CDTL Brief

Centre for Development of Teaching and Learning February 2001, Vol. 4 No. 1

Aims of Laboratory Teaching

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The teaching of laboratory courses in engineering and science is perhaps the weakest links in the chain of education. Touted as components essential for giving a practical orientation to education, there appears to be a lot of confusion regarding their aims and objectives. For an instructor, laboratory teaching is a low-priority job which does not contribute to his professional development, is largely boring and repetitive and to which his students are completely apathetic. The students view laboratories as boring but *cool* components of their curriculum, not intellectually challenging but involving multiple chores. But unfortunately, in spite of constant lip service paid to it, nothing much is attempted to improve the situation.

Many colleges complain about the lack of resources, modern equipment and infrastructure as the factors responsible for the malaise. This is true, to a degree, but not the whole story. It is believed by some that the root cause of the problem is a lack of clarity of the objectives and the resultant poor design of the pedagogical contents of laboratory instruction. These objectives can be classified into three categories:

1. Teaching of the *experimental method* (EM),
2. Supplementing the theoretical material covered in the lectures, i.e., essentially as a teaching aid (SL), and,
3. Incidental aims (IA).

An attempt has been made to classify the various possible specific aims of laboratory instruction into the above three categories (c.f. Table 1 below).

TABLE 1

Specific Aims

Familiarisation with	
• standard equipment	EM
• measuring technique	EM
Illustration of	
• physical phenomenon	SL
• concept taught in lectures	SL
Teaching of	
• attitude to experimental work	EM
Providing	
• closer contact with faculty	IA
• stimulation to independent thinking	IA
• feel of R & D labs	IA
Training in	
• observation	EM
• deduction from observation	EM
• critical awareness	EM
• keeping lab notebook	EM
• writing reports	EM
• acquiring specific information	EM

Next, we need to look at the cognitive levels of various objectives. For this we use Bloom's taxonomy for objectives in the cognitive domain (c.f. Table 2). It is quite difficult to assign the levels to the various objectives outside a specific context. Various persons at various levels, from technicians to researchers and even Nobel laureates, conduct experiments and therefore, depending upon the context, the cognitive level of an experiment should change. The level of the various objectives for experiments in a teaching laboratory should depend on who is being trained. Thus, a technician being trained to do routine well-defined experiments needs training only at levels 1 and 2 or, maybe 3. But the training of engineers, if carried out at such low levels, is not going to lead to any meaningful development of the requisite skills. It is believed that the present state of the all around dissatisfaction with laboratory teaching in the engineering colleges arises essentially because of the low levels in the cognitive domain that the various teaching objectives are aimed at.

TABLE 2

Bloom's Taxonomy for Objectives in the Cognitive Domain

Level 1	Knowledge
Level 2	Comprehension
Level 3	Application
Level 4	Analysis
Level 5	Synthesis
Level 6	Evaluation

It appears that the present day laboratory experiments are largely aimed at reinforcing the lecture material and not to teach the experimental method, which should be the logical aim of a laboratory course. The two aims are indeed quite conflicting. The first calls for a large number of experiments while the second calls for large amounts of time for experiments, the two being necessarily opposed. Similarly, if a large number of experiments are to be conducted, detailed instructions must be given so that students do not waste their time. But the teaching of experimental methods needs time for self-discovery with little set instructions, if any.

A major problem with all lab experiments is that they do not attempt to challenge students sufficiently and the whole exercise is at a rudimentary level. Vital aspects such as designing the apparatus, decisions on what measurements need to be taken and what variables need to be controlled are not addressed by the students. In fact, a student has no control on the experiment, including how the tests are to be conducted or how the accuracy is to be estimated. Students are given no opportunity to think for themselves.

It must be understood that familiarity with standard equipment, measuring techniques and use of standard calculating procedures are essential, but are all part of lower-order learning. Carefully developed demonstrations, videotapes, etc. can easily fulfil these needs.

The training of an engineer requires higher-order learning of the experimental method at the analysis, design and evaluation levels. An experimental course should teach students that (1) there is an experimental methodology, (2) it is field-independent, (3) it is reliable, and (4) it should be followed through with students making decisions at each stage from formulating the objectives to analysing the results.

I recently had an opportunity to teach a course on Experimental Aerodynamics and reformulated the instructions to the various experiments. The sample on the next page gives an extract from the general instructions given to the students before the course.

General Instructions

You are required to complete a set of experiments as detailed below. A new strategy is being attempted this term in which only the broad goal of each experiment is given to you. You will be required to plan your experiment around the equipment being made available to you. For best results you are advised to study the available equipment before the date of experiment, and to talk to the instructor. Make sure you understand the range of physical variables available to you for control and to plan your experiment in details before you come to the lab for experiment. Discuss your plan with your instructor before you begin. He may suggest modifications or he may not, depending upon his judgement as to the learning value of any mistakes that you might make.

This strategy has been adopted in the hope that it will offer you more control of the decisions that need to be made in any experimental investigation and that it may lead to a more efficient learning about the experimental method, which is seen as one of the more important learning objectives of the course.

Planning of an experiment requires fixing the values of the various parameters that control the experiment: speeds, diameters, angles of attack, etc. These are usually fixed depending on the range of non-dimensional similarity variables of interest. Therefore the first thing that needs to be done while planning experiments is to determine the range of control parameters available to you, and then decide the values that you are going to use so that the similitude parameters are within the desired range.

As it is made amply clear, the students are not spoon-fed the procedure. They devise their own theory, measuring strategies, number of measurements, and formulae to be used. The process takes a lot of effort, heartburn, exploration, errors, and accusations, but ultimately produces the joy of discovery.

Another deviation from the previous courses was requiring the students to make calculations of the error bounds using standard procedures for single-step experiments and for multiple-step experiments using statistical procedures. It was found that this perhaps is a single most educative step in a laboratory course where the students understand the limitations of their data, procedure and equipment.

The general instructions also include the following:

> *In addition, each student is expected to submit TWO experiments written up as formal reports, as if they were communications to a technical journal. The format specified for the technical notes in the AIAA Journal is to be followed. This would count for 20 points.*

I can confidently state that the course run was quite satisfying to both myself and the students.

In conclusion, it is important to look seriously at the aims of laboratory exercises, and to verify that there is enough there to teach at the higher levels of the cognitive domain. It is important to recognise that the primary aim of laboratory instruction is to teach the science and art of experimentation. Another core aim of a laboratory course is to teach students the art and science of experimental error estimation to guide them in planning better experiments. Another incidental purpose that a lab can fulfil is to teach formal written communication. ■

Demonstrations and Active Learning During Lectures

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Should lectures merely transmit information that is already printed in the textbook? Do our students actually learn during class time, or do they simply feverishly scribble down everything we say, hoping somehow to understand the material later? Can large lectures be thought-provoking, or only sleep-inducing?

Although there is considerable evidence that traditional approaches are often ineffective, most undergraduates in universities worldwide continue to be taught in lectures, often in large classes with more than 100 students. Alternative approaches such as *Workshop Physics* (Laws, 1991) that eliminate formal lectures have been used successfully, but substantial structural changes in the curricula are required for large universities such as NUS to implement such programmes. I shall describe my attempts to help enhance student learning of physics within the existing lecture/tutorial structure at NUS based on my experiences in teaching an introductory physics module to a large class[1] . Many of these ideas may also be useful in the teaching of other laboratory-based courses.

Lecture Demonstrations

There is often no better way to engage a large undergraduate class at the start of an early morning 2-hour lecture than with a well-chosen lecture demonstration. For example, I have demonstrated how to pull a ten dollar note from under an inverted bottle without toppling it (Newtonian mechanics), scooped freezing liquid nitrogen at -196 ½C from a dewar with my bare hands (Thermodynamics), and played yo-yo (rotational dynamics) in class. Of course the particular demonstration is chosen to highlight a physics concept that would be expounded in the lecture, and students are invited to provide a physical explanation. This normally results in a discernable increase in the attentiveness of the audience, especially since my lectures often start at 9 am, a time when most of the audience is brain-dead!

My suggested plan for an interesting lecture demonstration involves these steps:

1. choose a simple but effective demonstration that students can relate to in their daily lives;
2. begin by posing a question or asking for a prediction of the outcome;
3. get a student volunteer to help;
4. do the demonstration;
5. ask again for explanations;
6. provide a general explanation on why it works (or does not); and
7. invite students to submit a more detailed explanation.

[1] PC1131 *Physics I*, web page URL: http://www.physics.nus.edu.sg/~phyweets/PC1131.html

Do not take longer than 10 minutes for the whole event in order to sustain interest, and flow quickly into the main body of your lecture. Regarding point (3), insurance might be useful since a student was hit by a water rocket in my class! For a 2-hour lecture, posing a question using a demonstration before the half-time break encourages discussion and self-experimentation to continue.

Active Learning

While engaging the audience is important, we must create an active learning environment throughout the lecture class. How can this be done in a large class? Sokoloff and Thornton (1997) have developed a teaching and learning strategy called *Tools for Scientific Thinking Microcomputer-Based Interactive Lecture Demonstrations (ILDs)*. They used real-time data made possible by microcomputer-based laboratory (MBL) tools to engage the students during a lecture, and convert the usually passive lecture environment to a more active one. Briefly, the steps of their procedure are:

1. describing the demonstration without MBL tools;
2. getting students to record their individual predictions in a Prediction Sheet;
3. letting students engage in small group discussions;
4. getting students to record their final predictions as a result of their discussions;
5. eliciting common student predictions from the class;
6. performing the MBL measurement, suitably displayed;
7. students filling out the Results Sheet; and
8. instructor discussing analogous physical situations based on the same physics concept. The authors reported that student understanding of physics concepts are significantly improved when such ILDs are used in lectures.

The Use of IT and the Web

While there are several commercial MBL and other teaching software packages available, the lecturer must be comfortable using them in his/her lecture. It would be ideal for each lecturer to develop his/her own software package, but this takes substantial resources and time. I chose not to use such commercial packages, but have preferred to be selective about my resources to suit my individual style. Nevertheless, the principles of active learning described previously can still be applied. The Internet is a rich and free source of computer-based lecture demonstrations that can be selectively used in the lecture. All that is required is a computer (and projector) with an Internet connection in the lecture theatre; this is readily available in many NUS lecture theatres. An example of a good Internet source that I have used to illustrate physics concepts is *The Virtual Laboratory*[2] which contains numerous links to Java Applets for visualization and demonst ration in physics. Such tools are particularly useful when it is not physically possible to do a real demonstration, for example in demonstrating the kinetic theory of gases[3] or when showing the motion of charge carriers in a transistor[4].

On the use of IT in general, I wish to reiterate the fact that IT is just a tool and the web is just another medium of information communication. Even the most sophisticated use of IT will not a good lecture make. Delivering a good lecture is as much an art as a science, and enthusiasm and commitment are key ingredients for its success.

The Use of Questions

In order to address misconceptions about learning, Eric Mazur (1997) developed the method of *Peer Instruction*, which involves students in their own learning during lecture and focuses their attention on underlying concepts. Lectures are interspersed with conceptual questions, called *ConcepTests*, designed to expose common difficulties in understanding the

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[2] *The Virtual Laboratory*, web page URL: http://physicsweb.org/TIPTOP/VLAB/
Links to other resources can be found at http://www.ph.utexas.edu/~phy-demo/resources/resources.html

[3] This Java applet simulates a 2-dimensional gas of hard spheres: http://comp.uark.edu/~jgeabana/mol_dyn/KinThI.html

[4] A good site for the visualisation of semiconductor physics processes is http://jas.eng.buffalo.edu/applets/index.html

material. The students are given one to two minutes to think about the question and formulate their own answers. They then spend two to three minutes discussing their answers in groups of three to four, attempting to reach consensus on the correct answer. This process forces the students to think through the arguments being developed, and enables them (as well as the instructor) to assess their understanding of the concepts even before they leave the classroom. Meltzer and Manivannan (1996) made use of flashcards (labelled A to F) to elicit immediate student responses to questions posed during the lecture (with multiple-choice answers). These questions usually precipitate lively class discussion regarding the different choices.

When I pose questions to a large class, I often get good voluntary responses. I have also asked students to discuss concepts in small groups during the lecture, which turns the usually quiet environment into a "fishmarket"—a desired outcome! Naturally this activity has to be selectively used or the lecturer may not be able to cover much ground in class.

Concluding Remarks

I have briefly described how the use of demonstrations, IT and questions can promote active learning during lectures. The ultimate objective must be to facilitate student learning. If this focus is lost, then the use of even the most sophisticated techniques can distract rather than help the learner. A good lecture has to be well-orchestrated and rehearsed, incorporating the most suitable means to facilitate learning. It involves much effort and character building, but is nevertheless rewarding. ■

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We take this opportunity to thank you for your continued support, and we hope that our future issues will generate further discussion and reflection on improving teaching and learning in higher education.

CDTL

The Centre for Development of Teaching and Learning (CDTL) engages in a wide range of activities to promote good teaching and learning at the National University of Singapore, including professional development, teaching and learning support, research on educational issues, and instructional design and development.

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Printed in Singapore by Grenadier Press Pte Ltd.