Achieving Effective Learning in Engineering Laboratory Classes

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ABSTRACT

This investigation looks at how effective lab classes are in the Mechanical Engineering courses at Queen's University Belfast in the context of modern approaches to engineering education. The laboratory program here is of a traditional type, where students work through a number of separate three-hour lab classes associated with their engineering science modules over the semester. The laboratory exercises (29 in total) are grouped according to whether they are 'demonstrations'; 'controlled exercises' or a 'structured investigation' (a more open exercise where students must plan all or part of the experiments). Student feedback was sought on each of the exercises to evaluate how effective the learning had been in each case. The majority of labs, as with most traditional programs, are controlled investigations and these varied in the extent of active learning and exposure to problem-solving or real-life application. The student feedback correlated strongly with the degree of active learning and relationship of the exercise to a real engineering problem.

The laboratory evaluation also examined more generic 'aids' and 'barriers' to effective learning in lab classes. The effectiveness of the lab demonstrator/facilitator was clearly highlighted as being an extremely important factor to the student learning experience. Another issue which clearly impacts on the motivation of the students to learn is the nature of the lab assessment. In most cases students are required merely to follow the steps given by the manual/demonstrator so there is very little opportunity to assess students' contribution and skills. As a result, there is very little divergence in the individual marks allocated to students and little motivation for the students to actively engage in understanding/analysis/discussion of the lab.

Using the results of the student feedback and evaluation, general practice in setting-up a laboratory exercise has been identified and suggestions given for future improvement over a traditional lab programme.

KEYWORDS

lab classes, active learning, reflective learning, constructive alignment

INTRODUCTION

The laboratory programme investigated in this work applies to years 1 and 2 of the undergraduate courses in Mechanical Engineering at Queen's University Belfast (QUB). Approximately 80 students are enrolled in each year and these are divided into groups of five or six for the lab classes. Each lab lasts for three hours and groups rotate between the classes on a weekly basis throughout the semester; therefore different groups will cover different labs at different points during the semester. The laboratory programme is not part of any specific module but is intended to support all the engineering science subjects (Materials, Mechanics, Fluid Dynamics, Thermodynamics), with some labs aimed at more general, transferable skills (presentation skills, teamwork). Students are marked out of 5 for each engineering science lab and the average mark contributes to 5% of the overall mark for each of the aforementioned modules. The labs are run by Ph.D. students who allocate marks to each individual based on their contribution to the class. Laboratory classes occupy more than 10% of the timetabled hours for Mechanical Engineering students over the first two years of the course, hence it seems important to examine whether this significant time resource is used effectively.

The role of lab classes in engineering education

The roles of laboratory classes in engineering education have been discussed previously in the literature [1-2], with agreement on a wide range of goals including: learning scientific information; understanding the process of scientific investigation; learning technical skills (use of equipment etc.); appreciating the application of knowledge and methods; and developing communication and teamwork skills. However, there is a current need to address the role of lab classes within the context of modern engineering educational aims. A recent report commissioned by the Royal Academy of Engineering in the UK [3] has recognized that the UK is experiencing a shortage of high calibre engineers (despite increasing numbers of graduates post-1992). This report has identified a need to

'provide more experience in applying theoretical understanding to real applications and the open ended problems faced by industry' in engineering courses'.

The CDIO Initiative was developed with input from academics, industry, engineers and students and informs a framework of curricular planning and outcome-based assessment which emphasizes experiential and hands-on learning and, as such, promotes active and interactive learning techniques. The CDIO syllabus further emphasizes 'Problem Solving', 'Systems Thinking' and 'exposure to Conceiving Designing Implementing and Operating engineering systems' as key skills for students. As the lab programme comprises a substantial part of the interactive and 'hands on' element of learning for the early years of an undergraduate programme then alignment with these goals is important.

What is effective learning?

The Institute of Education [4] puts forward the following definition of effective learning:

'reflective activity which enables the learner to draw upon previous experience to understand and evaluate the present, so as to shape future action and formulate new knowledge'.

The key features highlighted in this and other definitions [e.g. 5] include:

- An ACTIVE process
- Involving REFLECTION on what has been learned to make connections between previous experience and present or future situations

In this light, the lab program in Mechanical Engineering is evaluated in terms of whether it aligns with the learning aims of modern thinking in engineering education and whether it offers sufficient opportunities to involve students in active learning processes and develop skills in self learning. It is important to examine issues which impede attainment of these goals and identify methods which result in more effective achievement of these learning aims.

EVALUATION OF LAB CLASSES

The evaluation of the Mechanical Engineering lab classes has been approached in a number of different ways.

1) Individual labs were evaluated by examination of the lab manuals to determine opportunities for learning and by student feedback.
2) General feedback from students was sought on the overall lab programme in terms of the CDIO syllabus.

Breakdown of individual lab classes

According to the UKCME (UK Centre for Materials Education) Lab Classes Guide [6], there are three types of lab class:

- Demonstrations – containing little of no student participation
- Controlled Exercises – Students are given instructions to carry out an exercise which has a known outcome
- Structured Investigation – The method of investigation is more open to the students, they are required to plan all or part of an experiment.

It is useful to group the lab classes in these categories and consider the relative strengths and techniques of each.

A number of the classes are largely demonstrations (e.g. of CAM and CAE software), where the students have little opportunity to actively get involved in the experiment. These types of laboratory class were largely unpopular with the students as they felt the material was irrelevant to their studies, and the demonstrations were not engaging. Many students also commented that for a number of these labs the material could easily be covered in the classroom and appeared to feel that this was a waste of laboratory time. Within these labs there was very little opportunity for the students to engage in active learning processes; student comments included '*we just followed instructions*' and '*learned nothing useful*'.

A large proportion of the labs fall under the category of 'controlled exercise' where students had more participation but followed a defined step-by-step methodology. These labs were generally associated with application of theory covered in lectures to a practical situation. This type of investigation was most popular when students found the theory particularly difficult (with many stating that they were able to understand the theory much better from taking part in the experiment than from lectures) and when the theory would be examined. Students also emphasized that good handouts and clear description of the theory was important. Students also appreciated when this type of lab class was clearly associated with a real-life application, for example in the case of engine testing, analysis of beam loading etc. Conversely, some labs had a very clear 'real-life' application (for example, selection of the most suitable material for a particular function by testing the physical properties of a number of different options), however this did not guarantee that the students found it interesting if they themselves did not have much opportunity to participate in the experiment or if the theory was quite simple and undemanding. Another example involves investigation of the properties of steam, which was pointed out to the students as being extremely important to power generation; however students found the actual experimental procedure boring, complicated and irrelevant. The electrical engineering labs which demonstrate circuit analysis techniques and electromagnetic theory were also unpopular. Students commented that the experiments did demonstrate the lecture material quite well but found them long and tedious and many failed to see any relevance of studying electrical engineering as part of a mechanical engineering degree.

Very few of the lab classes involved a more open, problem solving approach as associated with a structured investigation. A few good examples are present in the second-year program, which includes a competitive team exercise to design and build a beam with the best strength-to-weight ratio, and an assignment to design the optimum length of tripod legs where they are required to apply theory covered in class. These types of investigations are very popular with the students, who stated that they found them enjoyable and felt they promoted better understanding.

Evaluation of the overall lab programme

A large number of students (42 first years and 31 second years) were asked to evaluate the lab programme of their current year of study at the end of the year. The aim here was to look specifically at how well students felt that the lab classes gave them exposure to the key elements of the CDIO syllabus. They were asked to what extent they felt the lab programme in that year of study had developed the following:

- Technical Knowledge
- Problem Solving
- Experimental techniques
- Systems Thinking
- Professional skills
- Teamwork/Communication Skills
- Exposure to Conceiving Designing Implementing and Operating

The results are displayed in Figure 1.

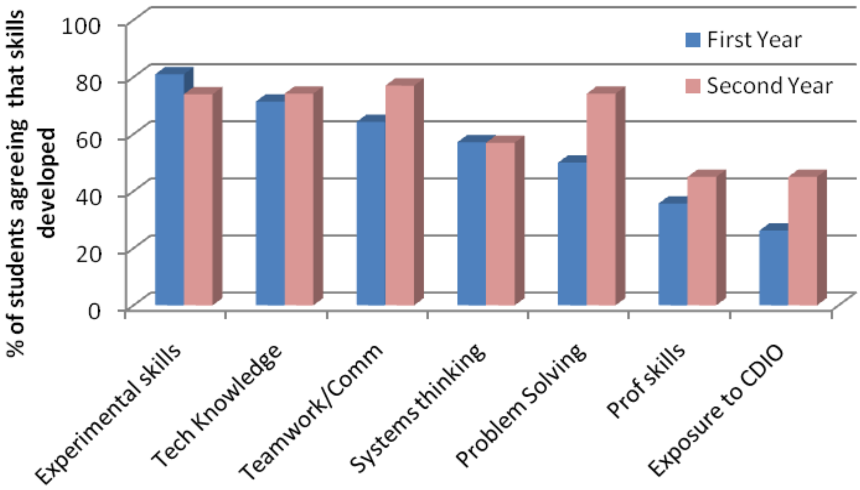

Figure 1. Percentage of students who agreed the lab programme gave them exposure to specific skills.

First years felt that the lab classes gave them good exposure to the traditional aims of lab classes: experimental techniques; Technical Knowledge; and Teamwork/Communication. However, the more aims more specifically associated with the CDIO syllabus were rated much weaker; only about half the students felt they'd had exposure to Systems Thinking and Problem Solving. Perceived exposure to Professional Skills and CDIO was even lower (36% and 26% respectively).

The results from the Second year evaluations were similar, except that there was much stronger agreement here that they had had an opportunity to develop problem solving skills. There was some improvement over the rating by First Years in the perceived exposure to Systems Thinking; Professional Skills and CDIO but again less than half the class agreed on these points.

Specific positive comments from the First Year students included gaining a better understanding of theory; having some good demonstrators; and they enjoyed working in small groups and meeting new people in the class. However there were also a lot of negative comments, with some labs being '*long and dull*' being the most frequently cited complaint.

Another common complaint related to the timing of labs – due to the rotations some groups covered certain labs before the theory was covered in lectures. Poor demonstrators in some cases also featured as one of the worst aspects of the lab classes – suggesting that the performance of the individual demonstrators can have a major influence on how much students get out of the lab. Other comments included '*lack of autonomy*', '*stress due to poor understanding*', '*not much analysis of results*', '*wanting more discussion and less dictation*', '*some labs rushed and poorly explained'*. There was also a worryingly high number of references to '*pointless calculations and pointless graphs*'. There was also a suggestion that most students lost interest after lab reports were submitted (essentially meaning that there were no further demands for assessment except to turn up).

Some of the feedback from Second Years was very similar; on the positive side with applying theory to practice, gaining better visual understanding, and exposure to 'hands-on' learning. On the negative side, timing was again a common complaint, some too long/dull and some poorly explained, were also echoed, as were sentiments relating to the lack of demonstrator enthusiasm and in some cases poor ability to explain the experiment. Some labs were seen as 'pointless' and one response stated a lack of creativity and interest in the lab program. There were conflicting responses from some students who felt they were given too much help and others who felt they were 'thrown in at the deep end' in some topics. Suggestions from students included affording a greater element of discovery for students; updating equipment; and including more project work.

IDENTIFIED BEST PRACTICE

It was clear from the student feedback that there are many shortcomings associated with the lab programme, however there were a small number of labs that were very popular with the students and which aligned well with the CDIO objectives. The most positive feedback related to the open investigations in the second year course which involve the students in active learning processes and more open-ended problem solving. The best example is a 'Beam Design and Test' lab – this involves students working in teams which compete against each other to design and build a beam with the best strength-to-weight ratio. The investigation is spread over three weeks: in the first the students work on the initial design of the beam and are encouraged to use the theory they have covered in lectures. In the second week, the students test their beam and are given an opportunity to identify the weaknesses and develop an improved structure. The final test is then carried out in the third week and students are encouraged to reflect on why certain designs performed better or worse than others. The teamwork and competitive aspects of the task make it an enjoyable one for the students and they felt it fostered greater understanding of theory than other more controlled investigations. This is one of the few labs to involve the students in both active and reflective processes and is an excellent example of applying Kolb's learning cycle [7] which states that learning requires a process of 'Doing, Reviewing, Learning and Applying'. Students have a valuable opportunity to learn from trial and error and from making mistakes [8]. This task allows appropriate amounts of support to be given to individual students to maintain interest and challenge yet ensure understanding – more help given to those who need it – either by their peers or by the demonstrators. An important aspect of the investigation is that the students are not led to any 'right' or 'wrong' answer; rather students are given the opportunity to 'construct' knowledge for themselves. Humans are '*active meaning makers*' [9], and according to Jackson [10] '*teachers must provide a learning environment where students search for meaning, appreciate uncertainty and inquire responsibly*'.

That said, the 'controlled investigations' are not without value. In these cases students were asked to follow a step-by-step procedure to arrive at a pre-determined result. This approach is not completely without merit; 'Doing' is a key factor underpinning successful learning [8] and obviously undergoing a practical process offers possibilities for greater depth of understanding than purely theoretical work. This is particularly true as some students will have a natural preference for 'learning by doing' [11,12]. Therefore physical experience of theory covered in lectures ensures that these learners who may struggle with written or oral explanations in the classroom have an opportunity to learn in a way that suits them. This is supported by several comments from students to the effect that they understood theory much better after covering it in a lab. However, such a 'closed' approach to laboratory investigation results in a fairly limited learning experience; student feedback indicates that many are bored and unchallenged by lab classes and want greater opportunities for discovery and to exercise initiative. Labs demonstrating pertinent aspects of the theory should not be discarded but ways of making them more active should be considered, while other demonstrations may be better delivered in tutorial classes or in lectures using video clips etc.

AIDS AND BARRIERS TO EFFECTIVE LEARNING

The evaluation of the lab classes highlighted a number of different issues impacting on achievement of learning aims. Firstly, the role of the lab demonstrator was clearly highlighted as being extremely important to the students. Lack of understanding and lack of interest in the lab was often due to poor explanations, lack of enthusiasm and rushing the lab on the behalf of the demonstrator. Lab demonstrators are given no training in small group teaching and preparation may well be limited to receiving a copy of the lab manual from the course lecturer. As a result, the postgraduate demonstrators may be ill-prepared for the lab in terms of the aims and objectives and may be ill-versed in the theory. Therefore, any attempt to enhance the content and structure of the lab programme should also address training of those delivering the teaching.

Another issue which clearly impacts on the motivation of the students to learn is the nature of the lab assessment. It has been stated that "*Assessment defines what students regard as important, …If you want to change student learning then change the methods of assessment*" [13]. As in most cases students are required merely to follow the steps given by the manual/demonstrator there is very little opportunity to assess students' contribution and skills. As a result, there is very little divergence in the individual marks allocated to students and little motivation for the students to actively engage in understanding/analysis/discussion of the lab. It has been argued that the descriptive nature of lab reports can lead students to adapt lecture notes as opposed to thinking in a reflective way about their work; alternative lab assessments including on-line quizzes and short hand-ins have been found to result in higher levels of student motivation and understanding [14]. If we want to develop skills in engineering practice and applying theory to solve problems we need to design assessment aligned with these aims [15].

CONCLUSIONS AND SUGGESTIONS FOR IMPROVEMENT

- The lab classes in Mechanical Engineering at QUB provide better understanding of theory by giving the students a chance to learn through practical experience.
- Effective learning is limited by the dominance of controlled experiments in the lab programme which do not engage the students in active learning processes.
- Some good examples are evident of laboratory activities which support modern engineering educational aims of enabling students to tackle open-ended problems and apply theory to 'real-world' engineering practice. Student feedback indicates that they want greater opportunities to exercise initiative and creativity through this type of exercise.
- Student feedback has highlighted the importance of the laboratory demonstrator in achievement of effective learning from the lab class.
- The nature of laboratory assessment should be addressed to align student learning with the modern aims of an engineering education.

In attempting to improve the lab programme, current experiments should be assessed first in terms of whether they afford an opportunity for students to engage in active and reflective learning process. Can the lab be adjusted in some way to make it more open-ended and give the students an opportunity to make mistakes? Could the relevance to real-world engineering problems be made stronger? If not, perhaps the experiment could be better demonstrated in a lecture/tutorial class.

With the current, traditional, lab programme many key skills are not being realised strongly enough. Our students struggled to understand the relevance of other disciplines (Electrical Engineering); to appreciate the links between the various aspects of engineering science in system and to understand how theory applied to Conceiving, Designing, Implementing and Operating systems. A fairly radical shake-up of the programme is necessary to imbed these skills and the need for more open-ended project work is clear. There is a need to move away from the standard 3hour exercises executed on a ‘round-robin’ basis throughout the semester. An alternative approach may be to run a more limited number of projects, similar to the beam test, were students work on planning, testing and redesign over a period of weeks and are given appropriate levels of support from tutors in a facilitator role. A staged approach, whereby students are given a lot of guidance in early labs in order to equip them with basic skills, going on to structured investigations and ultimately project work has implemented in some engineering schools [16]. Obviously there are challenges in covering all aspects of the curriculum and in timetabling and resources which require creative solutions – for example students could be divided into different groups to select from a variety of project investigations which they would then teach to their peers.

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Biographical Information

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P.J. Armstrong (RIP) was a Professor and Director of Education in the School of Mechanical and Aerospace Engineering. A leading figure in the international CDIO initiative and a driving influence for educational reform within his own department and beyond, he is sadly missed by his colleagues and peers.

Geoff Cunningham is a lecturer and Director of Education in the School of Mechanical and Aerospace Engineering at QUB. He has been active in the CDIO initiative for many years and is on the International Advisory Committee for the 5th International CDIO conference.

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