Using Interactive Lecture Demonstrations to Enhance Student Learning in Electronics

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Abstract: Interactive Lecture Demonstrations (ILDs) have been successfully used for many years to improve conceptual understanding in university and high school physics courses. In engineering and science disciplines (such as electronics), there is sometimes concern about whether students simply apply formulas to solve problems or whether they develop a deeper understanding of the principles that are used to interpret electronics phenomena. In a lecture-style environment, ILDs can be used to improve student engagement and learning outcomes. We have developed a set of ILD activities to teach Operational Amplifiers, which is a topic that many students have difficulties with in our university’s introductory electronics course. The ILD equipment and activity sheets have been designed to promote engagement and deeper learning. Results of pre- and post-testing of students, together with student surveys and focus group comments collected over a three year period are very positive, and indicate encouraging learning gains.

Background

Interactive Lecture Demonstrations (ILDs) using a Predict-Observe-Discuss-Synthesize (PODS) learning cycle have been used for over a decade to engage physics students in large lecture hall environments and to improve their conceptual understanding and deep learning in many topics such as mechanics, optics, heat, electric circuits. (e.g., Sokoloff and Thornton, 1997, Thornton and Sokoloff, 1998, Meltzer and Manivannan, 2002 ). ILDs are based on an active learning philosophy (e.g., Laws, 1997) that changes the role of the teacher from that of an authority figure who is the repository of all knowledge (“sage on the stage”) to that of a facilitator who encourages students to construct their own knowledge based on experimental observations (“guide on the side”). In an ILD, the facilitator sets up and explains the particular experiment that is to be investigated, asks students to form small discussion groups while still seated in the lecture hall, and then encourages these groups to predict and record what they think will be the outcome of the experimental activity. The facilitator performs the experiment and the students record their actual observations. Each group, and then the class as a whole, discuss any differences between their predictions and observations, and then synthesize their ideas of the principles underpinning the observed experimental outcome. The PODS learning cycle
(e.g., Sokoloff, 2006) is used to create a “cognitive disequilibrium” between what students’ believe (and expect will occur) and what they actually observe. This disequilibrium, which can create an environment where misconceptions can be confronted and deep learning can occur, is a more effective strategy that simply telling student the correct information (e.g., Nachtigall, 1990).

Although there is some ILD material (activities, teacher notes and conceptual evaluation tools, etc.) available for simple electrical circuits (e.g., Sokoloff and Thornton, 2006), there appears to be little published for more advanced electronics principles and circuits. In the large (approximately 300 students) introductory electronics course at our university, we suspect that a large number of our students have significant difficulties in understanding many of these more advanced topics. For example, we have noticed that students tend to take a “shallow learning” approach when studying operational amplifiers (OpAmps). Perhaps because they have had little or no previous exposure to OpAmp devices and their inherent properties (e.g., high open loop gain, high input resistance, low output resistance) or to the OpAmp’s basic amplification circuit design (i.e., the use of negative feedback to greatly improve stability by reducing overall circuit gain), students appear to simply memorize and then recall the formulas describing the gain characteristics of a small number of simple OpAmp circuits (e.g., inverting and non-inverting amplifiers). Although these students can calculate solutions to a number of simple problems, they seem to have little idea of how the OpAmp circuit works, or the role that negative feedback plays in determining why the circuit behaves the way it does. The following is a typical example of this “shallow learning” approach: Figure 1 shows the OpAmp circuit for the simple inverting amplifier as discussed in lectures. The voltage gain equation for this circuit is given by \( \frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{R_2}{R_1} \). We have observed that in exam and tutorial questions, if the labels for \( R_1 \) and \( R_2 \) in Figure 1 are interchanged and students are asked to calculate the voltage gain (for particular resistor values) of this differently labelled inverting amplifier circuit, many students still use the original but now incorrect voltage gain equation shown above. In other words, it appears that many students have simply recalled what they believe to be the inverting amplifier voltage gain equation without really understanding how it is derived or used. In our teaching, we have seen many other examples that seem to indicate that students have serious difficulties in understanding advanced electronics concepts and circuits such as those associated with OpAmps.

**Methodology**

We wanted to investigate whether ILDs could significantly improve the conceptual understanding and level of learning of students studying our introductory electronics course, especially for the topic of OpAmp circuits. In our introductory electronics course students were divided into several lecture groups of between 50 and 150 students, each with different lecturers who were free, within the lecture framework, to cover the syllabus in their own particular style in line with accepted faculty practices. During our period of investigation (2006 - 2007) one staff member chose to use a traditional lecturing approach with his group, while the two other staff covered exactly the same syllabus by using a blended approach of traditional lectures with some ILD classes for the OpAmp topic. Each of the lecturers used the lecturing style (i.e., traditional lectures or lectures plus ILDs) that they felt was most beneficial for their students. All three lecturers were very experienced and had consistently achieved excellent student survey results over many years of teaching electronics. The students in all groups had the same type of laboratory and tutorial instruction, so that any significant learning changes could hopefully be attributed to different lecturing styles. The traditional lecture group had 6 hours of lectures on OpAmps, whereas the other groups had 2 hours of traditional lectures (OpAmp introduction) followed by 2 hours of ILD activities (basic OpAmp circuits) and then another 2 hours of traditional lectures (OpAmp consolidation).

For the 2 hours of ILD activities, we developed several worksheets, covering the OpAmp activities associated with the “comparator”, the “inverting amplifier” and the “non-inverting amplifier”. The worksheets were designed to encourage students to construct their understanding of how OpAmp circuits work via a set of guided activities that followed the PODS learning cycle. Each worksheet was in two parts: a “prediction sheet”, where students could write down their individual and group predictions, and a “results sheet” where students could write down their observations, discussions (and
hence resolutions to any differences between predictions and observations). Prediction sheets were collected for further analysis by the researchers. Results sheets were kept by the students to assist them with their studies. An example of one activity in the prediction sheet used with the “non-inverting amplifier” ILD class is shown in Figure 2. As can be seen from this activity, we were trying to encourage students to think about the various concepts needed to develop an understanding of why this OpAmp circuit behaved as a non-inverting amplifier. The ILD activities could not be successfully completed by simply recalling the non-inverting amplifier gain equation.

The circuits described in the prediction sheets were constructed at the front of the lecture hall using a purpose-built OpAmp plug-in board. A live video image was displayed on a large projection screen. The board used for the OpAmp ILDs, as it appeared on the screen, is shown in Figure 3. The OpAmp board layout shown in the figure is the same as the circuit shown in the prediction sheet of Figure 2. To minimize confusion for students during the demonstration, the OpAmp board was designed to look very similar to the circuits shown in the prediction/results sheets. Each circuit used in the predict/observe activities was constructed in front of the students using components mounted in H-plugs. Appropriately labelled multimeters with colour-coded leads were used to observe the predicted voltages and currents around the circuit. The common predictions and actual observations were recorded on an overhead projector screen or whiteboard, and discussed in class.

In order to test the efficacy of the OpAmp ILDs, we developed a diagnostic test consisting of 7 multiple-choice questions designed to measure students’ conceptual understanding and level of comprehension of the OpAmps devices and circuits covered in the ILD activities. The test questions were designed so that they could not be answered by the simple application of formulas; instead, these questions required a much deeper understanding of OpAmp principles in order to be solved. For the purpose of the test, two groups were identified: the “blended instruction” group (traditional lectures plus ILDs), which was made up of all students who had attended the lectures plus ILD activities in 2006-7 and had participated in the test, and the “traditional instruction” group (traditional lectures only), which was made up of all students who had attended the lectures-only stream in 2006 and had participated in the test. As shown in Table 1, students were asked to take the test after two hours of traditional OpAmp lectures but before the OpAmp ILDs (ILD pre-test) for the “blended instruction” group or before the remaining traditional lectures (Traditional pre-test) for the “traditional instruction” group. This meant that all students had been given some traditional instruction in OpAmp fundamentals before taking the pre-test. We felt that this was important as most students would not have studied OpAmps prior to this course. Students were then asked to take the same test at the end of the OpAmp section of the course (ILD post-test and Traditional post-test). This methodology is well established in physics education research (e.g., Hake, 1998).
The number of students participating in the study exceeded 50 for all group. Results were analysed to see if there had been any improvement between the two tests for the two groups of students. In addition to the pre- and post-tests, in 2006 we collated students’ comments from two focus groups. A total of 15 students took part in the focus groups. Finally, we administered a student survey to one of the introductory electronics groups that were taught via traditional lectures plus ILDs (including the OpAmp ILDs). 36 students responded to the survey questionnaire, which probed whether students felt that the ILDs were effective and useful.

Evidence of Success

The students in the focus groups were interviewed to gauge their perceptions in regard to the teaching effectiveness of our lecture, laboratory and tutorial classes in general, and the OpAmp ILDs in particular. The responses were generally very positive (and this was particularly evident when students discussed the OpAmp ILDs). Some of their comments concerning the OpAmp ILDs were as follows-

"With our lecturer, he… …actually set up an experiment to show us how it works and there was a sheet to fill in our predicted answer, like what we think it's going to look like, and then we conduct the experiment and get the actual answer and get that and compare it. And then on the bottom of it you have to explain why you think the answer will be like that, then why the result is the same or different. So you kind of know where you went wrong."

"It's more interesting, it engages you, it makes you wake up and you know, look at the board, look at the experiment..."

"I guess with the experiment it actually proves to you, it convinces you that that's the real answer...""

"It is good when we have to work with the people around us and he'll like give us a question and we have to find the answer and explain it to each other so then we get different ways of hearing how other people do it and understand it."

"not just knowledge in a book.... … visualise it, see it in action, picture it in action."

Student responses to the student survey questions were gauged using a 5-point Likert scale (ranging from strongly disagree to strongly agree). Students’ responses to the survey were generally very positive. For example, 91.7% of students agreed or strongly agreed that the ILDs were more helpful in explaining concepts that the traditional lectures; similarly 83.3% thought that ILDs did help them learn by discussions with their peers. The survey also showed that 83.3% of students wanted more ILDs in their electronics course.

The results of the pre- and post-tests for the “traditional instruction” group and the “blended instruction” group (lectures plus ILDs) are shown in Figures 4 and 5 respectively. Assuming binomial distributions and that the seven questions can be treated as independent items, the observed improvement for Q4,5 & 6 for the blended instruction group are statistically highly significant, while there is no statistically significant improvement for the other questions. For the traditional instruction group, none of the observed differences were significant at the 5% level. The observed overall trends
with this group may be significant but this has not been tested. Clearly while the pre- and post-test results are encouraging they are not conclusive and more research needs to be done before we can determine whether ILDs improve student learning in advanced electronics topics such as the OpAmp.

![Figure 4: Traditional Pre- and Post-test results](image1)

![Figure 5: ILD Pre- and Post-test results](image2)

**Reflections and Recommendations**

Our informal discussions with students indicated that our ILD OpAmp board was still a little too complex and that some students had trouble seeing the one-to-one correspondence between the circuits constructed on the OpAmp board and the figures in the worksheets, even when we covered up functional components on the board that were not directly relevant to the OpAmp ILDs (see Figure 3: upper-left and middle-bottom areas of the OpAmp board). We therefore need to redesign the board (or perhaps use multiple boards) to make it easier for students to follow the ILDs. Nevertheless student feedback suggested that they did appreciate seeing the circuits constructed in real time, and seeing actual measurements that could verify or refute their predictions.

We also find that year by year we are getting better at facilitating the OpAmp ILDs. 2006 was the first time we attempted the OpAmp ILDs and we acknowledge that we were still spending far too much time lecturing students rather than facilitating their discussions. We believe we are improving as facilitators and need to do some additional research to see if our effectiveness has also improved.

Our survey and focus groups seemed to indicate that many of the students appreciated our ILD strategy and that they seemed to be responding to the PODS learning cycle in the way we had intended. This is very encouraging as the ILDs were designed to get students actively thinking rather than passively listening, which is not always what students expect in lectures.

Our pre- and post-test results are inconclusive. One problem with our analysis was that, for the “traditional instruction” group, the number of students participating in the pre- and then post-test went from 93 to 53, whereas for the “blended instruction” group, the participating students went from 110 to 119. The drop in numbers for the “traditional instruction” group possibly indicates that most of the students who did the post-test were still following the lectures, and that the rest just stopped coming to class. On the other hand, the slight increase in numbers for the “blended instruction” group is possibly an indication that a few students who were not regularly attending lectures came and did the post-test when they heard that something new was being tried in class. One solution to this problem might be to anonymously track pre- and post-test pairs for each student who attempts the tests.

A more serious problem is that we believe that several of the questions in the pre- and post-tests were too difficult and overly complex, and that many students struggled to answer them. Question 1 was particularly poorly answered. This question was related to the OpAmp’s open-loop gain. Most students were confused about this concept, and thought that the open loop gain only referred to OpAmp circuits with no feedback loop. So we clearly need to emphasise that open loop gain is an intrinsic property of the OpAmp regardless of the circuit. Question 2 was very complex requiring students to understand how an OpAmp circuit changed from a comparator to a non-inverting amplifier.
when a switch was closed. This question seemed to involve too many conceptual steps for the majority of students and showed little improvement between pre- and post-tests. Question 3 involved a simple OpAmp voltage follower circuit: the voltage follower was not specifically discussed in lectures— at least with the “blended instruction” group. We were disappointed that the ILDs did not improve our students’ ability to answer this question, as the concepts covered in the ILDs were of direct relevance to this question. Questions 4, 5 and 6 all dealt with determining voltages and currents at various points around the OpAmp inverting and non-inverting amplifiers, and comparators. These simple circuits were discussed in both the “blended instruction” and the “traditional instruction” groups and it is encouraging to see improvement in the percentage of students answering these questions correctly. It is interesting to note that there was a marked improvement for students in the ILD classes; clearly students participating in ILDs seemed to have a good understanding of the ideas covered, although they may not have been able to synthesise these ideas to solve problems in unfamiliar situations (like question 3), at least without further independent study. Question 7 was a very challenging question about OpAmp comparators requiring a synthesis of several different concepts, and so it may not be surprising that there appeared to be little or no improvement in the post-test results for either group. Overall, it appears that ILDs can improve student learning. Further investigation is needed to determine the extent to which our blended approach (traditional lectures plus ILDs) improves the conceptual understanding of students and their ability to analyse unfamiliar circuits.

References


Acknowledgements

We would like to acknowledge the support and valuable advice received from our colleagues in the Engineering and Science Education Research (ESER) Group within the Faculty of Engineering and Industrial Sciences (FEIS) at Swinburne University of Technology. We would also like to acknowledge financial support for this project from Swinburne’s LTPF and FEIS.

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