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8. Development of Student Centred Physics Labs from Years 1 to 4

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Abstract

Physics laboratories, with their usual relaxed atmosphere combined with the exploratory nature of physics should help to create a student centred learning environment in which the students develop the necessary lab skills. However in reality most physics labs, especially in years 1 and 2, are recipe driven and the students follow a set of instructions from a manual which require no or minimal student exploration of the physics involved. The assessment methods also appear to be misaligned as they often only assess the product (report and logbooks) and not the desired learning outcomes of the module.

During this project we evaluated and re-aligned the learning outcomes, teaching and assessment methods for years 1 to 4 of the physics laboratory programmes. We found that although they were aligned on paper they were not aligned in practice. We developed a new suite of first year experiments which are more exploratory based and build the students' skills so that they are able to work more independently by the end of the programme. A new first laboratory manual and corresponding tutor guide was also developed. In the higher years (2, 3, and 4) of the laboratory programme we identified core competencies, developed new experiments, and assessment methods. The assessment methods are more closely aligned with the laboratory learning outcomes.

Key words: curriculum alignment, exploratory, physics, laboratory, student centred

Outline Fellowship Project

Introduction

Physics labs, by their very nature, should be inherently student centred. The exploratory nature of physics should help to instil the students with a sense of learning by inquiry. The relaxed atmosphere in the lab, combined with this sense of exploration, should encourage a student centred learning environment in which the students develop the necessary lab skills. Unfortunately this is often not the case, as in reality most physics labs, especially in years 1 and 2, are recipe driven and students follow a set of instructions from a manual. There is often no or minimal student exploration of the physics involved. This problem seems to be compounded by the assessment methods which often appear to only assess the product (report and logbooks) and not the actual desired learning outcomes of the module. The implementation of modularisation in the Dublin Institute of Technology has also led to a misalignment of the development of lab skills up through the four years of the physics programmes. Concerns expressed by teaching staff over the past few years strongly suggest that physics students may not be achieving all the required learning outcomes through all four years of their physics programme. In addition, students who are taking physics labs as a service course might not be achieving these learning outcomes. As a result many of the key skills required by physics, engineering, chemistry and biology graduates are not being developed.

The aim of this project was to evaluate the current physics lab modules throughout the DIT's School of Physics, to build on the recent work in physics education research and to create a student centred physics lab programme from first to fourth year and across into its service courses. The project aimed to evaluate the development of lab skills from years 1 to 4 and look at the best ways to ensure that these skills and learning outcomes are achieved.

Approach and Main Findings

Curriculum misalignment: The first part of the project involved checking the alignment between the laboratory programme's; learning outcomes, teaching methods, and assessment methods. This was done for years 1 to 4, through both physics major courses and services courses, and in both level 7 and level 8 programmes. During this part of the work the learning outcomes of the relevant lab programme were compared to the teaching method (lab manual). Although various staff may interact with the students differently, it is the lab manual (or handout), its procedure and proposed method of analysis, which ultimately determines what the students do in the lab time. The assessment methods for each learning outcome were listed. It was possible to write down an assessment method for each learning outcome (LO), and on paper there appeared to be alignment between all three components of the curriculum matrix. However on closer inspection it was clear than many of the assessment methods were formative and did not appropriately assess the skill or learning outcome.

For example, in year 1 of the lab programme there is a learning outcome 'demonstrate the ability to use a micrometer'. The teaching method is to show/explain to the students how to use it and then get them to use it to measure the thickness of a piece of aluminium. There were three assessment methods listed with this LO: tutor questioning (formative), logbook (formative and summative), and formal report (formative and summative). However none of the assessment methods specifically test this learning outcome. The most obvious way to assess it is to get the student to measure something using the micrometer and see if they get the correct value. There were many examples of this misalignment between the three components of the curriculum matrix, although on paper it is possible for the laboratory programme to appear to be aligned. In general most of the laboratory learning outcomes, through all years of the programmes, were assessed using either logbooks or reports. While many desired lab skills, such as circuit building, use of equipment, uncertainties, were not directly assessed.

After talking to the laboratory supervisors from all years of the programme several concerns were also identified. Below are some examples and proposed solutions.

1. *The second year students did not have a rigorous scientific approach.* The suggested cause of this was that the year 1 experiments were too open-ended. The proposed solution to this was to change the teaching method in year 1 and strike a balance between structured, semi-structured and open-ended experiments.
2. *The students had a poor ability to use specific equipment.* It was noted that students can pass the lab programme without achieving this learning outcome. For example, analysis of the students' lab exam marks revealed that a student can get 40% (pass mark) in building an electrical circuit. However 40% of a circuit is not a circuit and it will not work. This is an example of misalignment of both teaching methods and assessment methods. The proposed solution was to increase the use of specific equipment, set them as core competencies (discussed below), and to continually evaluate these skills using the lab exam results in the future.
3. *The students have poor report-writing skills.* Although the students write between 20 and 30 lab reports over the four years of their degree the standard and quality of the reports are still very variable in their final year. This is despite report writing being one of the main assessment methods in all years of the lab programme. The proposed solution to this was to introduce a draft report step into the report writing system. This is a change in the teaching methods and is discussed later in this paper.

Teaching methods: The next phase of the project was to align the three components of the curriculum matrix. This involved changing both the ‘teaching methods’ and ‘assessment methods’ used in the lab programme. Changing the ‘teaching methods’ meant the modification of, or development of, new laboratory handouts. These were designed to not only help the students to understand the experiment, but also to allow them scope to explore the physics. It also led to the development of a new first year lab manual for the level 7 Science programme.

The new lab manual contained several new features. Firstly, the students had to complete pre-lab questions to prepare them for their lab session. These pre-lab questions were worth 20% of their mark. Secondly, direct instructions (structure) in the lab manual were present in early experiments but removed as the students progressed through the year. For example, early experiments contained a written experimental procedure (structured experiment), while in the later experiments the students had to design their own procedure (semi-structured). Also early experiments did not involve graphing, but graphing was introduced after a few weeks. The laboratory supervisors were also encouraged to question the students and draw out their knowledge instead of directing the students with instructions. Another noticeable change in the ‘teaching methods’ was that one of the experiments was removed and replaced by an in-lab graphing tutorial.

Assessment methods: In general most students are assessment driven. It is unusual for a student to try and achieve a learning outcome if they are not getting marks for it. What the lab supervisor thinks is important and what the students think is important are often two very different things. If the staff think that the ability to build a circuit is important, but they only grade the final report, then the student will put all their effort into the report. If there are marks awarded for doing something then it is important to the student. Awarding marks for the achievement of a learning outcome is one way for the staff to inform the students of what is important. With that in mind the learning outcomes are best achieved with both summative and formative assessment (with clear feedback). However, the assessment must match the learning outcome. Therefore, and it may seem obvious, if there are many different learning outcomes there needs to be an array of assessment methods to match them. Basically, one size does not fit all.

This project developed clearer curriculum matrices for years 1 to 4 of the level 7 and level 8 Physics programmes. Table 8.1 shows an aligned curriculum matrix for a typical physics laboratory. Specific years of a laboratory programme would have more detailed learning outcomes but the table shows generalised learning outcomes, teaching methods, and assessment methods. The table shows that different learning outcomes require various assessments methods. Also it is important that each learning outcome is taught in an appropriate way. It would be unfair to a student to assess a learning outcome when the teaching method does not promote the achievement of the learning outcome. A common example of this is the ability to use equipment. It would be unfair to assess a student on the use of an oscilloscope if they have only used it once during the year. The learning outcome (demonstrate the ability to use an oscilloscope) is valid, assessing it in a lab exam is valid, but only using it once (teaching method) causes misalignment. If the ability to use an oscilloscope is important to the staff, then the students should use it repeatedly during the course of their laboratory programme.

Core competencies: The idea of testing core competencies in the physics lab was based on DIT’s Optometry programme (DT224). Core competencies are skills which the students must possess (and demonstrate their ability to do) in order to progress to the next year. They are not graded but are either pass or fail. The students get up to three attempts to pass the core

competencies otherwise they must repeat the year. Several of these core skills were identified and the level of competency in the skill was identified for each year. For example the ability to use an oscilloscope was always considered as an important skill in a physics graduate and so it was set as a core competency. The competency level increases, as the students move from year 1 to 4. Such competency levels in using an oscilloscope are outlined below and are the minimum levels expected of the students.

Year 1: Read frequency and voltage values from an a.c. signal on an oscilloscope screen.

Year 2: Connections, channel selection and other settings, peak to peak amplitude, frequency.

Year 3 & 4: More advanced external trigger usage, internal and ring, Fourier analysis.

Learning outcome	Teaching method	Assessment method
Determine sources of experimental uncertainty and significant figures	Record in logbook, tutor feedback	Core competency and logbook
Use various instruments, e.g. oscilloscope	Use instruments (repeated and often) during experiments, tutor feedback	Lab supervisor and lab exam
Investigate the theoretical background to an experiment	Pre-reading and pre-lab questions, class discussion	Report and oral exam
Keep a well-maintained and instructive laboratory logbook	Use laboratory logbook, tutor feedback	Logbook assessment
Design experiments to test a hypothesis and/or determine the value of an unknown quantity	Move from structured to semi-structured to open-ended experiments	Lab exam

Table 8.1: An aligned curriculum matrix for physics laboratory

Report writing: As mentioned above, staff expressed concerns about the quality of the students' report writing. This is despite the fact that students write between four and ten reports per year, and that it is traditionally the main assessment method used in the physics labs. As part of this project a system of draft report writing was introduced to the first year of the level 8 Physics programme. The year 1 students usually write four reports on four separate experiments. They are also given a handout on how to write a physics lab report. The reports are marked and the students receive written feedback on where to improve their report writing. However in general the students are more interested in the mark they receive and pay little attention to the written feedback. As a result, the second, third and fourth reports often contain the same mistakes as the first report.

This year the staff decided to get the students to reduce the number of reports to two but get the students to submit two versions (draft and final) of the same report, both of which are marked. The reasoning was that the students are unlikely to ignore the feedback if they are re-submitting the same report. The average class marks for the reports, are shown in Table 8.2.

Report 1	Draft	Av. mark 51%
	Final	Av. mark 69%
Report 2	Draft	Av. mark 64%
	Final	Av. mark 79%

Table 8.2: Effect of feedback on report-writing marks

Table 8.2 shows that in general the students responded to the feedback on their first draft report and implemented the suggested changes by the staff member. This is indicated by the higher marks for the final version of the report than the draft version. This is probably to be expected. However the interesting result is that the average mark (64%) for the draft of the second report is similar to the average mark of the final version of the first report (69%). This suggests that the students remembered their feedback from the first report and implemented it in their second report. This result suggests that it is not the number of reports that is important but the response of the students to the feedback. The draft system with feedback (summative and formative) appears to be one way of achieving this.

Evaluation of Project and Main Outputs

The project was evaluated using several methods. As mentioned above, the new lab manual was piloted and specific lab skills were assessed. The effect of changes in either teaching methods or assessment methods, were evaluated based on the students' ability to perform the desired learning outcomes. Any changes which were judged to be effective, e.g. draft report writing, core competencies, new lab manual, will be expanded into other years and programmes. The proposed changes will be presented to the DIT's School of Physics in September 2010 and if accepted will be incorporated into the relevant programmes across the School of Physics. Many of the findings have already been presented to the DIT's Management Forum (May 2010) and the DIT's Showcase of Learning and Teaching Innovations 2010 (Jan 2010).

The main outputs were: (i) clearly aligned curriculum matrices for the lab programmes through years 1 to 4. (ii) A variety of assessment methods were developed to match the variety of learning outcomes. (iii) Core competencies were identified for years 1 to 4. (iv) A new exploratory based lab manual with tutor guide was developed and piloted.

Recommendations

The main recommendations of the project are the following.

1. Many of the lab's learning outcomes, teaching methods, and assessment methods can be aligned on paper while not being aligned in practice. It is important that effective learning does not get lost in a sea of paper and documentation. It is easy to achieve alignment of the curriculum matrix on paper, but this work has shown that with small changes in the assessment and teaching methods, that alignment can be achieved in practice too.
2. A variety of assessment methods are needed to match the variety of learning outcomes. This may sound obvious, but matching the appropriate assessment method to the desired learning outcome, and providing effective feedback, makes a

big difference. The 'one size fits all' approach to assessment of learning outcomes is very limited.

3. Core competencies are an effective way to showing the students which learning outcomes are really important. The pass/fail system removes the complacent attitude that 40% of a skill is okay.
4. The laboratory manual is a key teaching method in the laboratory. The way it teaches, and what it teaches, really affects the way students learn. Excessive direction leads to 'doing without thinking' and is the laboratory equivalent of rote learning. It is important that the students learn to think, as well as do. A progression from structured to semi-structured, to open-ended experiments is recommended.
5. It is important to continually evaluate the skills the students are developing. They need to be measured, recorded, and compared to previous years. This makes it easier to see whether changes in the laboratory's assessment and teaching methods are effective.

Proposed Future Work

All the goals of this project could not be achieved in one academic year. The project will continue and the proposed changes will be rolled out into all years and programmes throughout the School of Physics. The students' skills and achievement of learning outcomes will be continually measured. Hopefully this work will help to produce physics graduates which possess core lab skills and are self-directed learners. Ultimately the long-term goal is to develop a greater awareness of student centred learning in the School of Physics, not only in the laboratory but in all of its teaching spaces.