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JASA ARTICLE

Human-centered design in acoustics education for undergraduate music majors[a)]

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ABSTRACT:
An acoustics course for undergraduate music majors should take advantage of the natural affinity between acoustic science and musical practice. In this study, current students and recent graduates of one university's music school were surveyed with the goal of assessing their unique needs in an acoustics curriculum. The results of the survey are reported, and several curriculum recommendations are provided based on the principles of human-centered design. In particular, the acoustics course can harness musicians' intuitive understanding of sound by incorporating musical instruments into classroom demonstrations. Also, acoustics instructors should strive to introduce students to acoustical software, which is also used in the music industry. Finally, the survey findings suggest that the contemporary shift toward active learning and technology-based instruction in acoustics pedagogy is beneficial to music students.
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I. INTRODUCTION

An important priority of the college instructor is to tailor his/her teaching to the needs and experiences of the students. While acoustics is a field of basic science research, students of such diverse disciplines as engineering, broadcast journalism, architecture, and music all stand to benefit from a foundational education in acoustics. However, these students vary in their mathematical, scientific, and acoustical backgrounds, as well as in the subfields of acoustics that will assist them the most in their eventual careers. An effective acoustics instructor teaches at the intersection of his/her acoustics knowledge and his/her students' abilities and career goals. This article considers one such intersection: an acoustics course for undergraduate music majors and how it may be designed to take advantage of their intuitive understanding of sound and the natural affinity between musical practice and acoustic engineering.

This intersection is worth investigating because increasing numbers of music students are venturing beyond the traditional venues of performance and education to pursue careers in business, project management, and sound design. The acoustics class is often the only science-based class required of music students and, thus, plays an important role in preparing them for their career search. Also, many musicians find the ability to speak "scientifically" about sound helpful in a performance context because the language that acousticians use to describe sound can be more precise and objective than the more abstract terms traditionally used among musicians.

The present study draws on the principles of human-centered design (HCD) to investigate how the acoustics class can be tailored to the unique experiences and needs of music students. In Sec. II, we review previous articles on acoustics education for nonscience majors, paying special attention to the techniques that acoustics instructors have used to engage music students' latent knowledge in the classroom. Next, in Sec. III, we report the design and results of a survey that asked current and former students of Seoul National University (SNU) College of Music about their background and interest in music, science, and acoustics. In Sec. IV, we reflect on the survey results and offer three recommendations for teaching acoustics to music students: First, the instructor should strive to create an integrated pedagogy that teaches acoustics *through* music. Second, to the extent possible, introduce students to software tools that are used by musicians and acoustics professionals. Finally, encourage students to teach themselves by implementing an active-learning system and maximizing the number of laboratory activities.

II. LITERATURE REVIEW

First, we will review previous studies of acoustics education for nonscience majors. Then, we will introduce some of the principles of HCD that we followed in designing our survey.

A. Acoustics education for nonscience majors

Several articles on acoustics education have addressed techniques for tailoring the acoustics curriculum to a particular student population. The most detailed accounts are those of acoustics courses for engineering majors. For example, Kessissoglou (2012) related that a change in Australian

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road noise regulations had brought about an increased demand for acoustics consulting services. Thus, her fundamentals of noise course was gaining popularity among mechanical engineering students interested in working in this growing field. Kessissoglou (2012) was able to leverage her industry connections to bring in guest speakers and provide students with hands-on learning experiences. Similar examples of acoustics courses targeted at students with strong engineering skills are described by Robertson and Parker (2012) and Bös *et al*. (2012). The latter especially reflects Kessissoglou's interest in connecting engineering students with career opportunities in the growing field of acoustics consulting.

There are some pedagogical studies of acoustics classes for the general (that is, nonscience) undergraduate audience. Neilsen *et al*. (2012) described classroom demonstrations and laboratory activities used in the introductory acoustics course at Brigham Young University. In this setting, the authors found that it was possible to improve knowledge retention by using brief, daily online quizzes to encourage continuous engagement. The instructors also offered a variety of extra-credit opportunities to encourage students to take an active role in their learning. Conference presentation abstracts suggest a similar trend toward active, experiment-based learning and flipped classrooms in introductory acoustics education (Hansen, 1993; Morrison, 2013; Sakagami, 2016). However, the courses discussed in these studies do not place special focus on *musical* acoustics.

On the other hand, at many schools, there is a physics of music course for nonscience majors. At some universities, the physics of music is a general education elective open to students regardless of their background in math or music, although it may be especially popular among music students. At other schools, the physics of music course is taught within the music department and, therefore, assumes that students can read musical notation and play an instrument or sing. Thus, the physics of music label really encompasses two distinct courses: a general education class for general audiences and a specialized class for music majors.

Previous articles on the physics of music course have focused on the general education context. Because students typically take this course to fulfill a science breadth requirement, this kind of class is best understood as a *vessel* for science education writ large. For example, Ramsey (2014) suggested that the physics of music can introduce nonscience majors to scientific inquiry by drawing on students' inherent interest in music to overcome the aversion to science that such students may have felt in high school. Ramsey also reported that three-quarters of his students can play an instrument or sing, although the course was not planned around an assumption of musical experience. In a similar vein, Anderson *et al*. (2016) described an acoustics class for nonscience majors that focuses on string instruments but also includes material on acoustics of speech and singing. Although not all of the students in the class were music majors, the instructors provided opportunities for musicians to bring their preexisting knowledge to bear on the course material. For example, in their discussion of the partial frequencies of a vibrating string, they note that bowing a violin close to the bridge produces a brighter sound, and then they provide the scientific explanation that this bowing action excites higher partials.

In the examples above, the presence of students with a musical background in the physics of music general education course was a happy accident that enabled the instructor to elicit interdisciplinary connections. However, when an acoustics class is offered *within* the music department, students' musical knowledge is guaranteed. Thus, we argue that teaching acoustics to music majors offers a unique opportunity to harness students' intuitive understanding of the mechanics of sound. Moreover, music majors stand to benefit from an effective education in the fundamentals of acoustics not merely as an introduction to science but, moreover, because acoustics yields immediate and practical applications in musical performance. Nonetheless, the intersection of acoustics and musical proficiency in undergraduate education has not been granted much attention in previous literature. It is this gap which the present study seeks to fill.

B. Human-centered course design

The notion that acoustics education, and education in general, can be improved by viewing the students of a particular course as a target demographic with unique needs is not new. For millennia, educators have pointed out that learning is not a unilateral process but an ongoing interaction between the pupil and instructor; recently, this insight has found new expression in the language of HCD, which posits that the design of a product must take advantage of its user's capabilities while providing support where the user is likely to encounter difficulty. Inasmuch as a college course can be viewed as a product and the students as its user or consumer, proponents of HCD would argue that before writing a syllabus and planning classroom activities, the college instructor should familiarize himself/herself with her student population and tailor the curriculum accordingly (Maziku 2019; Frank and Bogard, 2022).

Our interpretation of HCD follows the principles outlined by the International Organization for Standardization, which defines the design of any interactive system or service as consisting of four phases (ISO, 2019). The present study concentrates on the first of these phases, "understand and specify the context of use," with respect to the design of an improved acoustics curriculum for music students. What experiences and previous knowledge do the students bring to the table, and what specific pedagogical needs do they possess? Such questions help the designer discover the actual needs (whether stated or unstated) of the course participants; accordingly, this phase of the design process is often called simply *needs analysis.*

In curriculum design, "needs analysis" entails considering the course's purpose, its target audience, and which curriculum elements can provide the greatest value. For example, when planning an English language course, the course goals and level of difficulty will depend on the age of the students and even among students of the same age, the course materials must respond to the diversity in students' language proficiency. An essential tool of the HCD methodology is the opinion survey because survey results can serve as a check against the designer's hidden biases and assumptions (Luke, 2013).

III. A SURVEY OF UNDERGRADUATE MUSIC MAJORS

Bearing in mind the HCD principles outlined above, we designed a survey within the HCD paradigm to assess the needs of music students with respect to an introductory acoustics course.

A. Student context

Our setting, acoustics education for music undergraduates, has a few points in common with that of the general education acoustics course. Music undergraduates are not expected to have a strong background in math beyond algebra; in fact, the acoustics course is often the only math- or science-based course taught in the music department. It is safe to assume that music students are about as likely to have a recreational interest in science as other nonscience majors. Finally, whereas students majoring in music typically intend to pursue a career in a nonscience field such as performance, music education, or arts management, in these fields, students with strong technological and critical-thinking skills have a competitive advantage on the job market.

On the other hand, music students are unlike other students who might enroll in an introductory acoustics class in that they have a substantial amount of latent knowledge of the physics of music that can speed up the learning process. For example, most students who play string instruments already know how to produce partial frequencies or "harmonics" by gently muting the string at its integer divisions while students whose interests include music production already know how to interpret spectrogram output on a computer screen. Another difference between music students and general nonscience majors is that the former can apply the acoustics of venue design, microphone placement, and instrument design to their performance practice.

B. Survey design

The principal goal of the survey was to analyze music students' needs within the larger framework of acoustics education to elicit specific course-design recommendations. The respondents to the survey were 50 students and recent graduates of the SNU College of Music. The marginal distributions of student characteristics appear in Table I. We elected to include a mix of current students and recent graduates in the sample population to obtain a balanced picture of both the status quo in music pedagogy and the perspective of students who are currently working or searching for work. The sample included students pursuing or holding degrees in Korean traditional music; piano, vocal, string instrument, wind instrument, and percussion performance; music composition; and musicology and theory. We conducted the survey using Google Forms (Google LLC, Mountain View, CA), while the data analysis was performed using Python (v3.8.8) and the scikit-learn package (v0.24.1).

TABLE I. The survey respondents.

Gender	
Women	35
Men	15
Age	
Less than 25 years old	19
25–30 years old	29
30 years old and older	2
Status	
Current students	19
Recent graduates	31

The survey itself consisted of 6 basic information questions, 17 multiple-choice questions using a 7-point Likert scale, and 4 free-answer questions. In creating the survey, we avoided using the word *acoustics* because we wanted respondents to answer freely about their interest in acoustical *topics* without being primed to respond on the basis of an acoustics course that they may have taken. At SNU, the music school offers an acoustics course that, although not mandatory for music students, is a popular elective because it is taught in English, and the college requires students to take at least one course in English before graduation. The survey was given in Korean; a translation of its contents appears in the Appendix.

The Likert question items were divided into three categories according to the HCD principles expressed in the ISO (2019) standard. The first category concerns students' background knowledge and values with the goal of "increasing usability for people with a wider range of capabilities and thus increasing accessibility" (ISO, 2019). The purpose of these questions was to identify population factors, such as students' mathematical knowledge, musical knowledge, and personal views on science education, to maximize the accessibility of the course to diverse constituents of the target population. The second group of questions reflects the principle of "improving user experience" by identifying the needs that are particular to music students. The purpose of these questions was to identify interest in, necessity of, and practicality of a scientific approach to music from the perspective of music students. Finally, the third group of questions concerns "increasing the productivity of users and the operational efficiency of organizations," which, in our context, reflects the extent to which the acoustics curriculum accords with students' professional goals and trends in the industry. The questions in this group reflect students' postgraduate career plans as well as the increasing demand for technology skills, including acoustics software, in the job market.

To analyze the quantitative survey items, we computed descriptive statistics and used a K-means clustering algorithm (explained below) to identify subgroups of respondents with similar traits. We also quote students' text responses when they are relevant to the analysis.

C. Survey results and discussion

The results of our survey suggest that there is a substantial overlap between the topics covered in an introductory acoustics course and the interests of music undergraduates. In all three question areas, students expressed interest in a scientific approach to music. While the respondents expressed low confidence in their math and science ability, they also expressed a desire to deepen their knowledge of the same. In particular, they expressed interest in a scientifically informed class related to their major and career ambitions. Students' confidence in their musical ability and sonic comprehension was high, which suggests that an acoustics course for music students can leverage this preexisting knowledge to elicit better learning outcomes. (In the conclusion in Sec. IV, we will offer a few suggestions for how this can be accomplished.) The summary statistics for the Likert-scale questions are given in Fig. 1.

One area of agreement between music students' learning goals and those of the typical acoustics course is the desire to put abstract sonic qualities into concrete language. Musicians often use abstract, intuitive vocabulary such as "misty" or "assertive" to elicit specific tone qualities from their musical collaborators, but these terms are subject to individual interpretation as evidenced by the survey responses. The respondents expressed a desire to describe musical qualities using specific terms and scientific principles. If musicians have a common foundation in acoustics, some of this ambiguity can be clarified by enabling musicians to reference specific qualities of the sonic waveform.

Another area in which an acoustics course can serve music students is by providing hands-on experience with technologies that are used by acousticians and musicians alike. This is evidenced by students' affirmative responses to questions concerning career preparation, the necessity of classes that reflect industry trends, and the importance of learning software tools. The following responses are representative:

> I would like to have the opportunity to take a class on acoustics software.
>
> To make money in music, there is a pressing need for a MIDI (musical instrument digital interface) class.
>
> I think it would be best to hold classes tailored to each major.
>
> With the arrival of the post-Covid era and other such generational changes, I think that after graduation, it is becoming necessary to have skills for working with digital programs, and this class will be a big help to its students.
>
> It would be nice if there were opportunities to practice things like relevant software languages.

While the overlap between the software tools used by acousticians and musicians is not perfect, these responses

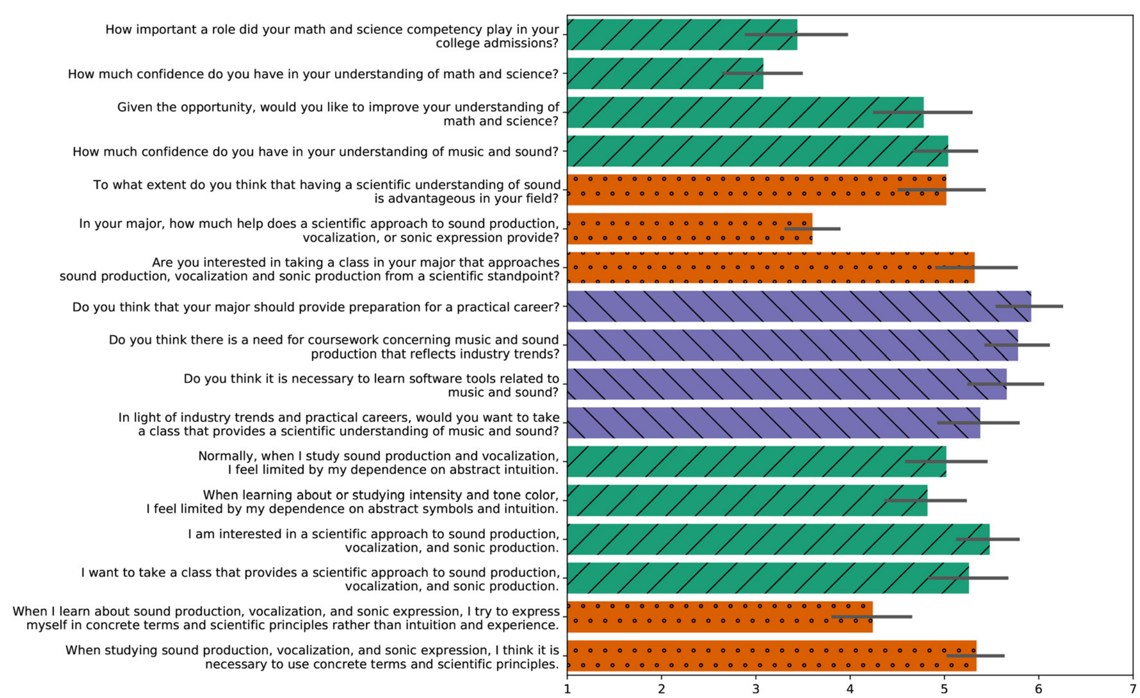

FIG. 1. (Color online) The average responses for the 17 Likert-scale questions, where a response of "1" indicates strong disagreement and a response of "7" indicates strong agreement with the prompt. The bars are colored and textured to show each question's correspondence to the three areas of HCD detailed in Sec. III B. The error bars indicate the range in which 95% of the responses fall.

suggest that many latent opportunities for cross-disciplinary learning exist in the acoustics class for undergraduate music majors.

It also appears that the active-learning techniques common to acoustics classes can provide music students with a refreshing and challenging learning environment. The traditional college music curriculum focuses on students' mastery of a fixed canon of masterworks (Schippers, 2009), whereas the active-learning techniques discussed in the literature review encourage students to discover and solve problems on their own. But, as suggested by one student's free response to question 27 (which concerns the relationship between science education and career goals), self-pedagogy is an essential skill in today's rapidly changing job market:

> When preparing students to graduate and embark on a professional career, there is no way to predict how industry trends will change. (Even three years ago, who could have predicted that the coronavirus pandemic would deal such a heavy blow to the world of musical performance?) I think it is impossible, realistically speaking, to design courses on an individual basis while bearing in mind every student's practical career goals. As an undergraduate, the thing I need most from my degree coursework is not merely "information" about music, but rather "the ability to teach myself" regardless of whether I enter a musical field or not. So, if a subject like acoustics is added to the required curriculum, I hope that it can be a class that allows us to grasp the overall big picture.

Student-directed learning activities, such as acoustics laboratories, meet this students' need for opportunities to teach himself/herself and, potentially, provide a stepping-stone to an independent career in the music industry or elsewhere.

To further investigate the relationship between music students and science education, we applied a K-means clustering algorithm to the 17 Likert-scale questions. K-means clustering is a type of unsupervised machine-learning algorithm that identifies groups of survey respondents with common characteristics. When each respondent's vector of quantitative responses is represented as a point in m-dimensional space, statistical dependency among the responses means that certain regions feature a higher density of points, and K-means clustering attempts to identify these regions. The algorithm used here, known as Lloyd's algorithm, is initialized by selecting (typically at random) a set of K vectors in m-space, which are called the cluster *centroids*, and each student is labeled as a *member* of the cluster whose centroid is closest in Euclidean distance to her own response vector. In the iterative step, each cluster's centroid is updated to equal the mean response among its members, and students are relabeled according to the (new) nearest centroid. This process is repeated until no respondent switches clusters between iterations, which indicates that the algorithm has converged to centroids that are "in the middle" of a dense region of survey responses. This algorithm was first proposed by Lloyd (1982) in a signal processing context and has been widely adopted by data scientists in other disciplines because each centroid vector offers a legible, compact representation of the typical response within the corresponding cluster (Berkhin, 2002).

In our case, $m = 17$, which is the number of Likert-scale questions. We chose to use $K = 2$ clusters owing to the study's relatively small sample size. The summary statistics for each cluster are reported in Fig. 2. These results indicate that music students are divided in their attitudes toward science. Students in the larger cluster expressed a relatively low level of confidence in their science ability and, accordingly, low interest, whereas those in the smaller cluster expressed higher confidence and, accordingly, high interest—in both expanding their scientific knowledge, in general, and acoustical topics in particular. These results suggest that from the perspective of music students, acoustics is definitively a "science" class. Whether acoustics can "cure" skeptical students of their aversion to science depends on how the class is taught, but the larger claim by Ramsey (2014) that the acoustics course can form a bridge between the sciences and nonsciences appears to hold.

IV. COURSE-DESIGN RECOMMENDATIONS AND CONCLUSION

The results of the survey above indicate that music students are not unlike other students from nonscience majors who express low confidence in their math and science abilities. However, our survey respondents *did* express some interest in a scientific approach to the phenomenon of sound and to some extent, it appears that this elevated interest can be attributed to the natural kinship between acoustics and musical practice. If so, then the acoustics course for music majors constitutes a unique opportunity for cross-disciplinary collaboration. Acoustics instructors can harness music students' confidence in their intuitive understanding of sound by teaching acoustics concepts through musical activities. Such an integrated pedagogy enables the acoustics course to overcome students' aversion to math without compromising on scientific rigor. For example, the musical concept of tonality is grounded in the harmonic series. Musicians who play string instruments can generate the harmonic series by playing harmonics on their instruments, while wind instrumentalists can alter their embouchure to excite different partial frequencies of the horn's fundamental frequency. Moreover, variation in the material and design of individual instruments causes differences in the shape of the waveform and distribution of sound energy across the various partials. Devoting class time and laboratory activities to a music-based exploration of these issues not only promotes learning by showing students the relevance of acoustics to musical practice, but also enables the instructor to create a more challenging class that complements the traditional music curriculum by exposing students to the scientific method.

The principles of HCD suggest that effective pedagogy takes place at the intersection of the students' needs and

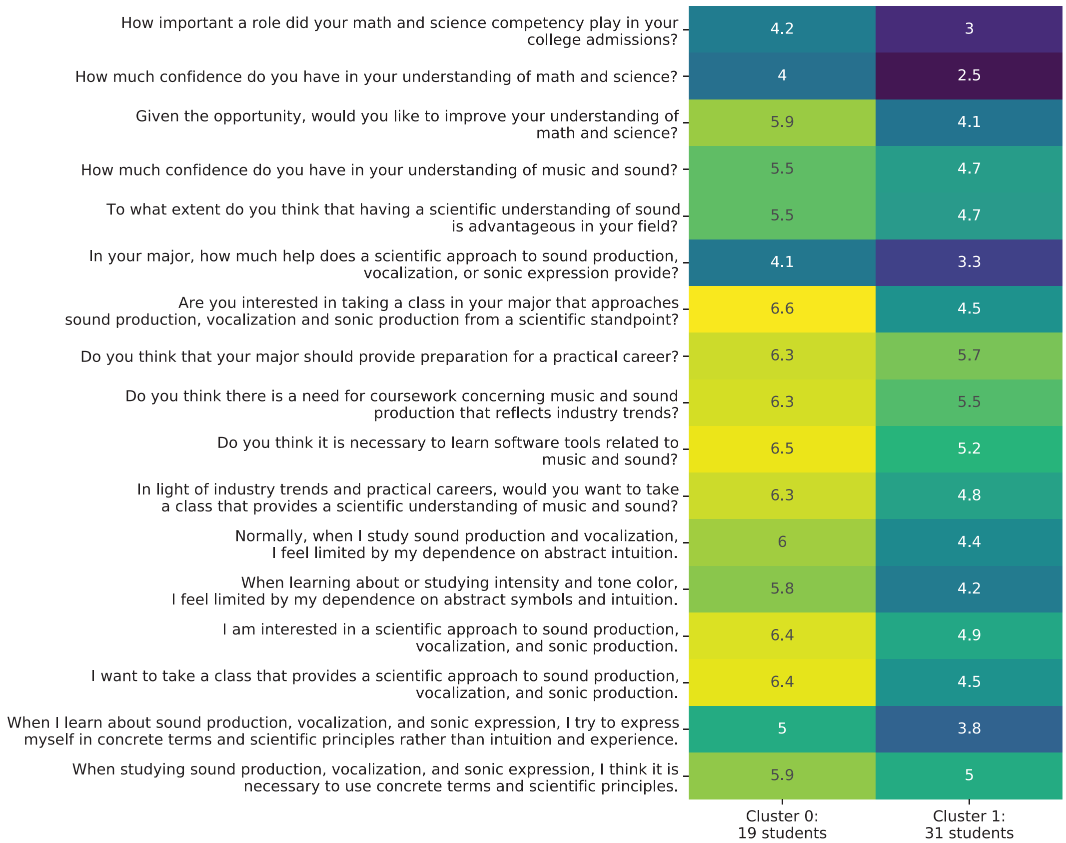

FIG. 2. (Color online) The results of a *K*-means clustering algorithm over the 17 Likert responses. Each value indicates the corresponding element of the cluster centroid vector—that is, the average response to the given question within the cluster. A response of "1" indicates strong disagreement and a a response of "7" indicates strong agreement with the prompt. The cells are colored according to the magnitude of the corresponding numerical entry.

instructor's knowledge. An increasing number of music students pursue careers in technology-oriented fields, such as sound design, project management, and music business, and in our survey, students expressed interest in learning the technologies that are used in these professional fields. Thus, we recommend that acoustics instructors strive to introduce students to acoustical software that is *also* used in the music industry. At the professional end, Max/MSP (San Francisco, CA) and Adobe Audition (Adobe Inc., San Jose, CA) are examples of sound design programs used in acoustics research, sound design, and music; a free alternative is the open-source sound editor Audacity. These programs allow the user to view and manipulate the sound's physical characteristics in real time and could be the basis for many valuable laboratory activities. By making effective use of these software programs in the laboratory section, acoustics instructors can harmonize the three goals of teaching acoustics, stimulating student interest, and preparing students for a practical career.

Overall, our findings indicate that the contemporary shift toward active learning and technology-based instruction in acoustics pedagogy is beneficial to music students for two reasons. The first reason, as acoustics instructors have reported, is that more *learning* takes place when instructors use hands-on demonstrations and activities to draw explicit connections between acoustical science and musical practice (Sakagami, 2016; Hansen, 1993). But for music students, there is a secondary benefit: An active pedagogical approach offers a welcome contrast to the conservative, top-down pedagogy that is typical of university music pedagogy (Schippers, 2009). Encouraging students to solve problems on their own teaches students to *teach themselves*, a rare but essential skill in today's dynamic job market.

The curriculum recommendations above reflect the interests and needs of a subset of Korean music students and, therefore, may not generalize to every context. Ideally, we suggest that acoustics instructors survey their own students during the first class session to inform a human-centered course design. This is because although each instance of the introductory acoustics course serves the same overall purpose, students differ in their prior experience, pedagogical needs, and academic goals. Then, the course contents can be modified in light of the students' major breakdown, musical level, mathematical and scientific background, and interest in an acoustics-related career.

In this study, we focused on the first phase of the HCD process specified in the ISO (2019) standard, namely, to understand and specify the context of use. However, the fourth phase, "evaluate the design against requirements," seems worthy of further attention in the context of undergraduate acoustics education because college courses produce concrete data on student outcomes in the form of test scores, attendance records, and course evaluations. By comparing these metrics with the ability and motivation expressed by students in the initial survey, instructors can gain a macroscopic understanding of how well the overall composition of the curriculum aligns with broader pedagogical goals such as scientific literacy and critical thinking.

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APPENDIX: SURVEY TEXT

(Likert: low/high) indicates a seven-point Likert response formatted as follows.

Low ○ ○ ○ ○ ○ ○ ○ High

Section 1

(1) Gender
- ○ Male
- ○ Female

(2) Age
- ○ Below 25 years old
- ○ 25–30 years old
- ○ 30–35 years old
- ○ 35–40 years old
- ○ 40 years old and older

(3) Graduation status
- ○ Current student
- ○ Alumnus

(4) Major
- ○ Piano
- ○ Voice
- ○ Strings
- ○ Wind instruments
- ○ Composition
- ○ Theory
- ○ Percussion
- ○ Korean traditional music
- ○ Other

(5) If you responded with “Korean traditional music” or “other,” please elaborate. (short answer)

(6) For how long have you been studying music with the intention of majoring in it (up until now)?
- ○ Less than 5 years
- ○ 5–10 years
- ○ 10–15 years
- ○ 15–20 years
- ○ 20 years or more

(7) How important a role did your math and science competency play in your college admissions? (Likert: unimportant/important)

Section 2

(8) How much confidence do you have in your understanding of math and science? (Likert: low/high)

(9) Given the opportunity, would you like to improve your understanding of math and science? (Likert: uninterested/want to improve)

(10) How much confidence do you have in your understanding of music and sound? (Likert: low/high)

(11) To what extent do you think that having a scientific understanding of sound is advantageous in your field? (Likert: not very advantageous/highly advantageous)

(12) In your major, how much help does a scientific approach to sound production, vocalization, or sonic expression provide? (Likert: does not help/helps)

(13) Are you interested in taking a class in your major that approaches sound production, vocalization, and sonic production from a scientific standpoint? (Likert: uninterested/want to take)

(14) Do you think that your major should provide preparation for a practical career? (Likert: unnecessary/necessary)

(15) Do you think that there is a need for coursework concerning music and sound production that reflects industry trends? (Likert: unnecessary/necessary)

(16) Do you think that it is necessary to learn software tools related to music and sound? (Likert: unnecessary/necessary)

(17) In light of industry trends and practical careers, would you want to take a class that provides a scientific understanding of music and sound? (Likert: uninterested/want to take)

Section 3

(18) Normally, when I study sound production and vocalization, I feel limited by my dependence on abstract intuition. (Likert: disagree/limited)

(19) When learning about or studying intensity and tone color, I feel limited by my reliance on abstract symbols and intuition. (Likert: disagree/limited)

(20) I am interested in a scientific approach to sound production, vocalization, and sonic production. (Likert: uninterested/interested)

(21) If you are uninterested, why not? (short answer)

(22) I want to take a class that provides a scientific approach to sound production, vocalization, and sonic production. (Likert: uninterested/want to take)

(23) When I learn about sound production, vocalization, and sonic expression, I try to express myself in concrete terms and scientific principles rather than with intuition and experience. (Likert: do not try/try)

(24) When studying sound production, vocalization, and sonic expression, I think that it is necessary to use concrete terms and scientific principles. (Likert: unnecessary/necessary)

Section 4

(25) Considering your background knowledge and experiences, write any ideas that you have for a science-based class on music and sound. (short answer)

(26) Write any ideas that you have for a science-based class on music and sound as it relates to your major. (short answer)
(27) Write any ideas that you have for a science-based class on music and sound as it relates to practical careers and industry trends. (short answer)

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