Taking Experiential Learning Online in an Acoustics Elective Course

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Abstract

Starting in 2007, this survey course has been part of an acoustics minor. Originally envisioned to capture foundational concepts of acoustics that would be essential to a wide variety of engineering and scientific applications, this course is aimed at a junior/senior level audience to reflect the initiative and maturity required of the student. Topics emphasize the interdisciplinary nature of acoustics in industry, incorporating digital signal processing, psychoacoustics, and applications in room acoustics and environmental noise. Its evolution from a face-to-face studio environment to a hybrid and then fully online course has retained a hands-on experiential course design. Themes of art and design have been essential to its success. Challenges arose in teaching the course online, and solutions to promote learner engagement and consistency are described.

Introduction

The subject of this paper is a survey course in acoustics, taken as an elective by engineering and science majors. As a niche topic, this course is very important to only a small proportion of engineering students. Managing teaching assignments in its home department has been a challenge, and this has motivated a conversion of the class from the face-to-face studio environment to an online delivery. The main challenge of the conversion has been maintaining the emphasis in the course on active, experiential learning for the students. Promoting that kind of engagement in the course without a physical meeting space or collective time to meet together required very intentional instructional design decisions. Most of the course activities involve active learning, but collaborative and cooperative learning tasks[1] were ruled out of the course design due to logistical and facilitation constraints. The focus of the course design is student engagement, through low-stakes activities and assessment, and formalized, personal interaction with the instructor. This interaction has been shown to contribute to student learning and satisfaction,[2] but in earliest versions of this course, the student-instructor interaction was not intentionally and inherently designed into the course. Ad hoc or on demand interaction was used.

Academic courses in acoustics tend to fall into two broad categories.[3] On one end of the spectrum is the *descriptive acoustics* course that is offered at the lower-level undergraduate position, often for an audience of music or music technology majors (the science of sound), or students in speech or audiology programs. At the other end of the spectrum are the graduate-level courses in acoustics and vibration that treat topics with full mathematical rigor. Between these extremes, there are examples of upper-level undergraduate courses with robust scientific and engineering content,[4] but these are scattered and relatively few in comparison with the need for knowledge of engineering applications and interest in audio in the entertainment industries.

Many engineered products now must incorporate sound quality as a design criterion, and the availability of equipment for do-it-yourself home recording studios, home theaters, and car audio has never been greater. A little dose of practical knowledge of acoustics for undergraduates in engineering can be personally engaging and professionally valuable.[5]

The present course is designed as a one-course introduction to acoustics for students who have a personal and/or professional interest in the field. The student audience for the course is drawn from engineering programs in mechanical and electrical engineering, and includes majors in engineering physics as well. The course is designed to have a fairly low prerequisite, the introductory sequence in physics is required for topics in mechanics and electricity and magnetism. The typical student in the course is a junior or senior, perhaps with co-op experience with an industrial setting involving NVH or noise, or perhaps with a musical background. Musical interest is common in STEM students, and this course provides a way to take an academic and scientific perspective and explore these interests and experiences more deeply.

Content for the course is drawn from topics that would be found in any introduction to acoustics, combined with industry-relevant concepts and applications. Kettering University students write a thesis to satisfy a graduation requirement, and the topic of the thesis is usually based upon a project undertaken for and supervised by their co-op employer. A faculty member is additionally assigned to advise students during the thesis. While serving as the faculty advisor for more than forty such thesis projects in industrial settings, this author collected general expectations of content knowledge and skills in acoustics and NVH at the co-op level. The course content reflects the approach and knowledge base shared in many of these co-op thesis projects. In this way, one of the course design goals was to provide a service to employers who hire co-op students and provide experiences in NVH or similar divisions.

In striving for relevance and an emphasis on practical application, the original course design also drew inspiration from a series of editorial articles in a prominent trade publication.[6-14] These articles from esteemed educators and experienced industry professionals stress the importance of good communication skills, the validation of theoretical or simulation results with careful testing and measurement, and problem-solving skills in the context of realistic scenarios, which often seem messy or ambiguous compared with traditional problems from the end of the chapter in a textbook. In the instruction, development of skills, and assessment of student learning, the initial design and evolution of the course aim for authenticity.

The major topics of the current version of the course are presented in an organizational structure that mimics, to some degree, the source-path-receiver paradigm for analysis of noise problems. Table 1 outlines the course structure as it is taught presently.

Evolution of Instructional Design

The original design and facilitation of the course, beginning in 2007, emphasized experiential learning in a studio setting. The course was taught in that mode until 2012, when it transitioned to a fully online mode. That year, the course was taught twice. The first term, the class met for one hour per week, allowing a face to face opportunity to interact and discuss the online content presentation, activities, and assignments. In the second term, there were no regularly scheduled class meetings and all course material was presented online.

Table 1. Current course topic structure and organization

Unit	**Lessons**	**Task and objective**
Unit A: Source	Time domain signals Frequency domain signals Signatures of resonance	*You should be able to record sound signals from a source, analyze them for time and frequency information, and characterize the source through comparison to familiar models.*
Unit B: Path	Resonators Filters Wave behavior	*You should be able to identify the path(s) of sound propagation in the human environment, and use filters to predict the effect of that path on the sound from source to receiver.*
Unit C: Receiver	Computer "hearing" Human hearing Sound quality and psychoacoustics	*You will be able to interpret fundamental measurements (like spectral information from the DFT), and use the results to quantify human perception of the sound of a product or environment.*
Unit D: Room Acoustics *Or* Unit E: Noise	Reverberation time Design details Design goals *Or* Noise sources Noise propagation Noise metrics	For Unit D: *You should be able to analyze the acoustic characteristics of a particular room, and recommend improvements based on basic principles of room acoustics.*

Starting at the beginning, in 2007 in the studio mode, the experiential emphasis of the course motivated a minimal lecture component with significant time in class for hands on activities. These activities provided a great deal of the content delivery, with content presented in the midst of instructions for student tasks. In this way, the conceptual knowledge can be provided at the moment it's needed by the student to complete a task. Additionally, this pedagogical approach was readily transported to an online delivery mode.

As an example of this approach, and an example of the evolution of the instructional design in the learning modules, the following figures provide excerpts of materials related to the topic of Fourier Transforms and spectral content of signals. The learning outcomes of this lesson are currently provided to the student with this wording:

"After completing this lesson, you should be able to…

- explain the steps a computer takes to digitize a signal
- explain the steps and assumptions needed to discretize the Fourier Transform
- use window functions and anti-aliasing filters understanding the effects and tradeoffs"

Originally in the part of the course devoted to understanding how computers analyze time signals and produce spectra, students used MATLAB in a computer lab and worked face-to-face in a studio or laboratory style. Students would hear a short lecture on the continuous Fourier transform, and then apply those ideas by coding a "do-it-yourself" discrete Fourier transform, or DFT. Students would have a skeleton MATLAB script, so their job was to complete the lines that involved the critical calculations. The nested for loops can be seen near the bottom of the activity page, shown in Figure 1.

B. Type "help fft" at the command prompt to learn how MATLAB carries out a transform.

C. Set up a time vector and a signal:

```
Fs = 8192;
dt = 1/Fs;
T = 0.5;
t = dt:dt:T;
N = length(t)
x = 0.1*cos(2*pi*10*t);
```

Check the value of *N*, and try plotting *x* vs. *t* to be sure you have a reasonable sinusoid.

D. Set up the sum that is provided in the "help fft" description:

```
         N
X(k) =  sum   { x(n)*exp(-j*2*pi*(k-1)*(n-1)/N) }  1 ≤ k ≤ N
        n=1
```

Note carefully how this is different than the equation A.6 in Appendix A of Application Note 243!

- Indexes are used differently in the X() and x() expressions
- MATLAB starts indexes at 1, not zero; for example, *k*-1 is *m* in A.6

You should also take a moment to understand the derivation of A.6, as there will be questions on this later…

Here's one way to code this sum. The following lines are NOT complete, but here to provide a framework!

```
for k = 1:N,
    X(k) = 0;   %initialize
    for n = 1:N,
        X(k) = X(k) + x(n)*exp(...
    end
end
```

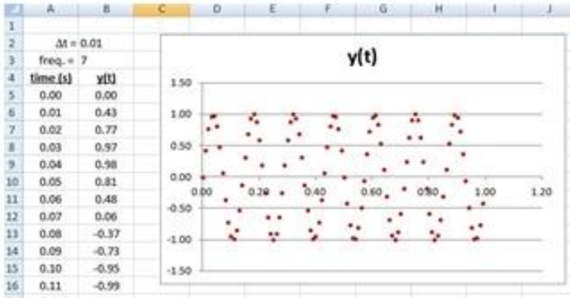
Figure 1. Excerpt from curricular material provided to students in the studio classroom, leading them through a hands on "do-it-yourself" discrete Fourier transform.

This activity really gave some of the students a sense for what's involved in creating a spectrum from a time series, but it really confused others. Also, it required a great deal of class time, required lots of one on one coaching, and was not structured for more independent learning in an online format. Direct feedback from the students indicated that the activity did not help the majority of the students meet the course learning objective for this topic. A root cause analysis showed that programming skills needed for the task were not sufficiently developed in the present course to support the work.

Therefore, the discrete Fourier transform lesson has evolved through the nine instances of the course. It is one of the lessons that provides a look behind the scenes of the tools used by NVH engineers routinely; a deeper understanding of the inner workings is part of the value provided by the course. The lesson's continuing evolution has been driven, in part, by student input. One consistent request is more graphical, visual illustrations to support the concepts. Therefore, Figure 2 shows a later version of the same lesson. In this section of the lesson, the learning objective is to understand the raw DFT rather than learn to code a MATLAB script, so the job of calculating is given to Excel. The students add in the Analysis ToolPak, and then use the Fourier Transform with a few steps shown in Figure 2. Plots of the input time series and output DFT (actually FFT) can be made easily, allowing for more immediate interpretation of these functions of time and frequency, as in Figures 2 and 3.

As seen in Figures 2 and 3, this later version of the activity emphasizes student tasks, as they can work through the examples with these explanations as a guide. This version strives to be visual and thorough in discussing what is to be done, why it is to be done, and how to understand the results of the tasks. It also retains enough of the view behind the scenes, so that the students can use FFT-based tools at work or in other courses with some knowledge of the fundamentals. For an example associated with these excerpts, the student would be intimately familiar with the complex output of the DFT or FFT, and how the real and imaginary parts can be converted to magnitude and phase. It might be observed that engineers might neglect the phase, concentrating on magnitude of an FFT, but that phase can be very useful in a number of applications.

Near the bottom of the excerpt in Figure 3, the student has just seen evidence of leakage, a problem inherent in a discrete Fourier transform due to finite record length. Immediately, the activity takes them to an audio editing software, Audacity, that provides analysis in the frequency domain in a "Plot Spectrum" command. Now that students understand where that frequency domain information comes from, they can use that tool to explore leakage and the remedies found in applying window functions. Again, the emphasis is on learning by doing, and guided interpretation of the results of the students' exploration.



Set up column B to be a sine function, again with a parameter at the top for frequency to make it easy to change. I used the cell formula "= SIN(2*PI()*B3*A5)" for cell B5 in this example. Notice the graph of the sampled sine in the screenshot has seven cycles in the one second of data.

To implement the Excel DFT (actually an FFT), click on the Data tab and locate Data Analysis. Select Fourier Transform, and click OK. The input range will be the 128 points in your column B sine function. I asked to have the output in a New Worksheet Ply, so it creates a new tab at the bottom, then clicked OK.

The first value represents the DC bias, or zero frequency contribution, so I set that to zero manually (the sine function was centered on zero, so there should be no bias. The rest of the values, you notice, are complex numbers. These are the real and imaginary parts, which I pull out into separate columns using the cell functions "=IMREAL(A3)" and "=IMAGINARY(A3)".

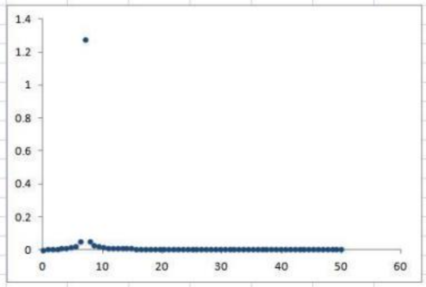
With those added columns, I can calculate the magnitude and phase using cell functions "=SQRT(B3^2 + C3^2)" for magnitude and "=ATAN2(C3,B3)" for phase—consider the complex plane mentioned in the Prezi for these fundamentals. The result looks like this:

	A	B	C	D	E
1					
2		**Real par**	**Imag. Pa**	**Mag**	**Phase**
3	0	0	0	0	#DIV/0!
4	0.195521205312864+6.4929454510059E-002i	0.195521	0.064929	0.20602	1.250171
5	0.198365437776093+0.134885452635477i	0.198365	0.134885	0.239881	0.97363
6	0.203637921833385+0.21630480039832i	0.203638	0.216305	0.297079	0.755244
7	0.212397546711305+0.319366258841923i	0.212398	0.319366	0.383546	0.586889
8	0.226919925219832+0.46336518850231i	0.22692	0.463365	0.515946	0.455391

Figure 2. Excerpt from curricular material with Excel rather than MATLAB, illustrating the shift from students coding the DFT to focusing on interpreting the input time signal and output transform.

spacing of $\Delta f = \frac{1}{N*T}$, so I calculate that and use it to increment a list of frequencies in column F. Only the first half (64 points) need to be populated, of course, as we're only going up to half the sampling rate. The result of all this is shown below.

	A	B	C	D	E	F
1					Δf =	0.78125
2		Real par	Imag. Pa	Mag	Phase	Freq. *f* (Hz)
3	0	0	0	0	#DIV/0!	0
4	0.195521205312864+6.4929454510059E-002i	0.00391	0.001299	0.00412	1.250171	0.78125
5	0.198365437776093+0.134885452635477i	0.003967	0.002698	0.004798	0.97363	1.5625
6	0.203637921833385+0.21630480039832i	0.004073	0.004326	0.005942	0.755244	2.34375
7	0.212397546711305+0.319366258841923i	0.004248	0.006387	0.007671	0.586889	3.125
8	0.226919925319832+0.46336518850231i	0.004538	0.009267	0.010319	0.455391	3.90625
9	0.252686880220109+0.692633999505879i	0.005054	0.013853	0.014746	0.349816	4.6875
10	0.306503545385939+1.14090299601483i	0.00613	0.022818	0.023627	0.262453	5.46875
11	0.4753921396976+2.4975619811332i	0.009508	0.049951	0.050848	0.188092	6.25
12	-7.85923621036177-63.4601266367049i	-0.15718	-1.2692	1.278899	-3.01837	7.03125
13	-0.167647615877784-2.55899514762195i	-0.00335	-0.05118	0.05129	-3.07617	7.8125
14	-1.7662293786314E-002-1.35728642765115i	-0.00035	-0.02715	0.027148	-3.12858	8.59375
15	3.31705557626641E-002-0.941722463692027i	0.000663	-0.01883	0.018846	3.106384	9.375
16	5.85276711324285E-002-0.728917000306017i	0.001171	-0.01458	0.014625	3.061471	10.15625
17	7.3605357335859E-002-0.598434473844809i	0.001472	-0.01197	0.012059	3.019211	10.9375
18	8.3531629407244E-002-0.509562092644157i	0.001671	-0.01019	0.010327	2.97911	11.71875



You'll notice a few things slightly amiss here: the point nearest 7 Hz has far and away the most magnitude, as expected, but it's a little *greater* than 1 (our amplitude of the sine function). Also, the neighboring points have some amplitude as well, as if some of the signal "leaked" out into other frequencies. These are related to inherent artifacts in the discrete transform. Let's explore this a bit more using Audacity in the next section.

See the concepts in practice—Audacity

Open Audacity. Before doing anything else, change the Project Sampling Rate (at the lower left corner) to 8000 Hz.

Figure 3. Excerpt from curricular material, also with Excel, providing discussion that helps the student interpret the output of the transform, in the frequency domain, and leads into applications using Audacity audio editing software.

Assessment Structure

The assessment of student learning in an online environment is predominantly low-stakes assessment, with many opportunities for students to check their own learning, reflect upon the meaning of concepts in light of their activities, and discuss concerns to eliminate areas where they recognize that they are uncertain. Each Unit of the course is divided into Lessons, covered at a pace of roughly two Lessons per week in an 11 week term. These chunks of content each have an assignment, but the assignments are not graded.

Student accountability is tied to assessment, encouraging personal interaction and fostering student engagement. Each student meets with the instructor once a week for 30 minutes for what is called a "Check In." These appointments reflect accountability by mimicking a professional environment, as if the student is a team member that checks in with the manager or supervisor once a week for a progress update. Here, the project is the Unit of content, and the expectations are made clear through the assignments that are provided with each Lesson within the Unit.

Check In meetings are the opportunity to go over the assignments, clear up any misconceptions—these often emerge in conversation, if the student didn't recognize them at the outset—and plan ahead for the coming week. Students not available on campus for an office visit conduct these meetings via Skype or telephone.

Table 2. Rubric for Check In meetings

On pace with the course…	Check In appointment…
❒ All work submitted on time, up to date and complete	❒ Kept as planned
❒ ______ Lessons are late/incomplete, **with** prior notice	❒ Adjusted with prior notice
❒ ______ Lessons are late/incomplete, **without** prior notice	❒ Met, but late
	❒ Missed… Follow up:
Quality of the work…	
Outstanding	Demonstrates clear command of concepts or calculations through answers to assignment questions or Check In conversation.
Satisfactory	Most concepts or calculations are clearly understood prior to Check In; misconceptions are removed in conversation.
Marginal	All or nearly all work is attempted, but many misconceptions or major errors indicate the content was not well understood. The Check In resolved some or all of these issues.
Unsatisfactory	All or nearly all work is attempted, but significant errors indicate the content was not understood. The Check In didn't resolved many of these major issues.
Unattempted	All or much of the work was not attempted. The Check In involved basic learning.

The Check In meetings are part (40%) of the grade, and represent student performance on a day-in-day out basis. The rubric for evaluating student performance in these Check In meetings gives significant weight to content knowledge, but also includes professional behavior, as described in Table 2.

The rest of the course grade is determined by Unit Tasks, major written assignments designed to replicate tasks from a professional setting. Here, the students show that they have achieved the Unit learning outcomes as they demonstrate concept knowledge, skill with the tools of the course (for example, making good quality recordings in Audacity and analyzing the recordings using features of the software), and exercise communication skills. The first three Units have tasks worth 12% of the course grade, and each has a rubric tailored to the assignment. The rubrics are distinct, but all have a criterion for professional communication. These higher-stakes writing tasks are more suited to the online environment than tests, where proctoring becomes a concern.

The final Unit Task involves students in a consulting role, providing a recommendation for remediation of an architectural acoustics case or noise control problem. Skills and knowledge from the entire course is likely to be utilized in this final Unit Task, and so this serves as a final learning experience. (There is no final exam.) The primary deliverable is a formal report appropriate for communication to a client. With an eye toward improving communication skill, a draft is required roughly one week before the final version is due. Feedback is provided on this draft, and it's worth a small portion of the points. Because the scale of this task is significantly greater than the other Unit Tasks, it is worth twice as much (24% of the course grade).

Assessment of the Course

Student feedback drove much of the evolution of the course, and specific suggestions were implemented to fine tune the details of course delivery and procedures. Table 3 provides examples from a range of impactful student comments. Support for reading assignments remains as an area for development in the course; questions over the reading will be developed, and with some support, video mini-lectures from the acoustics laboratory with demonstrations would supplement the assigned reading.

Check In meetings developed out of a exigency in retention. Being an online class without regular classroom time in a student's schedule, procrastination became a problem for busy engineering students. Students would put off work for this course (only an elective, no face-to-face accountability) until they ultimately would end up dropping the course. One term this affected nearly one third of the students originally enrolled. Implementing the Check In meetings brought the problem under control; now in a class of ten, a single student may drop, which is reasonable for an elective.

The niche in which this elective acoustics course fits allows a fairly small enrollment. In line with best practices for online education, a soft maximum of 12 is allowed (enrollment can go higher with permission). This accommodates the intensive one-on-one attention from the instructor for Check In meetings and assessment of student writing. However, comparison to an upper level physics course in a specialty field, with four contact hours per week plus office hours, shows that six hours of Check In meetings is not unreasonable. The personal attention is also an attractive feature for recruiting students to the acoustics program.

Conclusions

This elective acoustics course was designed from its beginnings to incorporate experiential learning, relevant content and authentic assessment. The student focused activities that replaced most of the lectures in a face-to-face studio environment allowed for an easier transition to an online delivery mode that emphasizes active learning. Challenges in facilitation, particularly in promoting student engagement, were met through intentionally designed interaction between students and the instructor. Through student feedback and thoughtful instructional design, the course has evolved into its present form, optimized for science and engineering students with a practical mindset.

Table 3. Student comments from anonymous midterm survey instruments

Survey instrument: *This course will be revised for the next time it's offered. Please jot down your thoughts:* • *What were the strongest parts of the course, and why were they helpful to you in learning the material?* • *What two or three aspects should be improved, and how can we improve them?*
The strongest part of the course was *the online lab/work at your own pace/a guided, find your own answers type approach.* It helps the information learned to be remembered. The second strongest part was *great instructor feedback*. Having this feedback was crucial to staying on task in this unit. The weekly emails and detailed feedback on homework was monumental.
Hm - part of the course? That is difficult; I have learned a great deal from many of the resources. The activities are structured well for the most part and the external resources have usually been helpful, although the one textbook used two lessons ago (I think) was very difficult to find things in. I liked the animated site that explained resonators.
One of the biggest areas that needs to be improved is content. I don't think the course needs less content, *but it'd be nice if the course was two courses* or if there was an intro into this course. In the beginning the content was a bit overwhelming and needed lots of time to digest.
The large reading sections sometime make it difficult to find the important information. It has not be bad up to this point, but when we are told to read I often wonder if I got the information I was ment to find. This is mostly because there is not a class room discussion to reinforce the topics, the meetings do help a lot to make up for this.

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