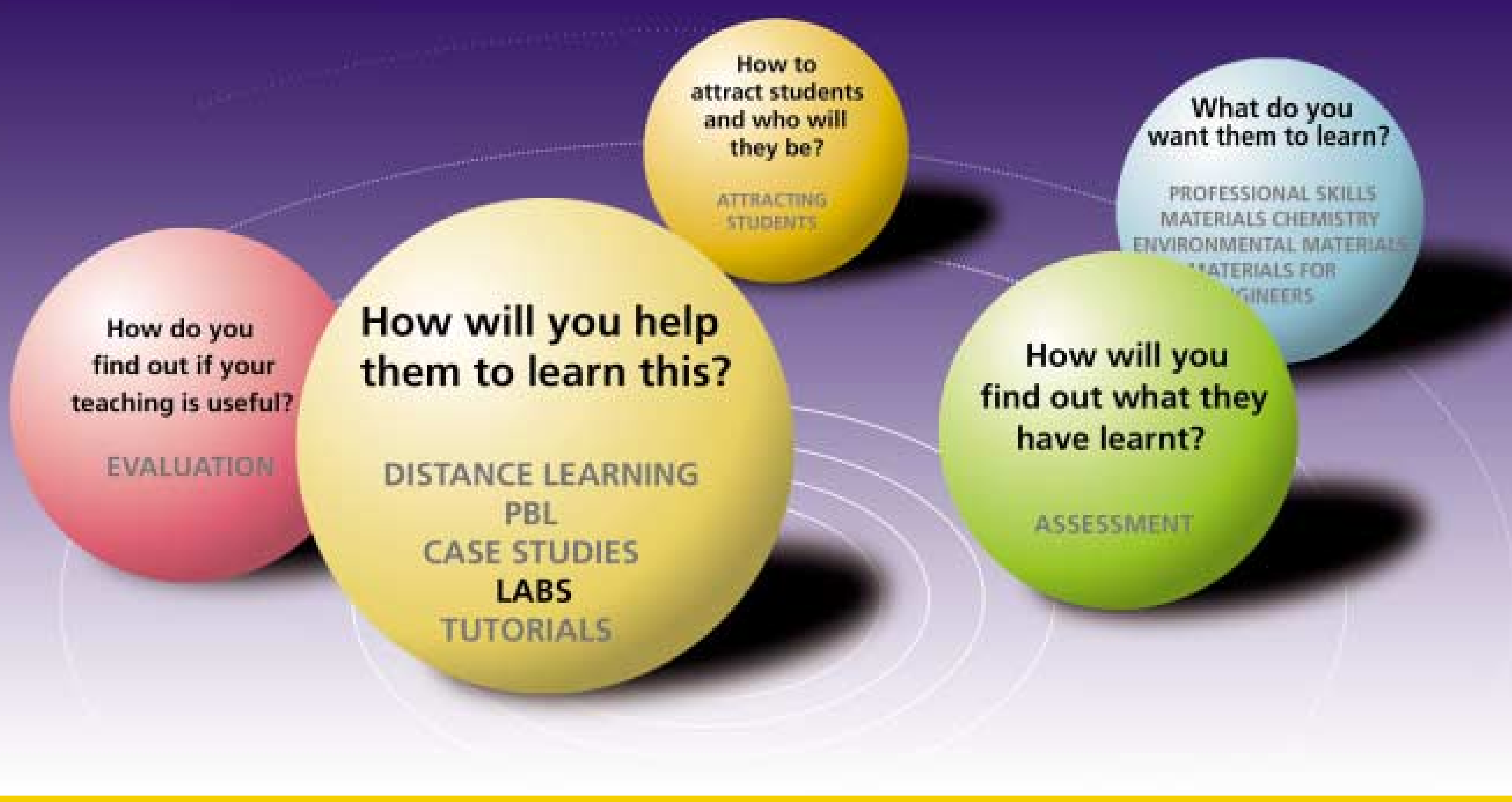
Teaching Materials Laboratory Classes

Caroline Baillie and Elizabeth Hazel



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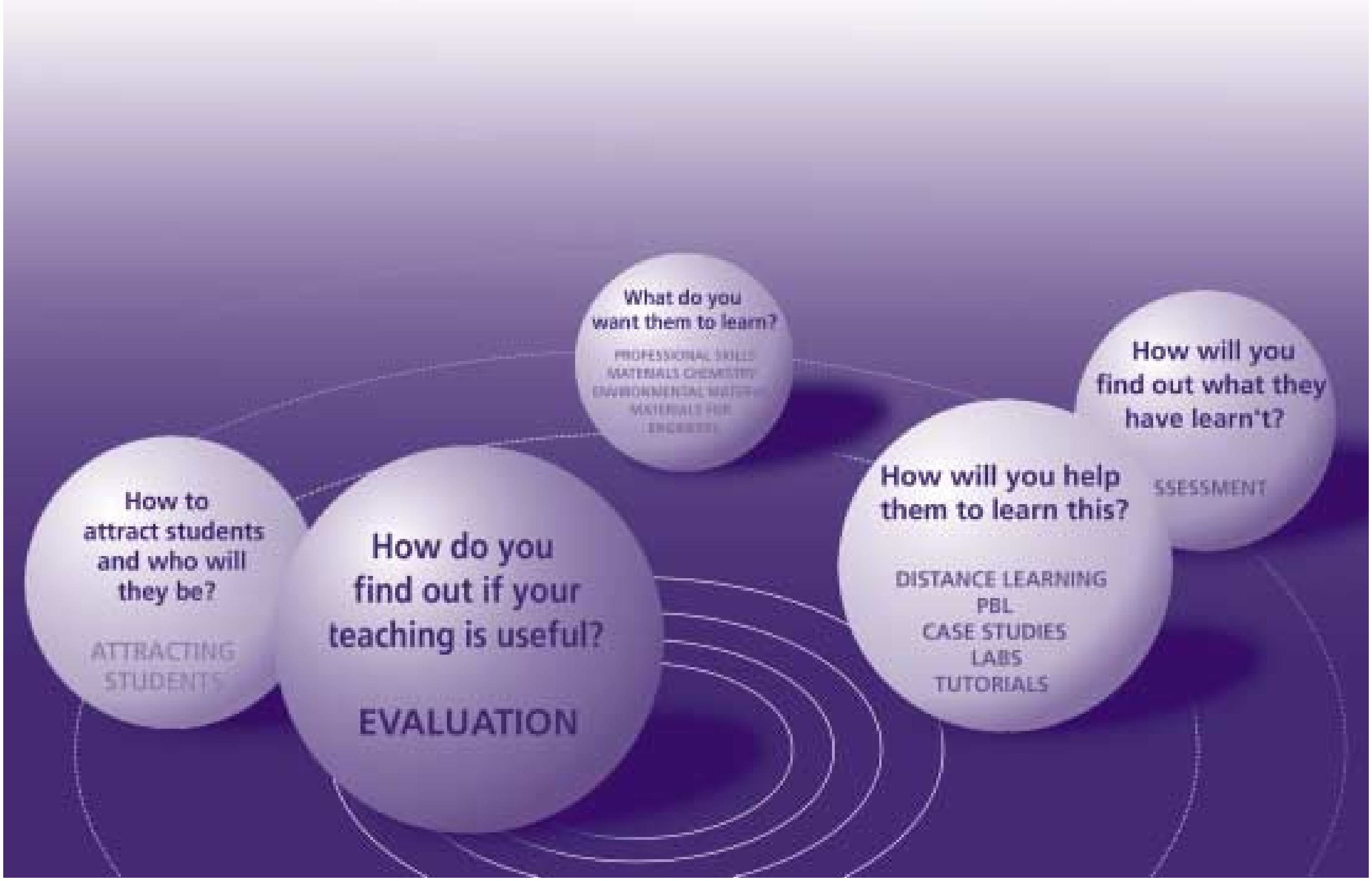
Controlled excercises

INTRODUCTION

Many of our community, lecturers in the disciplines of and relating to Materials Science and Engineering, have expressed interest in simple-to-use guides to support the workshops we run on learning and teaching. As part of our ‘Thematic Groups’ scheme, we have established 12 themes for this special focussed support, each of which is led by a ‘Thematic Group Leader’. During the first two years of the scheme, workshops have been held on these themes and this has enabled the leaders to further explore relevant issues with lecturers and feed the results into this series of booklets.

Learning and teaching is a continuous cycle represented in the diagram below:

We can start at any point around the cycle. If we are in the business of teaching it certainly helps if there is someone to teach! Not such a funny joke in the current climate with reducing numbers of students in technical disciplines. Hence one of our main concerns is how can we approach schools and work with school students to attract them into Materials areas. ‘Attracting Materials Students’ by Cheryl Anderson explores how we can work with schools and the wider community to ensure a diverse and inclusive group of able students on our courses. Once we have a class to teach, what would we like to teach them? The first reaction to such a question is to make a list of topics or knowledge. However, this is only a beginning, and a very limited one. Not only are there many skills and attitudes that we would



like them to develop, but learning is more complex than simply the what. It also involves the how. ‘Developing Professional Skills’ by John Wilcox explores the approach to empowering students to track their own skills development as they progress. ‘Materials for Engineers’ by Mike Bramhall, ‘Materials Chemistry’ by Stephen Skinner and ‘Environmental Materials’ by Cris Arnold, focus on what we might like to include in a specialised curriculum, for targeted students. The knowledge, skills and attitudes or learning objectives identified for each course must be assessed if we are going to give credit to students for learning what we want them to learn. ‘Assessing Materials Students’ by Lewis Elton gives support to the development of assessments and assignments that do in fact give marks for those things we want to acknowledge, rather than those aspects that are simply easy to assess!

Believe it or not it is only at this stage that we can really consider how we should teach the students to learn these things. We all know about lectures but will we use in addition or instead: tutorials (‘Tutoring Materials’ by Adam Mannis and Shanaka Katuwawala), labs (‘Teaching Materials Lab Classes’ by Caroline Baillie and Elizabeth Hazel), case studies (‘Teaching Materials Using Case Studies’ by Claire Davis and Elizabeth Wilcock), problem based learning (‘Learning Materials in a Problem Based Course’ by James Busfield and Ton Peijs) or even learning at a distance (‘Learning Materials at a Distance’ by Mark Endean)?

The final stage before we start all over again is to see if we have done what we intended to do. We may have already found out whether, and how effectively, the students learnt what we wanted them to (i.e. if the assessment matched the learning objectives and if our teaching methods suited the students’ learning approaches). If this has not proved to be as ideal a scenario as we would have wished we will need further input to analyse what has happened. ‘Were the course objectives inappropriate?’ ‘Am I sure that the assessment did not force my students into taking a surface approach?’ ‘Did the students take on surface approaches to learning because of my teaching?’ Ivan Moore’s ‘Evaluating a Materials Course’ will give you the tools of the trade to conduct your own thorough evaluation and enable you to develop an improved course for next year’s cohort. Which brings us back to the beginning of the cycle. ‘Are we attracting students with appropriate abilities for this course?’ And on it goes ….

In writing these booklets, and running the workshops we have had a lot of fun and we hope that you catch the flavour of this in using them. Stay in touch and give us feedback about your ideas in implementing any of the suggestions. As a community we can learn most from each other.

Caroline Baillie and Leone Burton

Editors

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WHY THIS BOOKLET?

Laboratory work is the hallmark of education in science and technology based fields. In the laboratory students can explore their understanding of the subjects being taught by placing their learning in context. Students can also be motivated to learn in the laboratory context if they can feel a spirit of excitement when investigating a scientific phenomenon, or when creating something that actually works. Many of us can remember an occasion where a laboratory class was particularly memorable or enlightening. We can also probably remember many hours of tiresome exercises which seemed to teach us very little. The design and delivery of laboratory classes and the forms of student assessment used in them, need to be examined critically for their contribution to effective student learning.

WHAT DO YOU WANT YOUR STUDENTS TO LEARN IN THE LAB? – GOALS AND POTENTIALS

There is much agreement in the literature on the following range of goals for laboratory work (Ramsden, 1992; Boud, Dunn, & Hegarty-Hazel, 1989):

1. Learning scientific information and concepts
2. Participating in the construction of scientific knowledge, understanding the interplay of theory and methodology
3. Understanding the processes of scientific enquiry and appreciating and emulating the role of scientists and engineers in enquiry:
   - observing and measuring
   - seeing a problem and seeking ways to solve it
   - interpreting data and formulating generalizations
   - building, testing, and revising a theoretical model
4. Developing imagination and creativity
5. Learning manipulative and technical skills and the use of equipment
6. Developing relevant professional values, attitudes, and interests
7. Developing an orientation to the social, historical, and philosophical aspects of science and engineering
8. Appreciating the application of knowledge and methods
9. Developing literature skills
10. Learning how to communicate verbally and orally
11. Learning to work cooperatively with colleagues, developing teamwork
12. Developing scientific attitudes

PROBLEMS WITH ACHIEVING THESE GOALS

At the same time as reaching some agreement on the potential goals for laboratories, there is also much agreement that only sometimes is the potential of laboratories fulfilled. The following problems have been highlighted in the literature (Boud, Dunn, & Hegarty-Hazel, 1989):

- Many of the goals are not exclusive to the laboratory and may be attained more efficiently elsewhere.
- Laboratory programs, and especially their assessment, may emphasize low-level goals at the expense of higher-level goals and may encourage students to concentrate on methodology without an understanding of the interplay of theory and methodology.
- Assessment often fails to provide evidence of whether goals are attained or not and it may be possible for students to do well in a course without even attending a laboratory.
- Many laboratory classes have too many, too diffuse aims and it would be better to do a few things well.
- Students often find labs tedious and boring and do not take them seriously.

HOW DO YOU DESIGN AND TEACH LAB CLASSES TO ACHIEVE YOUR GOALS?

There are several different ways of presenting laboratory work and they differ greatly in purpose and degrees of student autonomy. In order of decreasing teacher control and increasing student autonomy, these are controlled exercises, experimental investigations and project work. The differences can be recognised using the simple but sound scheme in Table 1 which analyses the level of openness for scientific enquiry in different laboratory exercises (adapted from Herron, 1971; Boud et al, 1989)

Table 1: A Way of Reflecting on Student Laboratory Exercises

Type of laboratory	Level of enquiry	Definition of level	Material	Method	Answer
		Aim			
Demonstrations	0	Given	Given	Given	Given
Controlled exercises	1	Given	Given	Given	Open
Structured investigations	2	Given	Given all or part	Part given or open	Open

CONTROLLED EXERCISES

These are activities which are wholly designed by the teacher and are often thought of as verification exercises. They can be completed by a student within a short timespan, typically one or two laboratory periods. There is a known outcome and if students follow the instructions, they should arrive at that outcome (more or less).

Advantages of controlled exercises

They can provide introductory experience with the materials and processes of a discipline, equipment, apparatus, organisms, and chemicals, as appropriate. In many disciplines, the whole procedure has become very well honed. Teachers who wish to use controlled exercises with their students can often locate suitable experiments in laboratory manuals from their own student days, in commercial texts, or in discipline-specific education journals. For faculty, a major appeal of using controlled exercises is the ease of finding them and the charm of their predictability. They can be used from year to year with minimum fuss.

Disadvantages of controlled exercises

A major disadvantage is that students often do not like controlled exercises very much, finding them dull and tedious. Students may not be very sympathetic towards the elegance of exercises nor regard their lab work as a microcosm of experimentation. They can find the pre-lab work a meaningless ritual, the introductory talks and the controlled exercises as lacking personal satisfaction or connection to their world. Results and reports from students in previous years are often readily available and there is the temptation for the task of writing up to become one of 'faking good' the results.

Examples of controlled exercises

An example of a controlled exercise which students found boring and alienating is the following from a materials science lab where students are expected to learn about the properties of polymers; specifically how polymers behave under different conditions. The students are asked to conduct a series of tests to explore the properties of polymers. They are given samples of a specific size established by standards and asked to test them in tension using a tensile testing machine. Usually they would not do the tests themselves, but watch whilst a technician conducts the tests. After the samples of a range of polymers have broken, the students are required to calculate the basic properties of each material. An assignment is to write the experiment up, with the emphasis being on presentation and producing results of the right order of magnitude. In all, there is little or no opportunity for the students to engage with the techniques or to relate the exercise to their world.

Contolled Excersises

By contrast, the following is an example of a controlled exercise which students found more engaging. It is on the same topic, how polymers behave under different conditions. Students are asked to test the bouncing power of squash balls at different temperatures, including first dropping them into liquid nitrogen. One student described it as an experiment which he found useful and which captured his imagination. He said the students had fun and got a physical feel for the glass transition temperature and its relation to mechanical properties. Here the squash balls are something that most students recognise. Both the balls and the use of liquid nitrogen have about them an element of drama. Students are asked to do the tests themselves rather than watching someone else and are required to show their results to their demonstrator.

EXPERIMENTAL INVESTIGATIONS

This term is used to cover a wide variety of teaching methods which foster deep approaches to study by encouraging students to take personal initiative in the performance of the exercise. This might range from experimental design, choice of variables for investigation, choice of materials or methods, choice of methods of data analysis, through to choice of the problem for investigation. The investigation would usually be limited in time and scope and would not qualify as a project. Thus, it might be an extension of a controlled exercise which appealed to the student, or a variation of a well-known theme or method. Experimental investigations can be more or less structured – and often this means shorter or longer.

Structured investigations retain teacher control of materials or methods whilst giving students an opportunity for enquiry. Unstructured investigations retain teacher control of the aim but allow students to plan the materials and methods. In practice, experienced teachers can do much to anticipate students' needs in the laboratory and avoid situations where unforeseen or unreasonable demands are placed on the technical support system.

Advantages of investigations

The first is the opportunity to allow students to practice skills of scientific enquiry, such as planning part or all of an experiment, whilst the second is the provision of a good motivational context. The two are linked: planning requires students to invest some personal initiative, and a sense of ownership and initiative is likely to be motivating. In the laboratory setting, it would seem that independent learning, project work, and experimental investigations share the qualities of independence and student motivation, but with decreasing freedom for independent learning.

Interviews with students show that they are very aware of the freedom for independence and of its effects on their motivation: the key to running successful investigations with junior students is not to throw them in from the deep end but to help them proceed from an adequate base of knowledge and skills. The idea of learning cycles is well described in the literature (e.g., Atkin & Karplus, 1963) and is further discussed in Boud et al. (1989).

Disadvantages of investigations

Why are controlled exercises retained as traditional fare? When do the disadvantages of investigations outweigh the advantages? Costenson and Lawson (1986) interviewed teachers and proffered a list of the top 10 teacher perceptions which have prevented the introduction of enquiry-oriented curricula into junior courses, or have resulted in this type of curriculum being discarded. Any faculty member introducing an investigative approach in undergraduate laboratory work might take note of which of these views they have heard expressed by colleagues.

1. Requires too much time and energy
2. Too slow
3. Required reading is too difficult

4. Risk is too high
5. Tracking – only the best students can cope
6. Student immaturity
7. Teaching habits are too ingrained
8. Sequential material is a management problem
9. Teacher discomfort with perceived loss of control
10. Too expensive

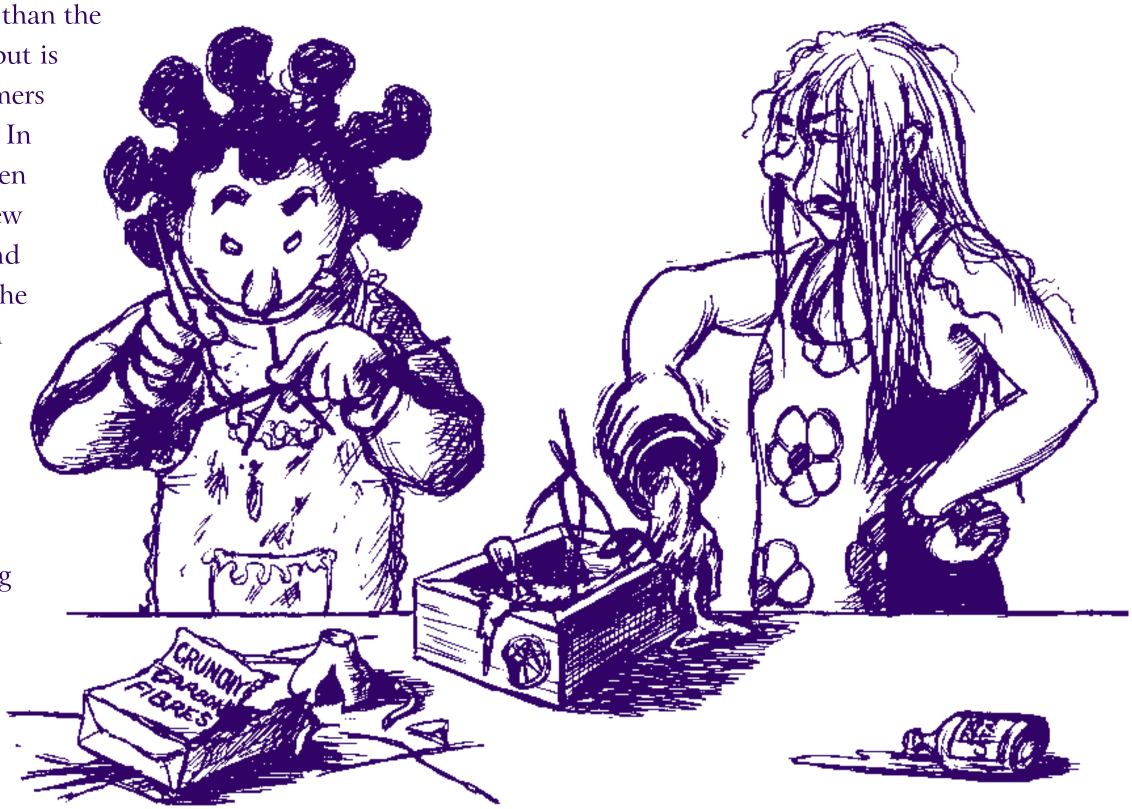
The issues at the heart of this worry list need to be seriously addressed although sometimes such views are based more on perceived threat, prejudice or conservatism rather than rationality and evidence. Two important factors in improving the successful running and institutionalisation of a program of investigations are teamwork and staff development.

Example of an Investigation

As an example of an experimental investigation, this one allows for more investigation than the controlled exercises discussed above, but is still on the same topic – how do polymers behave under different conditions? In this investigation, the students are given a series of different polymers, a few different testing apparatus and temperature controlling devices. The students are then asked to design an experiment which will explore the viscoelastic properties of polymers. There are many different possibilities including producing a stress/strain plot at different strain rates or temperatures, or by exploring stress relaxation, and these possibilities use the same basic equipment as before. Each student then produces a different piece of work, there can be no copying, and each feels as if they have done something useful. There is no right answer but a feeling of having discovered what the concept of viscoelasticity is all about. It can be related to a real life issue such as investigating the properties of a polymer for use in skis, which need to be used at different strain rates and temperatures.

Done as a structured investigation, the students are given ready-made test pieces from which they select the polymer and decide on the test conditions. As an unstructured investigation, students decide what test pieces are required and either make them themselves or ask the workshop staff to prepare them. They decide on the test conditions and plan accordingly.

Structured investigations



PROJECT WORK

Projects are major pieces of work which are intended to simulate elements of real-life research and development activities. It is usually necessary to devote significant periods of time to projects, likely to be from a few weeks to a semester or even one or two years of an undergraduate course. Project strategies are devised whereby students can apply prior knowledge to new problems, and, in doing so, to integrate various manual, technical, and enquiry skills in one coherent activity. Important characteristics are that the research problem must be a new one (where the student's experimental work and results could be seen as a genuine attempt to contribute to scientific knowledge) and that the student carries out the work in a research setting where there would be access to research supervisors or team leaders (in an apprenticeship role, with a potential mentor).

Advantages of projects

Historically, participation in research projects was the common mode of students working in science courses, but concerns of cost and convenience gradually led to the reservation of research projects for postgraduate students and the use of controlled exercises for undergraduates. However, since the mid-1970s, there has been a widespread return to the use of projects with undergraduates. This seems to be a recognition of the need for students to be involved in intrinsically interesting, personally involving activities which are true to the nature of a science discipline (Bliss, 1990; Bliss & Ogborn, 1977; Dowdeswell & Harris, 1979; Ogborn, 1977).

Benefits of project work are many. The learning is individualized and students are likely to find their project a unique experience. Students are encouraged to accept responsibility for a piece of work and to build up some commitment to the scientific endeavour; they get the satisfaction of working on a sustained task and the opportunity to enhance their oral and written communication skills.

Disadvantages of projects and improving them

Conceptually, the disadvantages of projects are few – they seem ideally suited to students enhancing their technical, enquiry, and many other skills within a holistic experience. Practically, projects can be risky. The initial choice of a problem may be misguided, practical problems can result in overruns of time, energy, and cost, and the supervisory relationships may not work well. In short, with the scale of project work, there is great need for careful planning by staff to ensure that the experience is a worthwhile one for each student.

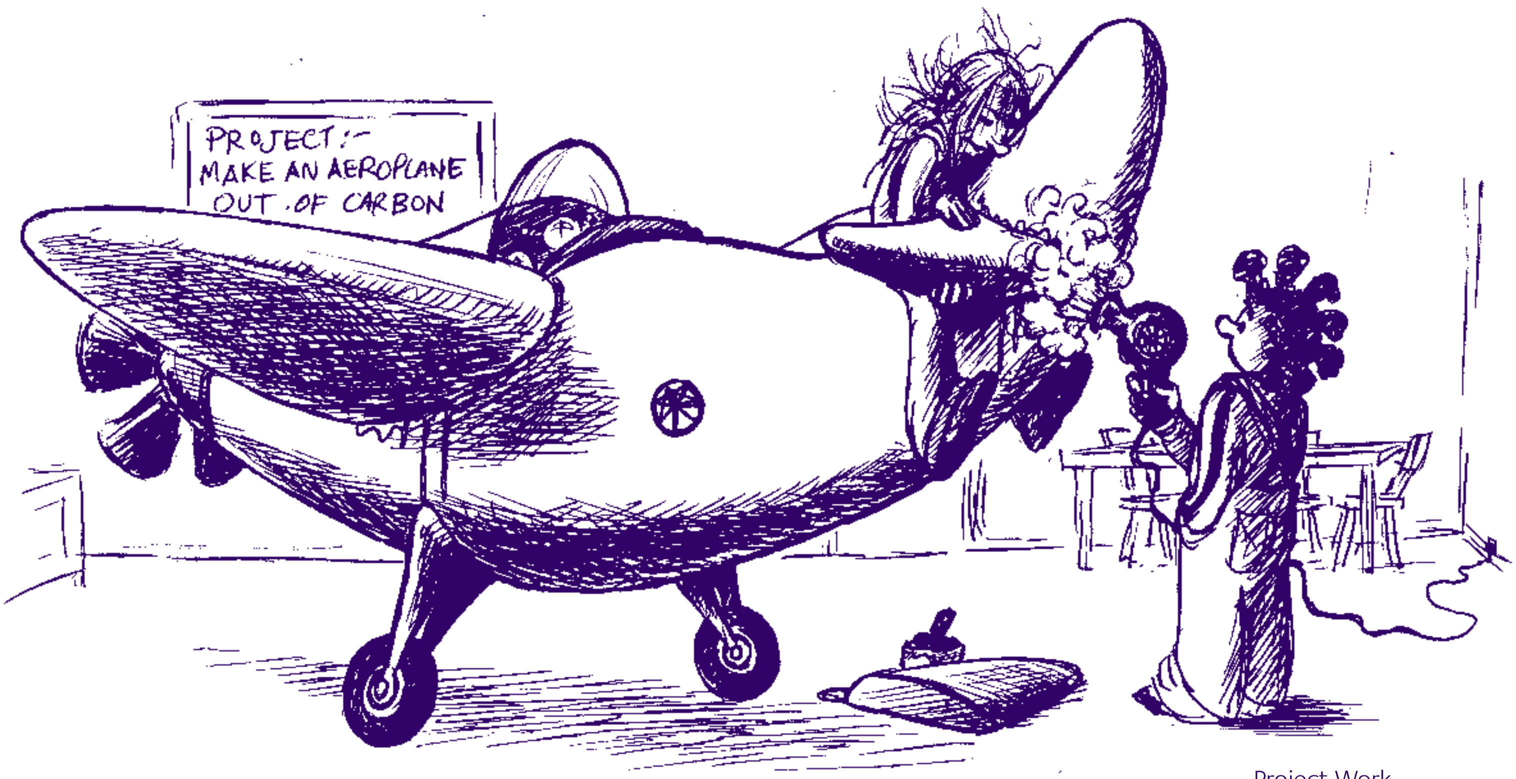
Examples of project work

While final year projects can draw on students' earlier undergraduate experiences, projects can be usefully employed in any year. They can be used from first year on with a degree of freedom suitable to the students' stage of preparation. An example is the projects which have been trialled with second year mechanical engineering students at the University of Sydney for the subject of 'materials selection'. During these projects, amongst other things, the students learn about polymer properties referred to in the examples of controlled experiments and experimental investigations given above. In essence the project is similar to problem based learning, where students are asked to solve a problem and by solving it they learn new facts and ways of thinking. Students in this case were asked to form materials selection teams working for a large engineering company. In their teams they were asked to choose a structural object and to decide on the best material from which to make it. They might choose a crash helmet or a sailing boat hull, for example. They have to back up their choice with real evidence, ie tensile tests relating the strength of the material to the load it must withstand, toughness tests which relate to the impact loads (eg hitting your head on the road!) to which the object will be subjected, etc. Students also need to know the latest cost of the material and of production.

Each student or group is therefore actually conducting the exercise which materials technologists would do in an engineering company in order to select the best material for a particular application. Students write up a report to the company manager to see if their idea is acceptable. Based on the evidence they provide and their argument, backed up by literature, they are given the commission, or they get a good mark! The whole project lasts three to four sessions of 3 hours per session.

ASSESSMENT OF STUDENT LABORATORY WORK

Before considering assessment for a laboratory class, teachers need to consider a set of aims and objectives for the lab and the subject overall which lead to desired outcomes in student learning. These will be the knowledge, skills and attitudes which you would like the student to achieve, rather than a series of factual contents. Once these have been established it is possible to design an assessment scheme which will ensure that you are testing for those attributes. For example, it has been found that if an assessment task is to ‘write up the lab’ and no guidance is given, students are most likely to reproduce what they did (or possibly what last year’s students did!). They are unlikely to reflect on why they did the experiment and what they got out of it unless they receive specific prompts and guidance.



Project Work

It should also be possible to use the assessment scheme that you devise as a way of both finding out what the students have learnt, and feeding back information to the students about how they are learning and how they might improve their learning. For example, showing reports written by previous students who approached their learning with understanding, or offering feedback on draft reports before final submission. You could go further by involving the students in the process of developing suitable criteria for assessment and in critiquing outcomes in relation to criteria.

How do you want to assess?

Providing you have clear statements of the subject and course objectives and a clear indication of which objectives should be met in students' lab work, your assessment can be directly linked to criteria. Criterion referenced testing simply means being able to select valid objectives for laboratory work and being able to specify the criteria by which successful performance would be recognised. For example, objectives in the polymer lab investigation described earlier are as follows:

- Define the relevance of the structure/property relationship in polymers to materials selection
- Demonstrate the ability to interact with a group
- Demonstrate and ability to select and perform appropriate tests, critically analyse results and recommend testing schedules for the selection of polymers

For any objective, there is usually a choice of assessment methods, some of which are illustrated below.

- Self assessment and peer assessment
- Written reports
- Verbal reports
- Design posters
- Practical tests
- Observations
- Written tests
- Portfolio assessment

The use of a range of appropriately chosen assessments should help students to understand the assessable goals of the subject (ideally, these are the most important goals), encourage students to take a serious approach to their lab work, and be suitably rewarded. In general it is helpful to be sensitive to any gender or cultural influences that may make one type of assessment more accessible to one group than another, and to provide practice assessments where necessary.

Example of a written report style assessment

An example of a written report with a difference is a case where students were asked to produce a user's guide for a materials selection lab class. The guide provides results of the experiments performed in the lab, together with data from references. Having tested the mechanical properties of a series of polymers or metals, etc, students create a user-friendly guide giving values of modulus, ultimate tensile strength, examples of stress/strain behaviour, etc which they have measured or collated. This helps students to realise the application of such a lab exercise and the student may refer to the guide in years to come to give a ball park figure for data. A material may then be selected for further analysis for a particular design, based only on this preliminary data.

DISCOURAGING FRAUDULENT PRACTICES

Anecdote suggests that fudging of laboratory assessments is very common. An important point is that almost all of this fudging occurs in controlled exercises – much less occurs in investigations and projects. It is as though fudging is a part of a certain culture where students take no ownership in their work and where matching a pre-ordained right answer is more important than anything else. Below is a series of hints on discouraging fraudulent practice:

- Take action to reduce student overload. Limit the range of goals for laboratory exercises.
- Reduce the emphasis on routine reports. Reduce the emphasis on right answers and increase the call for discussion and insight.
- Select an appropriate range of planning, technical skills and reporting to be done under exam conditions.
- Cut the number of written reports required. Select carefully those exercises which will be assessed by report.
- Allow student choice in the exercises to be assessed. They could choose the most stimulating, the most challenging, the one where they made the greatest personal contribution, etc.
- Discourage alienation. Avoid controlled exercises where possible. If retaining controlled exercises, find some way of making them a vivid experience for students.
- Encourage a sense of ownership and identification by favouring investigations and projects where possible. Allow reasonable choices of exercises to be undertaken.
- Set the lab work in a context where students can have some sense of identification and can see a clear vocational link or link to future course work.
- Introduce a log book system where students must record the day's results in a permanent form, available for inspection, before taking them away from the lab. Require that these results be addressed in any write up.
- Negotiate with students the special criteria for each report used.
- Ask students to compare critically their results with those of other students, or with certain literature.
- Increase the emphasis on 'own' work.
- Include in the program a discussion on issues in scientific ethics, perhaps with consideration of some of the more famous cases of scientific fraud – where possible include fraud cases from a diversity of cultures and eras.
- Emphasise the value to one's learning of finding what was different ('went wrong'?) when the answer didn't match the theory. This could include a discussion of serendipity in science, considering a range from more minor examples to those recognised and rewarded by a Nobel Prize.
- As far as possible any assessment should be based on a topic different from that of the year or two before. This need not militate against students learning from the past. For example, if there is something a little unusual for students, such as their first encounter with posters, you may wish to display the posters from past years and discuss explicitly different ways in which a poster can be effective. However, to discourage copying, ensure that the new poster addresses a new topic.
- In group assessment, identify the contribution made by individuals. Include further assessment of the project in a written or oral examination.
- Try a portfolio system showing each student's own profile.

TEACHING IN THE LAB – DELIVERY OF THE LAB CLASS

Often the person 'demonstrating' the lab class is not the same as the lecturer or designer of the lab. The following issues specifically relate to the person actually teaching in the lab session itself.

Potential issues

Knowledge base: Questions known to concern demonstrators are as follows:

- How do I integrate the learning from their lectures into the lab?
- How do I know what is expected of me before, during and after the lab; what should I know?
- What if the students haven't been to lectures or lack the fundamentals?

Student learning

- It is difficult to think about student learning when we get bogged down with technicalities
- How do I help students to learn without it being another mini lecture?

Student respect

- How do I deal with bad student behaviour?
- How do I gain their respect so they do as I say?

Knowledge base

Showing expertise. Being on top of the subject matter, being well prepared for the lab, being familiar with the ideas of the subject, the design of experiments, the use of equipment. Making it clear what has to be done and understood and why; making clear explanations about the ideas, material, and activities; using assessment methods which are valid and reliable; and giving students prompt and high quality feedback on their work.

Meeting students where they are in their learning. Find out where the students should be and where they are in their learning of this topic. Supervising students closely enough to recognize those having difficulties with the concepts on which the laboratory exercises are based. Checkout understanding. Showing encouragement and empathy. Giving students positive feedback and encouraging them to note their own achievements. Providing adequate opportunities for students to practice their skills and to receive precise feedback.

Student Learning

Fostering student independence and growth. Supporting students warmly when they are in high challenge situations; encouraging active participation by students; and avoiding having them stand around in an observational capacity in the lab.

Enhancing student learning. Emphasizing critical thinking, problem-solving, aspects of scientific enquiry, and other intellectual activities which require the students to think. Encouraging students to focus on the integration of the practical exercises with the learning of material taught in other components of the course. Encouraging students to have a lively understanding of the interplay of theory and methodology in the laboratory.

Facilitating not lecturing. Trying to avoid telling students the facts but helping them to find them out themselves by asking questions etc.

Student Respect

Respecting students. Demonstrating respect for each student as a person; valuing diversity; demonstrating a positive attitude and teaching free of discrimination or stereotyping of students because of gender or ethnicity; and monitoring student groupings in the lab and the nature of classroom interactions to bring out the best in each student.

Sharing enthusiasm and making laboratory work an enjoyable experience for students. Finding ways for love of the subject to come across to students, helping make the students' work relevant, interesting, stimulating, and challenging. Being friendly, helpful, and available to the students. Using humour and other techniques for fostering an enjoyable, relaxed, and non-stressful atmosphere in the laboratory. Being a good role model for students.

EVALUATION

Monitoring all aspects of the design and delivery of the lab class will help with subject improvement – for ideas on evaluation see the booklet in this series *Evaluating a Materials Course* by Ivan Moore. It is always difficult to make changes to a subject and a large amount of time spent on monitoring will be wasted if it is not possible to implement the recommended changes once they have been deemed necessary. However, it is never a waste of time to know what it is that is most effective for your students learning and to optimise this as much as possible within the imposed constraints.

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(See Chapter 3, Teaching Practical and Laboratory Classes)

NOTES

NOTES

Other Booklets in the Series:

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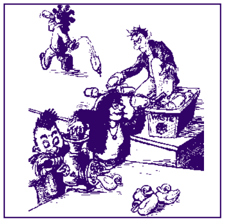

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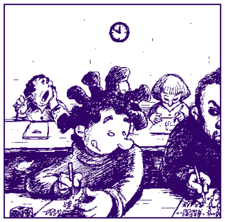

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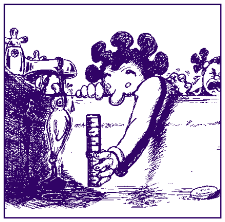

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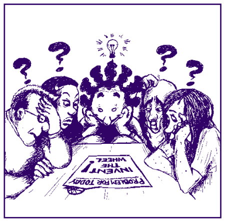

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