Creating an active-learning environment in an introductory acoustics course

Tracianne B. Neilsen,[a] William J. Strong, Brian E. Anderson, Kent L. Gee, Scott D. Sommerfeldt, and Timothy W. Leishman
Acoustics Research Group, Department of Physics and Astronomy, Brigham Young University, N283 ESC, Provo, Utah 84602

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Research in physics education has indicated that the traditional lecture-style class is not the most efficient way to teach introductory physical science courses at the university level. Current best teaching practices focus on creating an active-learning environment and emphasize the students' role in the learning process. Several of the recommended techniques have recently been applied to Brigham Young University's introductory acoustics course, which has been taught for more than 40 years. Adjustments have been built on a foundation of establishing student-based learning outcomes and attempting to align these objectives with assessments and course activities. Improvements have been made to nearly every aspect of the course including use of class time, assessment materials, and time the students spend out of the classroom. A description of the progress made in improving the course offers suggestions for those seeking to modernize or create a similar course at their institution. In addition, many of the principles can be similarly applied to acoustics education at other academic levels. © *2012 Acoustical Society of America*. [DOI: 10.1121/1.3676733]

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I. INTRODUCTION

The descriptive acoustics course at Brigham Young University (BYU) was originally formulated in 1969 with strong encouragement and support from faculty in several departments who were desirous of having a course that would expose students to scientific principles that are useful in a wide variety of disciplines. A descriptive acoustics course is a natural choice because acoustics is an inherently interdisciplinary topic[1] with broad appeal and an abundance of real-life applications. For over four decades, this general science elective has employed sound as a vehicle to provide students opportunities to view aspects of their own disciplines from a contrasting and complementary physical science point of view and expose them to a variety of topics that are related through the basic principles of acoustics. Over the years, the course has undergone changes to accommodate the students' educational needs and enrich their learning experience by applying some of the recommendations of physics education research and striving to create an active-learning environment.

The main purpose of the course has always been to expose students to physical principles of acoustics and help them appreciate how these principles are tied to their everyday experiences and their future courses of study. Students from music, music education, sound recording, communications disorders (which includes audiology), and other disciplines typically find that this course expands upon their understanding of the nature of sound because of the valuable perspective that the underlying physical principles offer. For physics and engineering majors, this course provides an initial exposure to many acoustics topics and builds a conceptual understanding that serves as a foundation for more advanced courses in acoustics.

Because of changes in the student population, education trends, and modern technology, the structure and presentation of the course have evolved over the decades. Regular adjustments have been made to the course content, not only to modernize the content, but to accommodate the needs of the different degree programs at the university whose students are populating this course. The recent emphasis[2] on the alignment of class activities and assessments that promote student learning and help the students achieve the course learning outcomes has also prompted changes to the course.[3] Additionally, advances in technology have provided opportunities to modify the course activities and assessments to improve upon the learning environment.

Many insights into what improves student performance in introductory physical science courses have been gained during two decades of physics education research. In large introductory physics classes, pre and post-tests given to thousands of students have shown that interactive-engagement methods can increase the effectiveness of the course.[4] An interactive-engagement method is defined as one in which the conceptual understanding of the material is encouraged through activities designed to get the students thinking and participating in the class and provide feedback. When a collection of interactive-engagement methods are used in a course, an active-learning environment is provided for students.[5] Since there is a lack of similar research done specifically for acoustics classes, we have tried to implement many of the recommendations from physics education research designed to promote an active-learning environment.

This article describes the efforts made to apply best practices from physics education research to the descriptive acoustics course at BYU. Because the course's longevity has

[a] Author to whom correspondence should be addressed. Electronic mail: tbn@byu.edu

allowed tried and tested content to be coupled with these current pedagogical practices, we hope that this article will provide readers with useful insights. The first section discusses the need to update concept-centered course objectives to student-based learning outcomes and the resources available to increase the students' role in the learning process. The current state of the course activities and assessments and how they are approaching the current best practices for creating an active-learning environment are then explained. The paper concludes with a discussion of lessons learned and the anticipated future directions for the course. Included as an appendix is a short historical summary of the course that sheds light on where this undertaking began.

II. COURSE OBJECTIVES

More than 40 years ago, Physics 167, "Descriptive Acoustics of Music and Speech" was created to provide a general education science course for non-science students. As of December 2010, 5415 total students are on record of having taken this course, with a 40-year average enrollment per year of 139 students. In 2004, the enrollment peaked at 286 students. The two most common majors of students enrolled in the class have been communications disorders (which includes audiology and speech/language pathology) and majors from the school of music: music, music education, and sound recording. The number of people introduced to acoustics through this course likely makes it one of the largest sustained educational/outreach efforts by members of the Acoustical Society of America.

A. Course objectives/learning outcomes

The initial course objectives were primarily content-based and included the development of basic physical principles, wave properties, aspects of the hearing mechanism, aspects of speech production, and the acoustics of musical instruments. The original text created for the course[6] contained five parts: fundamentals of physics, characteristics of sound waves, hearing, listening environments, musical instruments, and speech, all of which were covered in the course. While similar material is covered in the course today, the objectives have changed significantly and are being redefined as learning outcomes.

Over the years as the culture of education has changed,[7] the course objectives have been modified to emphasize the students' roles in the learning process and the skills that the students are developing as they participate in the course. This is in line with the pedagogical argument[8] that in order to shift to learner-centered teaching, the students must understand their role and be empowered to accomplish it. Specifically, educators on all levels are being encouraged to define learning outcomes for their courses in place of objectives.[3,9] The main learning outcome of the descriptive acoustics course is for students to develop a conceptual (and in some cases a limited quantitative) understanding of core physical principles of acoustics and their applications in explaining phenomena encountered in the production and perception of sound. Along with this, they are expected to understand the basic terminology of acoustics.

Another important learning objective is that the students learn to apply basic physical principles and simple models to complex systems and phenomena. For example, students apply a simple mass-spring vibrator model to describe the essentials of vocal fold vibration, reed vibration, and an instrument's body vibration. Furthermore, the concept of a cylindrical pipe open at one end and closed at the other can be applied to understanding of the neutral vocal tract, the auditory canal, and the air column resonances of the clarinet. Students' reasoning abilities are combined with analytical tasks such as using graphs and tables to build problem-solving skills. Ultimately, the overarching goal of student-centered learning outcomes is to promote student engagement as "stakeholders"[10,11] in the learning and the eventual assessment processes.

B. Student resources for learning

The resources provided to the student play a critical role in empowering them in the learning process and accomplishing the learning outcomes. In addition to the text,[12] which has undergone significant evolution as described in Appendix A, the students are given a number of resources to help them in their learning. Several of these resources are available to the students through the course website. Numerous external internet links are provided so that the student can learn more about a given topic. In some cases, there are links to online interactive resources (similar to "Physlets"[13] or Physics Applets) that can be used by students to interactively explore a concept. Some of these online resources are described in more detail subsequently. Additionally, study guides for each class period and exam review sheets for each unit are available to help focus the students' efforts and help them determine which information will be part of their assessment. The study guides are inquiry-based,[14] and pose questions to reinforce conceptual understanding and guide the student through increasingly complex scenarios such as the following: "Consider a compound transverse oscillator that consists of three balls equally spaced on a massless string. Describe the possible modes of vibration. How many natural modes would a similar system of 10 balls have? What if there were 100 balls? How many modes would a continuous string have? Describe the five natural modes of a violin string."

Another important student resource is the help sessions with the teaching assistants held several times during the week. These sessions complement the other resources, as students come with questions about the text, homework, study guides, and exam review sheets. The variety of the resources is intended, as mentioned, to help motivate and empower students to actively engage in the learning process. Some of these resources are referred to again as they relate to classroom activities and assessment.

III. COURSE ACTIVITIES

Over the past decade, a significant amount of effort has been spent preparing activities that hopefully aid the students in reaching the learning outcomes and create an active-learning environment. These efforts have resulted in classes built around numerous demonstrations both physical and

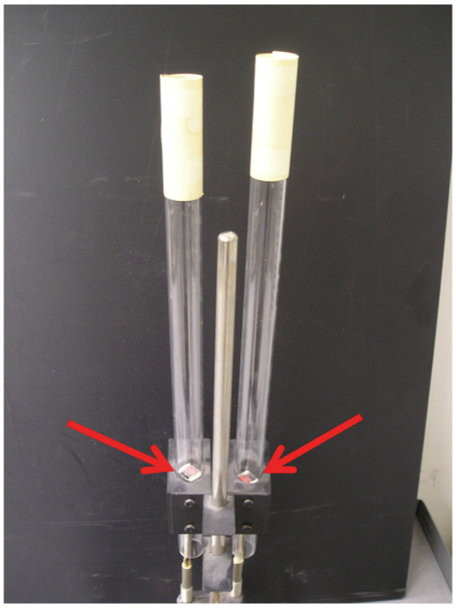


FIG. 1. (Color online) Photograph of the variable length pipes driven by heating elements (dual Rijke tubes) used to demonstrate beating (Ref. 15).

multimedia in nature, innovative approaches to classroom instruction, and an assortment of out-of-class activities. The ultimate aim of each of these activities is to help motivate the students, provide opportunities for them to actively engage with the material, and reach the intended learning outcomes.

A. Demonstrations

Thanks to decades of development, BYU has a large assortment of physical demonstrations that show basic principles of acoustics and applications of these principles. Some of these demonstrations are relatively complex, like or the dual Rijke tubes shown in Fig. 1.[15] The dual Rijke tubes can be used in an advanced setting in a discussion of thermoacoustic principles but are used in this course to illustrate beating by altering the length of one of the tubes. A list of some of the demonstrations is found in Table I and videos of many of them are available in the EPASA material accompanying this paper.[16] While many of the demonstrations are quite simple and involve everyday items such as springs, strings, and pop bottles, the simplicity adds to the effectiveness in that it helps students understand the everyday nature of these phenomena.

TABLE I. Examples of the physical demonstrations used in the course. Videos of many of these demonstrations are found in the EPAPS material accompanying this article (Ref. 16).

Principle	Demonstration
Modes on a string	Jigsaw excited modes on a string with varying tension
Driving system at resonance	Golf balls connected by springs driven by an electromagnet
Doppler effect	Loudspeaker mounted on a long wire
Vocal fold oscillations	Siren disk with pressurized air
Bernoulli effect	Levitation of objects with pressurized air
Vocal tract filtering	Artificial larynx with model vocal tracts
Waves in different media	No sound in a vacuum
	Frequency dependence on gas in a flutaphone
Modal coupling	Frequency of organ pipe dependence on cut-up and air speed
Resonances of rods	Singing rod (Ref. 43)
Resonances of plates	Chladni plate and bow

One such simple demonstration is the use of cardboard tubes to illustrate the difference between standing waves in open and closed pipes. The tube needs to be a tube of moderate length with a diameter large enough to enclose the ear. A collection of these tubes is passed around in class to let each student experience the difference between the resonance of an open-open tube, perceived when the tube is held a few centimeters from the ear, and the resonance of an open-closed tube, heard with the tube pressed against the head. The resulting shift in pitch of approximately one octave is readily noticed by the students and provides them with a physical connection to the different resonances of two types of tubes. The memory of this experience can be recalled when discussing the ear canal, vocal tract, clarinet, flute, organ pipes, etc. Table I contains a partial list of the physical demonstrations used in the course that help the students see and hear the principles of acoustics in action.

In addition to the physical demonstrations, numerous multimedia demonstrations are used in the course. The audio demonstrations on the Acoustical Society of America's (ASA) Auditory Demonstrations on Compact Disc[17] allow students to experience key principles of hearing and perception. NASA-produced demonstrations offer insight into hearing loss and speech communication challenges.[18] In addition, several in-house audio demonstrations have been prepared. In one example, the fundamental and formant frequencies of a recorded male voice are shifted to synthesize a female voice. This and other auditory demonstrations, along with technical descriptions of the parameters, have been made available through the EPAPS system.[16]

A number of videos are shown that provide excellent visual images for difficult in-class demonstrations. For example, when discussing sources of vibratory energy in speech and music production, the students are shown video recordings of the oscillations of the vocal folds (from the ASA's Measuring Speech Production DVD[19] and a trombone player's lips[16,20]). There are numerous other videos online. Links to several key videos are found on the comPADRE website, a digital physics library sponsored by the American Association of Physics Teachers (AAPT), the American Astronomical Society (AAS), the American Institute of Physics/Society of Physics Students (AIP/SPS), and the American Physical Society (APS).[21] As mentioned, links to the videos and audio clips are often included on the course website as a student learning resource. Access to these items encourages the students to increase their understanding by viewing or listening to them again or sharing them with friends.

Computer software also provides a tangible means of effectively demonstrating more abstract acoustic principles. Real-time waveform and spectral analysis software allows the class to view the time and frequency dependence of the sound waves and explore concepts using an interactive lecture demonstration (ILD),[22] which is a type of interactive-engagement method that helps promote the active-learning environment. Real-time spectrum analysis can be especially helpful when discussing, e.g., why various instruments sound so different when they play the same musical note, why the tone color of an instrument changes with volume, and how formant frequencies change with vocal tract shape. As an example of an ILD, students use an open-open tube model to predict the fundamental resonance on a flute with all tone holes closed. The lowest note is played on the flute by a student (there is usually at least one flautist in the class), and the real-time spectrum is viewed to determine the fundamental. After the students realize that the more appropriate length is the distance from the mouthpiece to the open end rather than the total length of the flute, the agreement between the open-open pipe model and the in-class experiment is quite good. This can be used to motivate a discussion of effective versus physical length.

In addition, there are websites that offer a wealth of information, animations and interactive simulations. Some web pages offer helpful animations that illustrate basic acoustic principles.[20] Others have interactive simulations that allow the physical parameters to be varied such that the outcome of a wide variety of cases can be investigated. Recent studies have shown that such simulations can guide students to develop a deeper understanding and build their intuition about the relationship between key properties of physical systems[23] because the students are actively engaged with the material. For example, the interactive simulations created by professors at the University of Colorado, Boulder, beautifully illustrate the features of sound waves, including one concerning Fourier transforms that is also useful for more advanced acoustics students.[24] Additionally, Paul Falstad[25] has educational applets on a wide variety of acoustical phenomena including a ripple tank to visualize two-dimensional waves and a speech synthesizer in which the user varies the length, width, and cross-section of the vocal tract and then allows one to hear how the formant frequencies change. The students really enjoy being able to control the parameters of the simulated experiments and gain a better conceptual intuition for the principles when they try a wide variety of situations.

The abundance of physical, multimedia, and technological demonstrations provides instructors the opportunity to choose those items they feel will enrich the class experience, aid in student learning, and that fit well with the instructor's preferred classroom techniques. Such demonstrations assist the students in forming a working understanding of acoustical principles and their applications and promote an active-learning environment.[5]

B. Class time

The descriptive acoustics course meets for three 50-minute class periods each week. Efforts are being made to move away from a traditional lecture hour to a discussion format, consistent with the principles of learning-centered education.[10,11] The goal is to have students actively engaged during class and to guide their thinking toward correct conceptual understanding. Most days, the instructor leads the discussion by posing questions to the class, helping the students work through examples, and responding to students' questions. Students are also encouraged to share short presentations with the class when they have a particular interest in or personal experience with the topic being discussed. For example, when learning about the speech communication chain, a student with a hearing-impaired relative might share their experience, or a student who has overcome a speech impediment might discuss techniques that helped them. Often, a student demonstrates a tonal language, such as Mandarin, for the class to help students understand differences between classes of language. During the discussions about singing and musical instruments, many of the students share their talents with the class and demonstrate the unique characteristics of their instruments. In addition, students often have created music electronically that they enjoy sharing with the class. These activities help the students be more engaged during class time and helps students become stakeholders in achieving the desired learning outcomes.

C. Optional activities

The students are provided with a large number of opportunities to continue learning outside of class. Extra credit is offered for these activities to encourage students to participate in observing and understanding acoustics. Although studies in other fields[26,27] have shown extra credit to be a useful tool in motivating student learning, care should be taken to balance the amount of credit offered with the regular course assessments. For the descriptive acoustics course, extra credit can account up to about 3% of the total points earned in the class. The optional activities include laboratory exercises (labs), which are performed in small groups with a teaching assistant, and self-directed observations and experiments. Although only anecdotal because of past differences in implementation, we have seen a positive correlation between participation in these optional activities and exam scores, similar to the previously cited studies.

A series of thirteen labs has been designed to provide hands-on experience with acoustic principles. As attendance at labs is optional,[28] small groups of students use equipment to take measurements and to directly observe acoustical phenomena. Group discussions at the end of the lab focuses on questions designed to solidify student understanding of a fundamental concept through application and problem solving. These lab-based tutorials, similar in concept to those developed by McDermott and the Physics Education Group,[29] help the students actively work towards clearing up difficult concepts, such as the difference between the fundamental frequency of the voice and formant frequencies of the vocal tract, the relationship between tension and density in determining wave speed and modal frequencies on strings. One of the students' favorite aspects of the labs is the opportunity to be in the state-of-the-art anechoic and reverberation chambers at BYU. It is exciting for the students to be in these unique spaces, to see where research takes place, and to practice applying the scientific method. It boosts their confidence in their ability to do science when they take basic measurements in these facilities. As an example, the worksheet used for our lab in the reverberation chamber is included in Appendix B. Other labs give the students hands-on experience with loudness, hearing perception, virtual pitch as well as modes of tubes, strings and membranes. Descriptions of the other labs developed for this class may be obtained by contacting the corresponding author.

To assist the students in connecting the physical principles of acoustics studied in class with their daily life, the students are invited to participate in self-directed, optional activities. These hands-on activities are performed either solo or within very small groups. When students participate in these activities, they practice observing and reporting about acoustical phenomena. The students then write a few paragraphs about their experience to receive the extra credit points. Some of the activities the students commonly choose are listed in Table II. By participating in these optional, hands-on activities, the students are actively connecting the course material with their everyday experiences, which helps to accomplish the course learning outcomes.

Together, the demonstrations, class discussions and optional activities provide students ample opportunities to develop a good conceptual understanding of key acoustic principles and how these principles impact their daily interactions with sound. When the students are guided and encouraged to engage with the material more than superficially, they are participants in an active-learning environment, which helps them forge connections between the terminology and models used in acoustics and their perceptual experiences with sound.

IV. COURSE ASSESSMENT

Although one might prefer to just enjoy the process of guiding students in their discovery of acoustical principles, an assessment of each student's mastery of the material and the learning outcomes must be made and a grade given. Originally, the single method for assessing student performance in this course was multiple-choice examinations: four unit examinations and a cumulative final examination, as was typical for college courses of the time.

Over the past 10 years, the course assessments have undergone significant changes. The overarching goal has been to create assessment materials that assist the students in reaching the learning outcomes. Specifically, this entails evaluation of their mastery of the basic terminology of acoustics, development of an understanding of the core principles, and ability to apply basic models to different phenomena. The assessment of student learning is based on daily reading quizzes and homework assignments, examinations, and an applications paper. These assessments provide regular feedback to each student and the instructor so that necessary modification to their approach towards the class can be modified and the course objectives best achieved.

A. Reading quizzes

Studies have shown that an important method for increasing the effectiveness of class time is for the students to engage with the material beforehand.[30] This begins with their reading of the assignment. However, most students need an incentive to place a higher priority on reading before class. A short, required reading quiz completed online before class is used to motivate students to read the assignment. We have found that the quizzes dramatically improve students' reading of the material prior to class, which then helps promote an active-learning environment.

Each reading quiz consists of three multiple-choice questions. The students are not supposed to master the material in the text before class but rather to read and understand the basic vocabulary used in the unit. The quiz is open-book, but an imposed time limit means that the students need to have read before they begin the quiz if they desire a good grade.

The reading quizzes are completed through the course website, which has the advantage of immediate feedback for both the students and the instructor. Students receive a score but are not told which problems they missed to limit their ability to help other students. The instructor, however, can see the statistics for the reading quiz questions before class and use the results to gauge student comprehension of basic concepts and definitions. The class discussion can begin with clarification of commonly held misunderstandings or extra emphasis can be placed on topics commonly missed on the reading quiz questions. This allows the class discussion to begin where the students are at and then build from there to enhance student learning.

It is important to note that these quizzes do not yet fully represent what is known within the physics education community as "Just-In-Time Teaching" (JITT).[31] In this method, the instructor will use student responses to preclass quizzes to

TABLE II. Examples of self-directed extra credit activities.

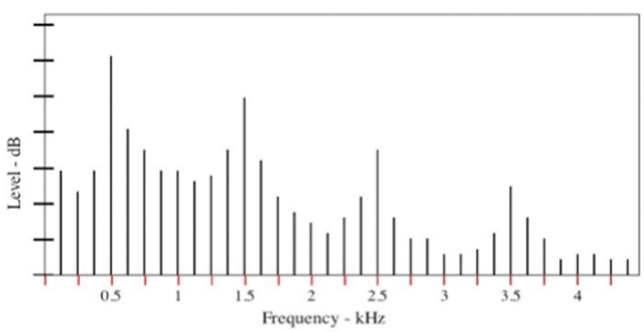
Activity	Description
Sound level meter	Check out a sound level meter (SLM) from the course instructor to measure levels of five to ten different sound sources around campus.
Audiogram	Have your hearing tested at the BYU Audiology Clinic
Hall acoustics	Attend a musical performance or a drama event and critique the hall acoustics and/or the sound system used for the event.
Children and speech problems	Spend 15-30 minutes with a young child who is learning to speak. Note which phonemes the child has difficulty with. Try to guess what may be going wrong in the speech process.
Vocal performance event	During the performance, pay attention to how the vocalists are applying the physical singing voice principles.
Instrumental performance event	During the performance, pay attention to how different instruments blend together and how well the performers play together as an ensemble.
Comparison of different instruments	If you play more than one instrument, compare and contrast the acoustics properties of two or more instruments.

modify the planned class content and discussion *just* before class. Because our quizzes are short and are primarily definition-based, they do not encourage the same amount of preclass engagement as is afforded by open-ended, discussion-type questions often found on JITT quizzes. In the future, reading quizzes may be modified to better match the JITT pedagogical style. However, the additional time required of the students, in light of the other activities and assessments, will have to be weighed against the possible benefit.

B. Daily online homework

During the most recent overhaul of the homework assignments, the goal was to shift the emphasis of the homework from recall to higher skills relating to comprehension, application and analysis to better fit the learning outcomes. This is in keeping with emphasizing the higher levels of learning according to a modified Bloom's taxonomy.[32] The new homework assignments provide students with more opportunities to practice their problem solving and data analysis skills while applying simple models to a variety of physical systems.

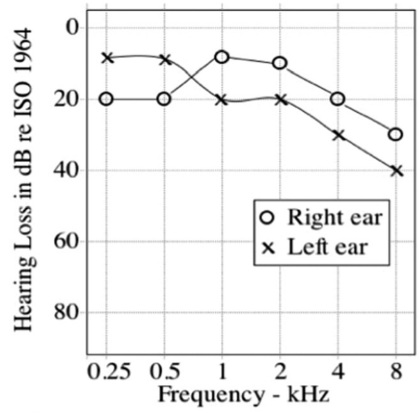
Each homework assignment consists of ten multiple-choice questions. Many of the questions contain links to graphs and require the students to apply their understanding as illustrated in Fig. 2. A vocabulary-based question about hearing aids might be, "What hearing aid gain is required for a person who has a 30-dB threshold shift at 4 kHz?" Although this question does require understanding of "gain" and "threshold shift" along with some basic application, similar information can be directly interpreted from a spectrum or audiogram, as in Fig. 3. This requires an additional skill of interpreting data, which causes the student's completion of a question to be shifted to higher level of learning. In other questions, the students use information gleaned from tables or apply simple mathematical relationships, as shown in Fig. 4, to answer the questions. The types of problems on the homework assignments encourage not only the development of a strong conceptual understanding of fundamentals of acoustics but also numerous skills the students can apply across disciplines to objectively analyze data. Thus, daily online homework is an essential part of meeting the learning outcome of the course.



What is the fundamental frequency of the voiced speech that produced the spectrum shown above?
a) 125 Hz
b) 250 Hz
c) 500 Hz
d) 1 kHz

Which frequency is most likely close to the first formant frequency?
a) 125 Hz
b) 250 Hz
c) 500 Hz
d) 1 kHz

FIG. 2. (Color online) Sample homework questions about speech.



Which of the following statements is true about the above audiogram?
a) The left ear can detect higher frequencies better than the right ear.
b) The right ear can detect lower frequencies better than the left ear.
c) The left ear has a hearing threshold of 20 dB above normal threshold at 1 kHz.
d) The right ear has a hearing threshold of 30 dB above normal threshold at 4 kHz.

FIG. 3. Sample homework question about hearing.

C. Examinations

Each unit is concluded with a closed book, multiple-choice exam that measures the student's mastery of the

1. What are the first three modal (resonance) frequencies of an open-closed air-jet tube if its length is 136 cm? (Assume the speed of sound in air is 34,000 cm/s.)
a) 125, 250, 375 Hz
b) 125, 375, 625 Hz
c) 62.5, 187.5, 312.5 Hz
d) 250, 750, 1250 Hz

2. The spectrum of struck string instruments contains __________.
a) only harmonic partials
b) only low-frequency partials
c) mainly high-frequency partials
d) slightly inharmonic partials

FIG. 4. Sample homework questions about musical instruments.

concepts and their ability to analyze data. The exams strive to test both the ability to recall terminology and principles of acoustics and the skills required to apply their knowledge. The few equations and large number of tables that the students need are attached to the back of the exam, representing a realistic work situation where one can look up a lot of the needed information. This helps shift the emphasis of the exam from memorization to problem solving. Additionally, approximately 25% of the problems require the students to decipher information displayed graphically when answering the questions. Whenever possible the questions are posed as realistic applications or situations in accordance with the learning outcomes.

Because students tend to be nervous about exams, the following additional helps are provided. Students are given a review guide to help them focus on the most important topics and skills for the unit. Additional study hours with the teaching assistants are provided. Some of the instructors choose to allow the students a second attempt at a different form of the exam for partial additional credit to emphasize the importance of learning and improving.

D. Applications paper

The most recent addition to the course assessment has been a single-spaced, two-page essay, referred to as an "applications paper." The nature of the course does not allow time to cover most acoustics applications in great depth. Consequently, the applications paper gives each student the opportunity to practice research and writing skills while researching an acoustics-related topic of their choice. The paper must contain at least three references, only one of which can be internet content. This forces the students to consult books or journal articles for information on their chosen topic.

There are a number of benefits to the inclusion of this paper in the course. First, the paper promotes the pedagogical practice of encouraging writing across the university curriculum.[33,34] Next, it gives outstanding students, who may otherwise find the course content basic, the opportunity to engage deeply in the material. Outstanding papers have been written on topics such as the SOFAR channel, ototoxic chemicals, the acoustics of whistling, Tartini tones, Tuvan throat singing, and a variety of ancient and modern musical instruments not covered in class. In some cases, the papers have been short reports on actual experiments conducted by the students. For example, one student conducted a spectrogram analysis to compare the voice of the character Gollum in the *The Lord of the Rings* films to the normal voice of the actor to hypothesize what the actor was doing to his vocal tract. The student then tested his hypothesis by trying to imitate the voice of Gollum and examining his own spectrograms. This was a creative piece of research conducted independently that went well beyond the scope of the assignment. In most cases, students choose a topic that relates to their reason for enrolling in the course (music, or audio, or a hearing/speech disorder) or that resulted from a question they have during the course that the instructor is not able to answer during class time. In the end, the most important advantage of the applications paper is that it encourages student engagement as stakeholders in their own learning and assessment as they explore a topic of their choice.

Overall, the current number and types of assessments appear to be largely aligned with the desired learning outcomes, but there is always room for improvement. Future improvements will be carried out in the context of better accomplishing the learning objectives, as they may change over time, and according to findings in ongoing physics education research.

V. CONCLUSION

The primary strength of an acoustics-based general education course is that it provides a natural introduction to science because students are familiar with sounds around them. Students can gain an understanding of how the basic principles of acoustics influence their lives and an appreciation for some basic models that go a long way towards explaining their experience with sound.

Students generally enjoy the descriptive acoustics course and find the principles they learn and the skills they acquire to be useful. The majority of the student comments about the course echo the sentiments of these responses: "I enjoyed coming to class and learning more about this exciting field," "[t]his class was surprisingly one of my favorites," "I learned more in this class than any of my other classes this semester," "[v]ery applicable to my major," "I love music and I have enjoyed learning more about how it works," "[t]his class helped us understand the real life application of physics."

As the course has evolved over the past four decades, the course objectives, activities, and assessments have been modified. Changes have been made as new techniques or technologies have been incorporated. When a new emphasis or direction in educational practices has been encouraged, adjustments have been made. While revisiting the course requires a good deal of time and work, these efforts have helped keep it fresh and relevant for today's students.

As course development is rarely ever "finished," we will continue to update the course objectives, activities, and assessments.[35] For example, the use of advanced technology, including audience response systems in peer instruction[36–38] and newer interactive simulations will likely increase. As additional recommendations of physics education research are explored, we will consider additional changes to help the students be actively engaged and take responsibility for achieving the learning outcomes.

Ultimately, preparation of this article has prompted further discussion of course content and improvement. It has reminded us how we can use acoustics as a vehicle for introducing the general student population to the way scientists think and providing them with opportunities to experience science in action. Establishment of an active-learning environment helps to ensure these aims are met.

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APPENDIX A: HISTORICAL SUMMARY

The genesis of the descriptive acoustics course occurred when William Strong joined the BYU physics faculty in 1967, after conducting research in musical acoustics at MIT and in speech acoustics during a military assignment at the Air Force Cambridge Research Laboratories. The interest at the time was to create general education science courses that provided science exposure for non-science students. A natural fit for this desire was a course in the acoustics of music and speech. Physics 167, Descriptive Acoustics of Music and Speech, was created in conjunction with Darrell Monson in electrical engineering. The course has been a favorite of the faculty and has been taught by nine faculty members from 1969 to the present, with five of the nine currently active.

A time-consuming endeavor that accompanied the development of this course was the creation of an appropriate textbook. The initial offering of the course took place during spring semester 1969. Because there were no texts available at the time that dealt with both music and speech, *The Acoustical Foundations of Music* by Backus[39] and *Horns, Strings and Harmony* by Benade[40] were used for musical aspects of the course, and *The Speech Chain* by Denes and Pinson[41] was used for the speech portion of the course. Extensive handouts were given to the students to supplement the books, provide exercises, and suggest further reading. These early efforts laid the foundation for a comprehensive textbook.

In 1975, the progressively more extensive handouts were incorporated in *Music, Speech, Hearing, and Environment: A Descriptive Acoustics Worktext* by Strong and Plitnik. The worktext was intended to provide, in a self-contained fashion, the material needed for the course content. In a practical sense, the worktext was a draft version of a future publication, *Music, Speech & High Fidelity* by Strong and Plitnik, whose first[6] and second[42] editions were published in 1977 and 1983, respectively. In 1992, a new version was published under the title of *Music Speech Audio* to encompass the broader content of the book.[43] The parts in this version were: I. Physical and acoustical background, II. The ear and hearing, III. Listening environments, IV. The human voice and speech, V. Musical acoustics, and VI. Electronic reproduction of music. The current version of the text is the third edition, published in 2007 by BYU Academic Publishing.[12] In this edition, the part titled "listening environments" was changed to "living and listening environments" to include material on noise and its effect on humans and the part titled "electronic reproduction of music" was changed to "sound recording and reproduction" to include material on the field of sound recording. The evolution of the course material is largely reflected in the changing content of the texts.

APPENDIX B: EXPERIMENTS IN THE REVERBERATION CHAMBER

Below is the worksheet that the students use in the completing the lab experience in the reverberation chamber with the assistance of the teaching assistants (TAs). Each lab is designed to help the students obtain hands-on experience with a basic principle of acoustics. The TA sets up the lab and guides the students, but whenever possible, the students are taking the measurements and making the calculations. This is facilitated by having a lab worksheet for each student who participates. The TA also helps the students solidify their new understanding by having a discussion about the key elements of the labs, which are summarized in the questions found at the end of the lab worksheet. While this lab is held in the reverberation chamber at BYU, a small classroom with hard walls gives good results for the x and y modes.

1. Lab worksheet

Objective: To understand how sound is attenuated, how room modes behave and how absorption affects reverberation times.

Equipment: reverberation chamber (5 m × 6 m × 7 m), signal generator, subwoofer, fairly large sample of absorptive material, stop watches.

Part 1: Experience the natural modes of a room with hard walls.

(1) Place the subwoofer in the corner of the reverberation chamber.
(2) Have the students stand against the wall that the door is on.
(3) Put a low frequency tone (~34.3 or 68.6 Hz) into the subwoofer and have the students slowly walk around the room. Listen for places where the sound basically disappears (nodal plane = zero pressure), and for places where the sound is louder (anti-nodes = maximum pressure). Map these areas out on a whiteboard or piece of paper.
    (a) How many antinodes did you find for this frequency?________________
    (b) What does the sound field/standing wave in the room look like? Try to sketch the nodal planes.
(4) Next put a lower frequency tone (~28.6 or 57.2 Hz) tone into the subwoofer and have the students walk from the wall to the right of the door to the middle of the room where another modal plane should be.
    (a) How many antinodes did you find for this frequency?________________
    (b) What does the sound field/standing wave in the room look like? Try to sketch the nodal planes.

Note: The frequencies and modal shapes, for rectangular geometries, can be predicted based on the following equation:

$$\omega_{lmn} = c\left[\left(\frac{l\pi}{L_x}\right)^2 + \left(\frac{m\pi}{L_y}\right)^2 + \left(\frac{n\pi}{L_z}\right)^2\right]^{1/2},$$

where $c = 343$ m/s, and L_x, L_y, and L_z are the chamber dimensions.

Part 2: Calculate reverberation time of a room and see how absorptive material affects the reverberation time (RT).

(1) Have two students insert earplugs and stand close to the door. Using a Larson Davis 824 Sound Level Meter and

a starter pistol, obtain a value for the RT at 500 Hz of the empty reverberation room. (Your TA has instructions regarding the Larson Davis 824 setup.) Repeat the measurement a few times and record the average time as RT for the empty chamber.

Average RT of empty chamber =__________

(2) Using the measured RT and the equation RT = 0.16 V/A, solve for the total absorption (A) of the empty chamber. The volume of the room, V, is 203 m^3.

A of empty chamber =____________

(3) Have some additional students stand in the chamber while a new RT measurement is taken. Repeat a few times and record the average as RT for the chamber and people.

Average RT of chamber + people=___________

(4) Calculate A using RT for the chamber and people. Subtract the A of the chamber to find the approximate absorption of the people. Divide this new A by the number of people in the chamber to find the total absorption for each person.

$A_{\text{chamber+people}}$ =___________

$A_{\text{people}} = A_{\text{chamber+people}} - A_{\text{chamber}}$ =___________

Average A for one person =______________

(5) Place pieces of absorptive material in the corners of the room, and measure the RT of the room. Repeat a few times and record the average as RT for the chamber and test sample.

Average RT of chamber + people+ samples =_______________

(6) Calculate A using RT for the chamber and test sample. Subtract the A found for the chamber + people to find the approximate absorption of the test samples. (If you have the people leave, then you would subtract the A of the chamber.)

$A_{\text{chamber + people + sample}}$ =___________________

$A_{\text{wedges}} = A_{\text{chamber + people + sample}}$ - $A_{\text{chamber+people}}$ =_______________

A for the test samples =____________

Questions:

(1) Define attenuation
(2) What materials attenuate sound best and why?
(3) How does wavelength effect attenuation?
(4) How does the absorption affect RT times?

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