound-specific and physics-specific constructs. This pattern suggests that the workshop influenced the areas where support was most needed. Teachers already liked teaching science and already believed students could enjoy sound-related topics. The workshop appears to have converted that general positive disposition into greater confidence and knowledge for teaching the specific content.

4.4 Future directions: extending the pedagogy beyond waves

Although the present paper focuses on wave physics and sound, the results also point toward future extensions. As a post-only exploratory item, teachers were asked whether they would be interested in future LTW resources for learning electricity and magnetism through making microphones and speakers. Responses were extremely positive ($M = 6.61$, $SD = .72$, $n = 44$), with 98% agreeing or strongly agreeing. This result is not treated as a primary outcome of the present study, because the workshop analyzed here did not implement an electromagnetism curriculum. However, it suggests that teachers see the sound-based pedagogy as extensible to other areas of physics. Teachers also responded positively to an exploratory post-workshop item about future LTW resources for teaching artificial intelligence through sound ($M = 5.91$, $SD = 1.46$, $n = 44$), suggesting a second possible extension of the pedagogy into emerging STEM topics. In future work, speakers and microphones may provide a coherent bridge from waves into electromagnetism by connecting electrical signals, magnetic forces, mechanical vibration, and sound.

5 CONCLUSIONS

This study examined the impact of a sound-based professional development workshop for a heterogeneous and largely out-of-field teacher population. The results show significant gains in teachers' confidence and perceived content knowledge for teaching sound and physics, strong expectations of student engagement, and very high ratings of workshop usefulness and enjoyment. Qualitative responses explain these outcomes by highlighting hands-on phenomena, visualizations that make sound visible, classroom-ready resources, and student-centered exploration.

The findings support the claim that sound-based physics instruction can help address a key challenge in science education: many teachers responsible for physics-related content do not have formal physics preparation. By grounding physics in perceptible phenomena and providing structured resources, the LTW approach gives teachers a way to teach abstract concepts through experiences they and their students can understand directly. This is not a replacement for disciplinary preparation, but it is a practical and scalable way to support teachers working in real educational contexts.

Future research should examine classroom implementation and student outcomes across the varied teaching contexts represented in this study. It should also investigate how the pedagogy can extend to electromagnetism and engineering through systems such as speakers and microphones. Together, these directions point toward a broader model of physics education in which sound, materials, and technology provide accessible entry points for teachers and students alike. Future work should also examine whether the sound-based approach can support emerging topics such as artificial intelligence, where sound classification and representation learning may provide accessible classroom entry points.

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