Lecture-Free Engineering Education

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[**Note:** To view lecture videos, videos from in class, and a master class (including Q/A discussion of this method): http://www.ctle.utah.edu/?&pageId=6266]

There are numerous references in the engineering-education literature to how effective "active learning" is [1], and how our traditional lecture style is not necessarily the most effective way to teach. I've tried active learning in my own classes for the last several years, mostly having the students work in small groups on examples, collecting questions, etc. [2-4]. However, I found it very difficult to escape the "sage on the stage" lecture paradigm. In engineering, it seems as if the students need a certain amount of basic information before we can have effective discussion, group work, etc. Thus, this paper describes my experiment using pre-class video lectures to replace the traditional lecture, and to leave class time for active problem solving and exposure to engineering applications. I am extremely pleased with the results in my classroom, and hope these ideas might help others try similar methods.

Video lectures can be used to replace existing in-class lectures (as I have done), to provide a review of existing in-class lectures (such as MIT's videotaped lectures), or to provide supplementary (additional) material beyond the in-class lectures (often used for tutorials or review material). Online classes often use video lectures, either in real time or recorded, and some online classes provide online methods for interfacing with the professor and other students. For example, the Khan Academy provides a wide variety of math and science lectures and a format for student collaboration in strictly online courses [5]. The unique aspect of my teaching is that I use the video lecture to replace the traditional in-class lecture, and use the in-class time for problem solving and applications. In addition to my students, these videos are being used even more extensively by other students around the world, who are in either traditional or online courses, to augment the explanations available from their professors.

This paper describes my experiences using pre-class video lectures to teach a large (50-80 person) required undergraduate electromagnetics course. I record my lectures on a tablet PC in advance of the class, and upload them to *YouTube*. Students watch them before class. During class, I try to help them make the transition from lecture to homework, hopefully helping them gain better problem-solving skills and strategies. I do this by having them begin the homework in small groups of students sitting near each other (two to three), wandering the class, and then bringing them back together for discussion of critical questions and interesting points. I hope to help them reach higher-level thinking skills as well, through this process and discussion. From the level of questions received, I believe this is happening, although I have no test data to prove it. I also have time in class to discuss an engineering application of the principles we are discussing that day. By the time they leave class, we have generally set up (but not fully solved) all or most of the homework problems, and had a discussion about applications of the ideas. Many students later go back to the videos for further clarification while completing the homework or studying for the exams.

This work should be considered a pilot project. The assessment I have is all self-reported student evaluations (including several mid-semester evaluations), and observations by a professional evaluator from our Center for Teaching and Learning Excellence. Test scores showed no significant difference from one year (not using this method) to the next (which did use the method). Student course evaluations were dramatically higher when using this video-lecture method, and student comments were highly supportive of the approach. Perhaps the thing I have noticed the most is that students seem to ask many more questions than they used to, and that the questions are typically higher level than before. I have no way to quantitatively evaluate this, because I no longer teach the class the old way. Additional evaluation and experimentation is needed to determine the very most effective approach(es) to this method, both the video content and the use of class time.

Teaching with Pre-Class Video Lectures

"ECE 3300 Introduction to Electromagnetics" [7] is our required junior-level EM class. Typically, 50 to as many as 102 students are in this course. This is a typical mathematics-intensive electrical-engineering course. The Web site [7] includes examples of both tablet-based and white-board-based video lectures, as well as homework assignments, lecture notes, etc. I have also done a similar method with "ECE 5340/6340

Numerical Electromagnetics," which also has an earlier version of video lectures (recorded on a white board) available online [6].

The Video Lectures

The video-lecture material is the same content I would previously have done on the board, compressed because of not being interrupted with questions and not reiterating or repeating content. I use a standard HP tablet PC with a *PowerPoint* template, which has some thin blue lines that help guide my writing in a more or less straight line.

I record the lectures in five-minute segments using software called *Jing* [8]. *Jing* can only support five-minute lectures, but another software package, called *Camtasia* [10], can support much longer lectures. Typically, it takes four to six segments, each three to five minutes long, to complete a lecture that was previously 50 minutes long. Students tell me they prefer the shorter format, so that is what I continue to use. I go quickly through the material. If the students want to slow it down, pause it, or hear it again, they have that control in the video player. I try not to repeat myself, because they can re-watch sections as needed. It takes me about an hour to record 20 minutes of video, because of going back multiple times when I don't like the way I am explaining something (a "rewind" I couldn't do in class on the board!). When I first started recording, it took me much longer. When I make a small mistake, I no longer go back and edit it (because that takes too much time). Instead, the students or I just leave a "comment" on the *YouTube* site to note the correction.

I then upload the videos to *YouTube* [10]. *YouTube* lets you upload as many videos as you want to, each under 15 minutes, free. You can also create "playlists" for each lecture, titles, keywords, etc., to help people find your videos. My students generally access them from the class Web site. Others find them from their titles and playlists. I also upload the *PowerPoint* file associated with each lecture (the writing I did as I recorded the lecture) to the class Web site. Many students print these out and take additional notes on them, sometimes on their own tablet PCs.

When I first started this course, I was hoping to record the lectures over the summer prior to the course. That would have been great, but I didn't have enough time. I ended up recording the last third of the class in 2007, and the remainder in 2009. This worked out well, because if I had provided the first third and then run out of time, the students would have been very dissatisfied. Now that I have this material recorded and posted, I make relatively few additions from year to year, so my time requirement is minimal.

Preparation for Class

I prepare another (different) set of *PowerPoint* slides for the in-class time. These are *not* lecture slides. These include the problems I want to work on in class, and the major equations, diagrams, and figures or tables we may need to solve the problems. They also include photos or videos to help me explain the engineering application I want to cover. (I used to do this the last 10 minutes of class, but have found it is a great "attention getter" to get the class excited to start, and to encourage people to be on time, so I now usually start this right at the beginning.) I teach in a classroom that lets you project on the side screen while still having full access to the blackboard. I thus project the *PowerPoint* on the side screen, and use the central part of the board for working out the solutions, etc.

In-Class Student-Driven Review

Typically, I start the class by raising the question for the day, such as "How do you design a single-stub matching network." I then have the class walk me through the steps needed to solve the problem, which were covered in detail in the video lecture. I write the steps on the board as the students recall them from their memory and notes. This takes about five minutes, and is more or less a student-driven review of the previous nights' video lecture. Alternatively, we just start with a problem, and write the steps needed to solve it as we go.

Active Small-Group Work

I next put up a problem (usually from the homework) they should be able to solve with the steps or method we just wrote down. This is on the *PowerPoint* slides I prepared for class, and is usually also in their text. They work in groups of two to three with their nearby neighbors, and begin to set up the problem.

When I first do this (first week or so of class), students are reticent to actually work with their neighbor, and will quietly start doing this on their own. As I walk around the classroom, I actively bug them to move over and work with their neighbors. One student said he learns much better alone and was very resistant to this. I bet him lunch that he would learn something from any student I put him with. He moved over with another group of students he knew were struggling, and when I asked him afterwards, he said he owed me lunch. Usually once students try this, they really like it, but I had to be quite (cheerfully) aggressive to get some of them to try it. Some groups of students are faster than other students. Slower groups will leave with the problems just set up. Faster groups may be well into the calculations before leaving class. This way, neither the faster nor slower students feel their time was wasted in class.

I walk slowly around the class, act interested in what each group is doing, look at their papers, ask how they are doing, did they get it, what was the plane of symmetry, anything. The fact that I am interested in what problems they are encountering often gets them to stop me as I wander by and semi-privately ask me a quick question they may have been too shy to raise to the larger classroom. It seems to take about two minutes for the students to get far enough into the problems to ask questions. Depending on how they seem to be doing, I usually let them go for four to five minutes before stopping the class and resolving the major questions noted as I walked around. At this point, I usually know what questions those will be, but it is still much more effective to let the students bump up against them before I help them evaluate the problem-solving strategy they are missing at that point. Basically my cues are the following: If they are writing and talking, they will have questions when I stop the class. If they aren't writing, they are stuck. If they aren't talking to each other, they are probably totally confused.

The slow walk around the classroom, collecting questions and observing problems, is one of the important aspects of this method. I have not increased the amount of homework required, even though I get much of it started during class. This method is really a reallocation of how time is spent at home and with the professor. Students have commented on how helpful it is to have their professor get them started on their homework.

Applications

The last (or first) 10 minutes of class, I try to show how the abstract concepts they learn in class apply in real engineering applications. Thus, almost every day I bring in an application (usually with parts to pass around, photos, videos, etc., that you can now readily find on the Web), talk about how it works, and either tell or ask the students how what we are learning that day applies in that application.

Issues and Problems

No teaching method is without its challenges. One of the common issues is getting the students to watch the videos before they come to class. If they do not, they are quite confused during class, wasting their time and potentially that of the rest of the class, if you cater overly much to their questions. I am quite insistent that students must watch these videos before they come to class, and won't waste class time to bring them up to speed if they haven't. The *YouTube* statistics tell how many students are watching them (typically, about 80% before and 20% after class). Possible incentives, such as in class quizzes, homework credit for notes taken during the videos, etc., might improve those statistics. This is the fourth year I have taught with the videos, and it seems this year, I have very few students who come to class without watching them. The students have clearly heard about this teaching method from other students, and come to the first day of class primed to learn this way.

Another of the common problems is that students can't ask questions as they go through the videos. I plan to provide incentive to watch the videos by making video responses to specific student questions turned in prior to class this year, and see how that goes.

Some faculty have worried this might reduce in-class attendance. In one early test, while I was still doing traditional in-class lectures, I put the video lecture up after class, and class attendance did drop markedly (the students knew they could get the material after the class). When I first experimented with not doing the traditional in-class lecture, I put the video up before class, and class attendance actually increased (the students said they saw the material was difficult, they had some questions, they knew the class would be devoted to their questions and problems, so they attended).

One of the challenges of this method is that the students have liked it so well they have pestered my other colleagues to do this for their later classes. Since this does require an initial time commitment and a significantly different teaching style for the professor, others may or may not choose to teach this way. Students have sometimes expressed dissatisfaction with otherwise very good professors because of having the advantage of video lectures in one class but not another.

Students from all over the world are now accessing these online lectures (mine and others). Some faculty have chosen to link to my courses specifically to provide this support for their students, while still doing traditional lectures in their own classes. Often, the students find them on their own. I think it would be very beneficial to have a database of EM videos available linked on the IEEE AP-S homepage for faculty and students to use in whatever ways fit their needs.

I have tried teaching the numerical EM course [6] as a self-study course (the equivalent of an online course), when student demand requested this course but we did not have faculty to teach it. This worked well with the support from a single, experienced teaching assistant. Without the TA to answer questions, I do not think it would have worked as well.

Evaluations

I asked the students to give me written feedback in the first through the fourth weeks. We did a formal assessment of the class in week seven. I had a professional evaluator sit in and evaluate the course when I taught it this way, and also when one of my graduate students taught it this way (professional teacher vs. novice teacher). I was specifically mentoring this graduate student in this teaching method, which provided interesting observations on what she and I were doing differently.

The feedback from the students was almost unanimously positive about this method. They did provide a lot of specific feedback on method, details, etc., which I will be glad to share with other professors who want to try this method.

The end-of-semester course student evaluations from three years are given in Table 1. In 2007, I did video lectures on a white board for about the last one-third of the class. I did regular lectures in class, and posted these after the class period. In 2009, I did video lectures on the tablet PC (and used the teaching method described above), posting them a day or two before class. In 2010, the students used the same videos as in 2009, but the entire collection was posted before the

Table 1. Student evaluation scores.

Evaluation	2007	2009	2010
Overall this was an effective course	4.98	5.68	5.61
Overall this was an effective instructor	5.13	5.85	5.82

semester started. Values are given on a 6.0 scale, with 6.0 being "Strongly Agree." Student comments again strongly supported the videos, with constructive suggestions I have incorporated in my teaching.

Student-exam scores have not changed significantly, either up or down, because of the video lecture method. I believe this is because I test my students at a specific level, and they will do what it takes to learn the material to that level. I believe one of the differences of this method is that students obtain a higher level of learning, a better understanding, and better problem-solving skills. However, I have not changed my exams to attempt to assess those skills, and I wouldn't have a comparison from previous years when I was teaching in the traditional manner, anyway. In class, I have seen a significant increase in the number and the technical/thought level of questions I receive. However, since I didn't record the types of questions I used to receive, I have no definitive evaluation of this change. It is strictly my own observation.

Perhaps the most telling evaluation of this method is the large number of students around the world using these videos. The most popular is (by chance) on "Gaussian Elimination," and has been watched over 48,000 times. Videos on Smith charts have been watched over 11,000 times. I get numerous comments from students and professional engineers each week, thanking me for providing these video lectures. I think this free and available access is one of the critical elements to providing a true transformation in undergraduate education.

Conclusion

I believe this pilot project has been extremely successful. I intend to continue to teach this way, and never plan to go back to "regular" lecturing again. I will be glad to mentor other professors interested in developing materials of this sort and using them in their teaching. I think it is important to provide the materials freely available publicly for use by other students. I have also provided all of my materials to anyone who would like to use them. They are freely available. I hope other faculty will provide my class links [6, 7] to their students, and will use them in any way that benefits their teaching. Electromagnetics is a challenging subject to learn, and a challenging subject to teach. There are many excellent teaching strategies that are effective, and everyone's teaching style is unique. I hope that providing these ideas and resources can help other educators develop strategies that help open the world of EM to more students.

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