ACOUSTICS COURSES AT THE UNDERGRADUATE LEVEL: HOW CAN WE ATTRACT MORE STUDENTS?

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A study conducted in 1996 by Patricia Kuhl, then Vice President of the Acoustical Society of America (ASA), and Joseph Dickey, then Chair of the ASA Membership Committee, found that the ASA membership is predominantly male and aging.[1] The ASA also is overwhelmingly comprised of majority populations (although we do not collect race/ethnicity data so it is not possible to provide hard data here). Students now make up 14 percent of the membership.

While there is nothing terribly surprising in the results of the membership survey, it suggests that the largest professional society of acousticians in the world is not very diverse. It also raises a question as to whether the number of students entering the field is sufficient to sustain the profession in the face of a large number of anticipated retirements in the near future.

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Every profession has areas that rise and fall in popularity with advances in the field. In acoustics, for instance, the biologically-related areas have become far more popular of late than some of the more traditional, physics-based areas. Many disciplines go through significant cycling of popularity driven by funding, applications, and social issues or large events. Civil engineering, for instance, saw an up tick in the number of entering students shortly after the catastrophic events of September 11, 2001 and the same is anticipated now in reaction to Hurricanes Katrina and Rita in 2005. It is also natural to see a general increase in stability in the numbers of people entering a field as it matures accompanied perhaps by a gradual decline in student numbers as they opt instead for emerging areas. However, as areas rise and fall, it is also true that groups of people can take actions to help sustain or grow them. It is in this context that we consider the role of acoustics education and focus on the undergraduate level.

The premise of this article is that acoustics is perceived as a mature field with waning interest shown by students, and that one means to counter this trend is to create more courses at the undergraduate level designed to attract students to the profession. We examine this by consideration of the unique characteristics that define the acoustics profession, through examination of the various elements of a good course, and by attention to the special opportunity afforded acoustics to address issues of diversity. Based on our findings, we present actions that might have a positive impact on student recruitment into acoustics and on the excitement associated with the field.

Characteristics of the profession

One means of studying the acoustics profession is to consider the ASA as a proxy for the professional demographics. The ASA was formed in 1929 as a scientific professional organization and it joined with three other such groups to establish the American Institute of Physics just two years later. Today the American Institute of Physics has ten member societies and 23 affiliated societies. Of these, the ASA is arguably the broadest in character, going far beyond a focus on physical matters related to sound. It is this characteristic of breadth that helps define us as a profession. It is visible in our journal, which presents scholarly articles on all aspects of acoustics from new musical instruments and animal communication to underwater sound propagation. Our breadth is also obvious at our conferences, which include presentations organized by our 13 technical committees, and in our standards, education, and outreach activities. Our members include physicists, biologists, engineers, architects, psychologists, musicians, physiologists, speech experts, and entertainment industry professionals. The types of jobs performed by our members include those from academia, government, consulting, manufacturing, and service industries—a greater breadth than normally found in the AIP member societies and broader than is typical of a single professional organization.

Our unusual breadth as an organization is both a boon and a curse. It gives us a much greater chance to appeal to a wide variety of people. However, it also requires us to offer a bigger range of activities to meet the needs of different groups and this has often prompted significant discussion within the ASA. A good example of the tension our breadth creates is our standards activity. Many of the academic members of the ASA see standards work as tedious and not very useful to them. However, our product manufacturers and service providers rely heavily on standards. Thus, to serve our membership we must include standards activity and assume a leadership role in the promulgation of standards related to acoustics.

A second important characteristic of acoustics is that it is generally a topic found in classes only at the graduate level. In this sense acoustics is like optics—both are graduate degree programs. However, unlike optics, which is normally mentioned (at least superficially) in required undergraduate physics and engineering courses, acoustics is rarely included in the core curriculum of any undergraduate major today. It is this lack of exposure to a wide swath of students that poses our greatest obstacle to the recruitment of students into the acoustics profession. At a minimum, it suggests that we need to create popular elective courses in acoustics to reach a wide student base.

While there are certainly a number of academic institutions that offer elective courses in acoustics, these tend to be focused on upper level undergraduates at the junior or senior level in science and engineering degree programs. Most often, a given institution has only a single such elective course, making it difficult for the interested student to pursue the topic further via a minor or concentration in acoustics. Additionally, because the elective might be taken in the senior year, it is often too late to have an impact on graduate school selection. An alternative to this approach is to offer an early elective course on acoustics that is intended to capture the imagination, and a later elective course that goes into greater technical depth. This sort of approach has been used very successfully at Tufts University, which introduced a series of freshman courses open to all students but focusing on technology with an aim of recruiting students to engineering. For instance, a freshman course called Gourmet Engineering is very popular and introduces students to the concepts of heat transfer and microwaves via a focus on cooking. These courses were found to result in a net flux of students *into* engineering, contrary to the more common problem of high student attrition *from* engineering. An example of the sort of acoustics course that might be offered early in a college career is offered at the University of Rochester. There, a freshman course called the Physics of Music has been a staple for decades (and was responsible for one of the authors choosing to pursue acoustics professionally). In a recent form, the students not only learned elementary physical properties of sound, but also made polyvinyl chloride (PVC)-pipe flutes that they used to perform original music that a student wrote for the PVC flute choir while in the class.

A third characteristic of acoustics is that there is a clear set of common products and manufacturers associated with the field. While this does not uniquely define acoustics, it does set it apart from particle physics, for instance. Common products that are entirely or primarily acoustical in function include musical instruments, microphones and loudspeakers, MP3 players, hearing aids, and all manner of telecommunication equipment. In particular, for college-age people, we have become a society obsessed with music. Where a mere decade ago .wav files were the purview of acousticians, they are now the common domain of students downloading music onto MP3 players, cell phones, Personal Digital Assistants (PDAs), and laptop computers. The proliferation of portable personal listening devices provides acoustics with a new tool for attracting students to the profession, although we have been slow to make use of the opportunity.

A fourth characteristic of acoustics is that it affects our daily lives, especially in our urban centers where the high density of people leads to greater intrusion of transportation and activity noise into homes. Daily exposure to high noise levels where we live and work alters both physical and mental attitudes and contributes to an overall reduction in the quality of life. Many urban dwellers are not even aware of their contribution to the problem, and building construction often ignores the need for improved isolation and separation.

The four characteristics of acoustics discussed above provide a context for thinking about how to make the profession more attractive to students. This leads to a number of questions such as the following: Are we offering undergraduate courses in acoustics that provide a glimpse of the breadth of the field and the wide range of job opportunities available? Are we providing enough chances for students to connect with acoustics before they need to make choices about jobs or graduate school? How can we take advantage of the plethora of common acoustics products and, in particular, the comfort level of students with music files on computers to engage students in acoustics?

In the following sections of this article we consider these questions and others that are similar by focusing on the elements of classes in acoustics—texts, applications, hands-on experiences, pedagogical techniques, and issues of diversity. We then conclude with a game plan for creating an environment that encourages students to consider a profession in acoustics.

Acoustics textbooks

The textbook chosen for a class is very important because students generally expect instructors to follow the chosen text closely. This is not simply a matter of preference. Tightly coupling classroom activities with the textbook and assignments tends to produce a class that enables students with a wide variety of learning styles to flourish and that reinforces learning. Some students do well, for instance, in reading the text before the class to prepare questions, while others intentionally read related text material after a class period to gain a broader perspective on the topic covered. Some, alas, do not read the assigned textbook at all and a significant fraction of these students perform well in the class nonetheless.

Because there is a limited number of acoustics courses, and the field is modest in size, the market for textbooks on acoustics is fairly small. Nonetheless, there are a number of textbooks on acoustics suitable for undergraduate use. These texts tend to segregate into two classes: those focused narrowly (as for instance books on speech or noise control) and those meant to be an introductory survey. Among the books designed to present a survey of acoustics, it is striking how similar each is to the others in terms of material coverage and order of presentation. While it is easy to see how this might result naturally from writing a book based on one's experience with acoustics, it stifles creativity in the classroom.

Undergraduate acoustics survey textbooks do exist at differing levels of sophistication. For instance, Raichel's *The Science and Applications of Sound*[2] is a popular text for college juniors, seniors, and beginning graduate students, while Rossing *et al.'s The Science of Sound*[3] is less mathematically intense and thus more appropriate for students below the junior level. However, it is striking to note what the typical survey text includes and excludes. For instance, virtually all of the survey textbooks put a discussion (and derivation) of the wave equation near the start of the book. This makes sense from a purely logical view of acoustics, as it allows a course to start with a discussion of one of the most important characteristics of sound—its propagation as a wave. However, from the perspective of student engagement (and therefore learning) it is an unfortunate choice. The wave equation is mathematically difficult, quite abstract, and hard to directly relate to applications. Thus, by putting this material in the very beginning of a course it is difficult to capture and captivate students. The alternative of introducing concrete applications (such as how loudspeakers work) using only qualitative discussions of sound propagation has some clear advantages from the perspective of student interest, and could be used to motivate a discussion of the wave equation later.

It is also interesting to note that although the topic of hearing is included in most survey textbooks on acoustics, few if any mention speech in the same manner. This is very unfortunate because students are much more accustomed to and interested in the subfields of acoustics that connect with them personally. Thus, speech and hearing both are great topics for engaging students and developing some comfort with major concepts. Speech is also one of the larger technical areas within acoustics, so ignoring it in survey textbooks distorts the field.

Similarly, survey textbooks tend to include a chapter on architectural acoustics but neglect musical acoustics. (Rossing *et al.'s* book is a notable exception here.) While both architectural acoustics and musical acoustics are very interesting to students, the typical preoccupation of students with music suggests that to neglect musical acoustics is to miss a golden opportunity to capture students where they live. The music industry, in all of its many aspects, also represents an enormous market in terms of the money dedicated to it annually worldwide. While admittedly not all of this market is related directly to acoustics, enough of the market is acoustics-related that it is desirable to include musical acoustics in introductory courses to demonstrate the vibrancy of acoustics and to provide students with a leg-up on employment should they wish to head in the direction of the music industry.

An observation about the resources associated with acoustics textbooks is also in order. Academic publishing is an important and profitable sector of the book publishing market. As a result, publishers work hard to get their newest text into classrooms and to keep it there as long as possible. Routinely, publishers now create Web sites for textbooks of popular classes and urge authors to load their text with impressive graphics, associated software (provided with the book on a CD or DVD), example problems worked out in the text, and vignettes that describe important applications of the concepts. While many students and faculty might argue that the price increases for texts do not justify this transition in publishing style, it is certainly true that new popular textbooks are far more than the material contained between the covers.

The resource-rich, highly Web-linked and technically-supported textbook relies on convincing a publisher that the market is sufficiently large to justify the enormous investment required for its creation. No acoustics textbook has hit the market with the new resource-rich model (although the prices of the texts have certainly gone up as though they had), presumably because the market niche is too small. As a result, acoustics textbooks simply are not as flashy and appealing as modern textbooks in subjects that compete for the attention of students. Further, since this is a purely financial consideration by the book publishers, it is difficult to see how an author or even a large group of professionals in acoustics might impact the decision.

Social relevance and applications

A significant amount of research has been done on what motivates students in science, technology, engineering, and mathematics (STEM) courses. The literature shows it is particularly important to demonstrate the social relevance of the topic and its interesting applications if one wishes to attract women and underrepresented minorities.[4,5] Further, while the impact on the majority males is less pronounced, the use of interesting applications and the focus on social relevance also helps attract and retain their interest. This research is having a significant impact on STEM education, albeit at a slower rate of change than many of us had hoped to see. As an example, engineering classes are moving from a focus on cars and aircraft, to applications such as prosthetic devices that enable people to improve their quality of life.

While the literature on the impact of applications to student engagement and learning does not deal specifically with acoustics classes, it seems logical that the results should hold for them. Fortunately, acoustics is a profession that is ripe with wonderful applications and with exciting issues of social relevance. However, development of application examples for a course requires significant work and there is little indication that our acoustics classes (at any level) are exploiting the hot topics and applications in our profession. For this reason we mention several acoustic applications and social issues here that ought to appeal to a broad range of students and excite them about the possibilities in the field. This is done in full recognition that merely listing them here is not enough. Lesson plans and supplemental material for each application need to be developed.

The obsession of today's students with music has been mentioned already in this article. More broadly, students today grew up with MTV and similar video music stations. They were using computers at a very early age, playing with various computer games in their youth, and were among the first to engage routinely in on-line chats and instant messaging. In short, the students in college today grew up multitasking and being actively engaged in the entertainment industry. Thus, applications of acoustics in the entertainment industry ought to appeal to students. Entertainment, broadly cast, provides a strong opportunity for introduction of many of the technical specialties of acoustics. It is a venue for discussion of speech communication, binaural hearing, signal processing, transduction, musical acoustics, architectural acoustics, and other acoustics subdisciplines.

While we never hope for natural and man-made disasters, those that have an acoustical link provide applications with tremendous appeal to students. Recent examples include the Indonesian tsunami, the Pakistani earthquake and the 2001 attack on the World Trade Center. Each of these has an acoustical link—primarily to wave propagation and to acoustic listening devices. These events showcase the importance of research in acoustics and emphasize its potential significance in times of challenge. They present acoustics as an opportunity to "do good" for the world, rather than in terms of military applications that students tend to associate with war and negative actions.[6]

Another major application area with great potential of appealing to students is the biomedical arena, largely because improvements in medicine are likely to have great social significance. Here specific topics such as ultrasound for diagnostic and therapeutic purposes, noise control and speech privacy in medical facilities, and the treatment of hearing and speech ailments can serve as interesting applications that engage students. Many of these topics also make it possible to examine ethical issues related to them, generally a very good means of engaging students while enhancing learning, and a means of fulfilling accreditation requirements in engineering.[7] As an example, consider the issue of treatments for profound deafness. While the acoustics technical issue relates to the design and use of cochlear implants, the controversy between restoring hearing and living with deafness (and using sign language) has been in the news frequently and provides a very interesting opportunity for students to engage in a discussion of the social issues surrounding technical advancements.

Another category of applications with significant appeal to a diverse student population deals with environmental issues. In particular, the danger to ocean animals from noise, the use of acoustics to determine ocean temperatures with relevance to global warming, and acoustic refrigeration that eliminates the need for ozone-depleting chemicals are three contemporary environmental issues with application to different subdisciplines of acoustics. Further, the potential danger to marine mammals imposed by man-made (anthropogenic) sounds is a topic of significant current controversy, so this particular application provides an opportunity to discuss how scientists go about resolving such differences. Exposing students to such a technical controversy can encourage them to pursue a research career.

Finally, the recent work to develop a classroom acoustics standard creates a fabulous benchmark by which every acoustics student can judge their classroom. This work, with its direct relevance to student learning, is an extraordinarily good application to bring into the acoustics class, because it can be taught at so many different levels. At the simplest level, it is possible to teach students how to use a sound level meter and to have them survey a classroom to see if it meets the background noise level requirement in the standard of less than 35 dBA. A high school student working with me for six weeks was given this as a project and managed to survey the majority of our classrooms. In the course of this work he found that our newest classroom building nearly met the background noise level requirement, but there tended to be a large spike in energy in the 16 kHz octave band. After some work with the facilities managers, we discovered that the motion detectors were emitting noise in that band. Although the instructors and facilities managers could not hear the high-pitched tone, many of the students could and found it irritating. As a result of this work, the construction contracts at Johns Hopkins University have changed to include acoustical requirements. At a higher level of sophistication, one could clearly have students measure both background noise and reverberation time and recommend changes to bring the classrooms into compliance with the classroom acoustics standard.

Clearly, there are innumerable other examples of applications and social issues that could be brought into an acoustics classroom. The examples presented above simply define some of the more obvious classes of acoustics problems that could interest students and be used to reinforce concepts being presented in class.

Hands-on experiences

In virtually all studies of how people learn, there is a strong link demonstrated between hands-on experiences and long-term learning. This is the reason that most science and engineering programs are loaded with laboratory experiences. In some scientific fields, it is quite difficult to introduce students to appropriate laboratory experiences. Astronomy courses might suffer from a lack of appropriate telescopes nearby, for instance, and biology classes might not wish to incur the expense of maintaining a vivarium to enable student labs dealing with animal anatomy and behavior.

Acoustics is a wonderful field for providing students with hands-on experiences and active demonstrations. Indeed the ASA, under the direction of Uwe Hansen, who served as Chair of the Committee on Education in Acoustics (2000-06) has provided special sessions for high school students at its biennial conferences as part of its outreach activities. However, lab exercises and active demonstrations have not been standard components in acoustics classes in the last decade, primarily because of the resources required to develop them—space, equipment, teaching assistants, and dedicated time of faculty. Admittedly it is difficult to justify the allocation of large amounts of precious resources for classes with relatively small attendance.

Given the fiscal realities of most universities then, one might ask what hands-on experiences can be provided in acoustics without great expense. The answer to this question provides a rich set of opportunities to reinforce the in-class learning that an undergraduate introductory class in acoustics might present.

Professional quality equipment in acoustics is expensive and fragile—not good qualities for student laboratories. However, much less expensive versions of many common elements of an acoustics lab are now available, and these can provide a reasonable hands-on experience for students without breaking the bank. For instance, there are many type 2 sound level meters available on the market that provide various filter networks (such as A-weighting) as a standard and that come complete with interfaces to a computer so that data can be downloaded for later analysis. Further, these sound level meters often can serve as a simple microphone and amplifier, eliminating the need to purchase additional equipment. Coupled with audio software on a computer, such as Adobe Audition, the sound level meter thus provides significant laboratory capability. The software, while listed for a cost comparable to inexpensive type 2 sound level meters, is usually available for an educational discount that renders it nearly free.

In addition to the computer and sound level meter, it is now possible to purchase very inexpensive MP3 players/recorders with built in electret microphones and digital interfaces, and inexpensive headphones of reasonable quality. These devices, added to the mix, complete the poor man's acoustics laboratory. The computer, software, sound level meter, MP3 player/recorder, and headphones can be purchased for a total of less than $1000 with educational discounts, and the space they occupy is hardly more than that needed for a desktop computer. The sound level meter and MP3 player/recorder are totally portable and powered by batteries.

There are a number of lab experiences possible that use the computer, software, sound level meter, MP3 player/recorder, and headphones. Many of these measurements can be conducted by students working on their own, so that teaching assistance support and faculty-dedicated time are minimized. For instance, students can find the quietest and noisiest places on campus simply by using the sound level meter. They can also consider the spectra and intensity of various noise sources, or estimate the speech intelligibility index (SII) of a space from the background noise. Students can measure reverberation time by making a noise (popping the standard red balloon if available) while recording the sound on the MP3 player/recorder and then using the computer audio software to analyze the decay as a function of time. This method is reminiscent of the one many of us employed in the past to determine reverberation time using a microphone and oscilloscope before the advent of modern equipment to automate the process. By introducing various materials into the room, students can also find the absorption coefficients of materials. Using two sound level meters, students can record sounds that are combined in the software to be roughly equivalent to a binaural recording, thus enabling a comparison between monaural and binaural listening conditions as played over headphones. One can also engage the same approach to recording various sounds and asking students to rate them in terms of annoyance.

The main point of the list of activities above is that it is possible to introduce meaningful hands-on experiences for students that span a number of the subdisciplines of acoustics using only modest equipment. To be sure, it is better still to have a sound chamber (reverberant and/or anechoic), and specialized equipment, but even with a very modest budget, lots can be done. In our case, the only significant addition to the equipment listed above in the introductory acoustics class is an artificial ear. One of the measurement assignments asks students to set their MP3 players to the music type and level they normally employ. We then use the artificial ear to estimate the sound pressure level at their ears and ask them to discuss the risk to their hearing from long term listening to the music. Almost without exception, the students are surprised to learn that they are listening to music far too loudly—typically 85–100 dBA.

Pedagogical techniques

The last decade or so has seen a huge expansion in our understanding of how students learn. With this knowledge, much of which is summarized in *How People Learn*[8] and *How Students Learn*,[9] has come a national push to modify how we teach to correspond better to techniques that foster learning. Thus, the old approach with a lecture during class time, weekly bite-sized homework problems, two or three midterm exams and a final, and a focus on individual accomplishment rather than team experiences is seen as outdated, ineffective, and insufficiently supportive of different learning styles. While STEM courses still use this lecture-style approach the majority of the time, there are signs that change is happening in the classroom even in STEM classes.

Most major academic institutions now support classes through Web-based educational software. Thus, classes are able to have an Internet component without great cost to instructors (neither in time nor dollars). As a result, students at many institutions have come to expect the class to have a significant online component. At a minimum, the software normally provides at least two components of interest to students: PowerPoint or other form of course material and a chat room for those registered in the class. There are those who argue that putting material presented during class time on the Web simply encourages students to skip class. However, the benefits of being able to review the material a second time are many and the problems of absenteeism can be dealt with separately (for instance, by taking attendance at classes and counting attendance toward the final course grade). The chat room allows students to get to know one another and to share concerns and approaches to assignments. It can be used as well to share data so that individual lab reports can include the results from the entire class instead of the results of a single person or team. A chat room is also an avenue for students to call attention to information they have found outside of class that they think might interest the rest of the class. It is thus a type of cooperative learning and fosters the ability to function on multi-disciplinary teams.[7] Acoustics lends itself well to use of an Internet component to enhance and reinforce the class. In particular, most educational software allows faculty to include audio files on the class site. These can greatly enhance the material presented during class time by providing more or better demonstrations.

Although technology is a major boon to acoustics classes, there are a number of other aspects of teaching-for-learning that work well with acoustics subject matter. For instance, students tend to learn material more deeply when they are presented with open-ended problems rather than a problem with a single correct answer, because it forces them to think about answers and justify their choices. Additionally, pedagogical advances encourage greater team experiences so that students may learn from one another as well as from the instructor. Acoustics can deal easily with these advances in pedagogy through use of realistic projects to replace or enhance homework. Such projects almost always have multiple correct solutions and lots of follow-on work that can be done. Further, the modern classroom engages students in more active learning, rather than sitting in a classroom and being lectured. Discussions in an acoustics class are quite easy to encourage by bringing in applications of interest.

It is also true that many students in STEM fields are unaware of the career and graduate school opportunities that await their completion of an undergraduate degree. For this reason, many undergraduate programs have developed courses that bring in speakers who talk about their career history and current employment. Students can be relied upon to value these speakers, particularly if they are recent graduates of the program. The use of outside speakers (especially female and minority speakers) in an acoustic undergraduate course is a superb way of demonstrating the diversity of acoustics and of connecting students with potential opportunities in their future. Clearly, not all locales have a strong acoustics presence, but at a minimum, virtually all locations have otolaryngologists, sound engineers, speech therapists, and musicians who could be prevailed upon to speak to a class of interested students.

Addressing issues of diversity

The engineering workforce is 93% male and 94% majority populations. Unfortunately, the physics workforce is even less diverse and the lack of diversity in most STEM fields is reflected in the membership of the ASA that we take to be a mirror of the acoustics workforce. Clearly there are areas within acoustics that have greater representation of women and minority populations, such as speech and physiological and psychological acoustics, but generally, the acoustics profession has not attracted a widely diverse group of students reflective of the population at large.

There are a few reasons why we should seek to achieve greater diversity in the field of acoustics. First, one could argue that survival of the field requires us to appeal to a broader audience than we have in the past. Indeed, starting in 2000 preschools in the US have been attended by a majority of students who would qualify as underrepresented minorities (where underrepresentation specifically refers to STEM fields). Today, the fastest growing population in the US is Hispanic, outpacing the growth of African-Americans, and each of these groups is increasing in size far faster than the traditional Caucasian and Asian-American groups that have dominated STEM. Unless we find a way to appeal to the Hispanic and African-American students, we might find it impossible to replace acousticians who retire and the field will shrivel. In fact, this is precisely the concern that the Navy has more broadly. It has found that the majority of its leaders, particularly in science, are nearing retirement and insufficient numbers of students are interested in replacing them.

Second, there is a strong business case for diversity, i.e., data have shown that more diverse companies do far better than competitors with less diversity. In the STEM fields, diversity is driven by a number of factors—the globalization of business requiring an employee base that is comfortable and accepted in a wide variety of cultures, the need for a broad range of perspectives to enhance the critical design function in products, and the need for more technically trained graduates to meet the demands of industry.[10,11] Thus, our lack of diversity in the acoustics profession could be hurting the ability of manufacturers to produce products that appeal to a broad audience.

Third, there is a compelling argument that seeking diversity is the right thing to do. Public education in the US was established as a public good and it has largely remained the best route out of poverty for disadvantaged people because education leads to jobs that pay enough for families to thrive in some measure of comfort. This is particularly true for education in STEM fields, where salaries tend to be higher than those in nontechnical areas at all levels. Given that minorities are disproportionately represented among those considered disadvantaged, encouraging students from underrepresented groups to pursue STEM education raises significantly their hopes of building a comfortable life. Further, it raises the probability that they will contribute to the economic welfare of their locale, an issue of importance to everyone living in that region.

While many in the STEM fields have recognized the importance of diversity for some time, the problem of attracting and retaining students has proven extremely difficult to address. Several projects that have produced impressive gains have been unsustainable without constant attention and dedicated resources. Having considered the projects designed to achieve a more diverse student body in STEM fields at the college and university level, we believe that a key problem is that most focus on infrastructural issues (tutoring, social networks, etc.) rather than the curriculum that forms the core of the experience for students. Unfortunately, when one considers the curriculum in STEM fields, it is perceived as uninteresting and unappealing, particularly in the first year or two, when students might not take a single course in their major department.

We believe that it is possible to impact the recruitment and retention of students in STEM fields, including acoustics, through development of a more appealing and appropriate curriculum. Primarily our work on this topic has considered the total revamping of the undergraduate curriculum in mechanical engineering.[12] Our hypothesis is that mechanical engineering will be more attractive to a diverse community if the curriculum is changed to show more connections between technical topics and between technical and nontechnical topics, to focus more on the social aspects and implications of the subject, to reduce critical path lengths to permit students to transfer into the major without requiring extra time in school, to introduce greater teaming experiences, and to create an atmosphere of inclusivity rather than exclusivity. While acoustics is not identical to mechanical engineering, we believe the same principles hold. It should be possible to attract a more diverse student population to the field through curricular change without reduction of technical rigor.

The literature points to some successful strategies for attracting and retaining underrepresented populations in STEM fields. For instance, women and underrepresented minorities are far more likely than majority males to choose a college major that will address issues of cultural and social importance and lead to improvements in the quality of life for disadvantaged populations. This suggests the development of new applications for classes that make the relevance of the field to everyday life clear. Further, the choice of application should reflect some cultural sensitivity to distinctions between various cultures and ethnic groups. In the US, for instance, Hispanic and African-American populations are far more likely than majority populations to be urban dwellers. They are far less likely than majority populations to own a car or to fly regularly. Does it make sense, then, to focus applications on cars and airplanes and wonder why the material does not attract minority students? It is this sort of cultural sensitivity that led Historically Black Colleges and Universities (HBCUs) to develop strong music programs early in their history as a means of appealing to a population well known for its involvement in music from an early age. In this sense, we have a wonderful opportunity to capitalize in acoustics as well, since musical acoustics is a strong part of the profession. However, there is little evidence that we have taken advantage of this opportunity to attract greater diversity to acoustics programs.

Entertainment represents one of the most popular professions in the Black and Hispanic communities, yet little has been done to introduce this population to the technical aspects of entertainment. Talent is certainly inspirational, but the underlying technologies represent a wealth of opportunities and should be a motivating factor for continuing studies in STEM.

While there have been great gains in women and minority students choosing a mathematically rigorous route in high school, there are still significant gaps between the participation of women and minorities on one hand, and their male counterparts on the other in such programs. It is possible to interpret this distinction as proving that women and minorities are less prepared for STEM higher education. However, one could also interpret the data as suggesting that STEM ought not to assume great mathematical knowledge in entering students. Indeed, although mathematics achievement is often used as an admission criterion for STEM programs, virtually all programs teach the mathematics required starting with calculus (and make it possible to take remedial courses in algebra). In considering undergraduate acoustics courses, this returns us to the earlier discussion of order of topical presentation in a survey course. By starting with derivation of the wave equation, arguably the most mathematically rigorous topic presented, we are sending a message that students without a great mathematical background need not attend. This inadvertently discourages women and minorities from acoustics.

As a final comment on diversity issues, we note that studies have shown that populations tend to see themselves as minorities if their presence falls below about 20% of the whole. This is important because the actions of students are shaped by how they perceive their standing in a class. Thus, even when acoustics classes are welcoming and without any evident bias, the mere fact that some students see themselves as different from the norm can impact their experience negatively. Successful ways to counter this problem seem to correspond to forcing more active participation of students with one another and with the instructor. Thus, discussions in class rather than the "silent lecture" and teaming experiences on homework assignments and projects are helpful.

A game plan for attracting more students to acoustics

Based on the prior discussion, it is possible to craft a game plan for making acoustics a more attractive profession to undergraduate students. We list the key elements of such a plan below:

1. *Create more, earlier, broader elective courses in acoustics.* Particularly at institutions that offer freshman seminars, the lower level acoustics survey class offers a chance to spark an interest in students from a wide variety of backgrounds and disciplinary interests. It is an opportunity as well to recruit students into departments that teach acoustics. At the junior or senior level, this also permits a series of acoustics electives to flourish, each of which could be more focused and rigorous than the earlier course.
2. *Develop better, more appealing textbooks.* Writing a textbook is a major undertaking, but the text options available for survey courses in acoustics are not adequate to the task of recruiting diverse student populations. Authors working together to create an innovative textbook with greater breadth and a nontraditional ordering of subjects could have a major impact on our field. Further, a group of authors working together might convince a publisher to dedicate enough resources to the project to produce something flashy and Web-enabled.
3. *Develop application case studies for use in acoustics classes and make them available online.* Although acoustics has a large and active consulting community, there are few detailed case studies of applications available for use in the classroom. Such case studies require significant lesson plan development, but creation of a host of application case studies online would make it possible to significantly broaden the material presented in acoustics survey classes and to make it much more connected to student personal experiences and concerns. One could even tailor such classes to the interests of the registered students.
4. *Develop a Web site or multiple Web sites that supplement course material.* There is currently no central repository for new acoustics demonstrations, for projects in acoustics, for connections of common activities (like downloading music) to acoustics, and for in-depth discussions of acoustics professions. By gathering this material together in one or more maintained Web sites, instructors of classes in acoustics would have significantly more resources than they can easily find now. Students and professionals outside of acoustics might also find such a site interesting as a way to gather information. Additionally, this could lead to an online and active job listing that works to list both people seeking employment in acoustics and companies seeking employees.
5. *Commit to development of a diverse student population interested in acoustics.* Making a commitment to diversity involves changing *what* we teach and *how* we teach in acoustics classes. It also requires committing to regular reviews of progress or lack of progress in achieving aims through demographic studies.

Many of the items in this game plan are too large to be accomplished by a single individual and several require the investment of significant time and money for successful completion. Ideally, what is needed is the activity of a committee of acoustics professionals actively interested in and engaged by acoustics education. Such a committee could begin by seeking seed funding for some demonstration work leading to federally or privately supported additional work (perhaps through proposals to the National Science Foundation).

Conclusions

The breadth of acoustics is a boon and a curse. The bad news is that acoustics is neglected at the undergraduate level. The good news is that the very nature of the discipline lends itself to a wide variety of appealing and relevant applications for a diverse student body. Much can be done with hands-on projects at minimal cost. Acoustic applications are ideal for realizing desired outcomes—multidisciplinary teamwork, understanding of ethical responsibility, and the broad education necessary to understand the impact of acoustics in a global, environmental and societal context. **AT**

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