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PossiBiLities

a Practice Guide to Problem-based Learning in Physics and Astronomy

A Physical Sciences Practice Guide

Editors

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Project LeAP

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Introduction

Tradition is the first refuge of ignorance. This is logical: if you do not know how something should be done then the least worst course of action might well be to do it as it has always been done. It is not however very scientific.

No-one knows exactly how physics students become physicists (in those happy cases when they do). In an elite higher educational system this ignorance was probably not very important: recall how Einstein marvelled at the way the physicists of his day survived a university education. However, in a mass education system it matters a great deal: because the majority of students who are not going to become academic physicists are not going to prosper 'whatever'.

In the absence of a full theoretical understanding of physics education we can at least turn to experimental observation. What we have known for almost a hundred years is that students learn what they do, not what they are told. So now every physics student is encouraged to do end-of-chapter exercises to demonstrate mastery of the material that has been delivered. But we are beginning to understand that this engages many students only at a superficial level (the ubiquitous pattern-matching). A better approach appears to be to provide problems first and material for solutions only later. This encounter with meaningful problems provides students with a way of engaging with science as it is practised, rather than with only endless training exercises. This approach goes under the title of problem-based learning (PBL), or project-based learning, to be distinguished from traditional problem-solving learning. To make the approach viable for large classes across the curriculum, and to emphasise the embedding of personal, transferable skills it is usually practiced in a group-work setting.

This practice guide, a product of the FDTL4 LeAP project, provides an introduction to PBL for physics teachers (and others) who want to find out enough to get started. Further support can be found on the Project LeAP website, through the annual LeAP PBL Summer School and the LeAP consultancy.

The guide is divided into four sections. Section one is the narrative of a PBL problem, its implementation and development. We use this to illustrate the nature of PBL, and this is elaborated explicitly in the accompanying boxed text. Section two contains 'composite' case studies based substantially on real situations, but drawn together to help us make a number of points efficiently. The variety of situations treated here should help readers decide for themselves the cost-benefit analysis of any particular PBL implementation and also illustrates that there are many different ways, both big- and small-scale, of bringing the benefits of PBL into your teaching. The third section is a set of real-life case experiences by invited contributors, many of which include samples of problems. The final section brings together a number of resources. We should be pleased to receive feedback on the guide for inclusion on the Project LeAP website.

"There is no greater joy than spending time teaching people and seeing benefits. The motivation for the staff, I think, is a wonderful thing."

- Paul van Kampen, School of Physical Sciences, Dublin City University

"practical learning: it really helped me to understand and apply the theory ... I understand a lot more"

- Leicester physics student

"One of the benefits to the staff is that, by having the students actually involved in the class, it's just much more satisfying to them than having students sitting passively, perhaps listening to what they're saying."

- John Berlinsky, Chair of Physics and Astronomy, McMaster University, Ontario

"we felt we needed preparation for PBL but, actually, PBL was a preparation for now"

- A 3rd year physics student after two years experience of PBL

"The problem-based learning students were much better at being able to explain how they learn, why they learn, and under what conditions learning suits them."

- Brian Bowe, School of Physics and Learning and Teaching Centre, Dublin Institute of Technology

"you have to learn it for yourself ... you have to have the experience before you can see how good it is"

- Leicester physics student

"The students were far more interested in thermal physics than they had been before. They developed problem-solving skills - all of them, including the weaker students."

- Paul van Kampen, School of Physical Sciences, Dublin City University

"In the future I would definitely consider a course where PBL is taught … because PBL would help me to use my knowledge … in realistic and life-like situations."

- A-level physics student, July 2004

Amongst those interviewed there appeared to be an understanding (or an assumption) of the purpose of/rationale for PBL... *"To introduce us to the real world I expect"*, said one whilst another explained that *"you have to do group work in any working environment"*. Another added that it was *"the most real life thing"* they had done and in another group one student thought that its purpose was *"to make us think for ourselves rather than follow a script"*. A colleague added that *"it's better in a group ... with everyone's input ... you can bounce ideas off each other ... and other's ideas might be better. In industry you work in teams"*.

- Undergraduate reaction to a first PBL experience collected by David Pierce (Centre for Recording Achievement) from University of Leicester physics students December 2003

In preparing this guide we are happy to acknowledge the assistance of our contributing authors. We are also grateful to the many members of staff, postgraduates and summer students who contributed to our knowledge and experience of PBL. The project was led at Leicester by Dr Derek Raine, at Hertfordshire by Dr Jim Collett, at Reading by Dr John McDonald and at Sheffield by Drs Craig Buttar and Chris Booth. The project was managed by Dr Sarah Symons. Alex Mack, Sam McCartney, and James Bober acted as project assistants. Ray MacErlean was the project's technician.

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Narrative of a PBL Problem

PBL has found widespread acceptance within competence-based professional disciplines, but in Physics, at least within the UK, its adoption (even if more widely defined in terms of PBL-like group project activities) has to say the least been patchy.[1] Even on a more international stage implementations of PBL in Physics rarely go beyond introductory (non-Physics major) level and are often restricted to theoretical work. One of the major obstacles to more widespread adoption has been the difficulty of developing 'real-world' problems within a professional setting. Most 'real-world' applications of physics tend to be overwhelmed by high-level technical detail and fail to be useful for illustration of basic principles. Indeed, in conventional physics courses, immense effort goes into the construction of highly artificial exercises designed to debug students' understanding of fundamental principles at the level of micro-management.[2]

At the opposite extreme the final year undergraduate project is now a major element of physics programmes and is usually a highly successful experience even for relatively 'weak' students (and their supervisors). It is usually assumed that students come to their project prepared by a thorough understanding of the fundamental principles of physics, and are therefore ready to undertake such project work, an assumption not entirely supported in many cases by prior academic achievement. The widespread anecdotal evidence points to the fact that students *acquire* their basic understanding through the project experience. This experience represents for most students their first exposure to what passes as the 'real-world' for the professional physicist. The idea of PBL in physics therefore is to replicate the project experience throughout the preparatory years. Moreover, physics being an experimental science, the distinction between theory, experiment, and computation is largely artificial at this level. Here we give an example of an attempt to integrate these aspects within a single PBL problem.

Most published expositions of PBL seem to involve highly successful projects with high levels of student attainment and satisfaction. This is often at variance with the experience of academic staff making modest attempts to introduce an element of PBL into an existing curriculum. Only off-line, so to speak, does one discover that success has often been

What is Problem Based Learning?
Problem Based Learning can be described as [Ref 1] :
"An instructional strategy in which students confront conceptually ill-structured problems and strive to find meaningful solutions."
In a PBL environment, students are encouraged to solve problems, which are set in a real world framework. The main components to a PBL strategy are as follows [Refs 2&3]
Group Work. Students work together in small groups (usually of four to twelve). Groups provide a framework in which students can test and develop their level of understanding. They also model real working environments. The complexity of the problems will be such that members of the group will have to divide up tasks to make progress. The students have a responsibility to the efficient working of the group as well as the development of their individual learning.
Problem Solving. The problems given in a PBL environment are often complex in nature and will in general require thought and enquiry. In many ways, these problems are indicative of the types of problems faced by physicists engaged in research in industry and universities.
Discovering new knowledge. In order to find a meaningful solution, students will have to seek new knowledge. From the very beginning, the students must decide *what they know* and *what they need to know* in order to continue. Group discussions connect this new material to the framework of understanding which they are trying to build.
Based in the real world. The main emphasis is to encourage students to start thinking like physicists early on in their careers, thereby easing the transition from University to the work place. For example rather than just having students perform spectroscopy to verify an end result, in a laboratory PBL session, they might be asked to use spectroscopy to resolve a disputed insurance claim. In many of the problems, both theoretical and practical, students will find that there is not necessarily a single correct answer.

Project- or Problem-Based Learning?
Project Based Learning and Problem Based Learning are often used interchangeably. In our view, the main difference in approach is that project-based learning focuses on the endpoint. In Problem-Based Learning, the output, if any, is just one piece of evidence for achievement of the learning outcomes.
Facilitating Problem-based Learning Savin-Baden, M. Open University Press 2003 discusses a number of further differences.

[1] Of our partner institutions in Project LeAP (Problem-based **Le**arning in **A**stronomy and **P**hysics) the University of Sheffield includes PBL in a second year laboratory, the University of Reading in a taught master's laboratory and the University of Hertfordshire in an Astronomy design study.

[2] For example the work of Lillian Dermott and the Washington group.

achieved only after several cycles of relative failures and reformulations. It is however from the failures that one often learns most.

In this example we shall describe an experience in integrating an element of PBL into a first year class and use the difficulties encountered to highlight important aspects of PBL. The example is based on an amalgam of actual experiences, but has been somewhat fictionalised for the purposes of illustration.

We begin by describing the context. The first year class numbered about 80 students who were studying physics for three or four years. Their programme was therefore entirely under the control of the Physics Department. In semester one the programme consisted principally of Mechanics, Electricity and Magnetism, and supporting mathematics. The fact that the core material was already taught by staff teams to an agreed Departmental agenda meant that the lecturing staff were used to a high degree of collegiality in the choice of level and approach. This had the disadvantage of a reluctance to change the core teaching, which had been unchanged for a number of years and was seen as reasonably successful. On the other hand it engendered a community approach to the development of the practical laboratory work to relate it to the core material. The pilot PBL project consisted of a two-week problem involving dynamics (Bernoulli flow) and electricity (CR circuits), partly based on new material and (as a result of the conditions imposed on the pilot by academic colleagues, and in contravention of the true spirit of PBL) partly re-enforcing previously studied topics. It should be emphasised that this approach to PBL, through the combination of experiment and core theory, was ambitious. We know of no other examples in physics, where even non-integral laboratory programmes are rarely PBL (although the integration of theory and practical is common in engineering).

Should I try PBL?

One of the main reasons for the shift to PBL is a genuine desire to give students a deeper understanding of the theories and principles of physics. In many cases students simply remember what they need to know for the examination and fail to make connections between courses. Research has shown [Ref 4] that students retain very little of what they are taught in a traditional lecture format.

PBL offers an attractive alternative to traditional education by shifting the emphasis from *what the department teaches* to *what the student learns*. For those of us used to lecturing the transformation can seem a little daunting, but the promise of greater student understanding and a better way of communicating physical principles makes it worthwhile.

What is a PBL problem?

A problem is the basic structural unit of PBL. A problem has a start point (a hook, a trigger, a scenario and/or a problem statement, see below) and a process usually leading to an output from the group (which can be as simple as a single learning outcome, or can be a product such as a report, a poster, a set of experimental results, and so on). Often, there is no one 'answer' (in which case the problem is 'open-ended' to some extent); sometimes there is a defined answer but many possible paths leading to it.

A problem is designed to cover one or more learning outcomes, which may be facts, concepts, technical or personal skills, professional practices, ideas, and so on. Materials designed with the problem (for example facilitators' notes) may detail learning outcomes in categories such as core and optional, and how they relate to the overall syllabus for the course.

Problems can also include stages, where information is released to the students bit-by-bit, and assessment schemes if these differ from problem to problem.

A complete set of problem documentation may contain:

- syllabus or learning outcomes
- problem brief
- student schedule
- staff schedule
- assessment scheme and materials
- facilitation notes (content and process expectations)
- equipment list

What is a hook?

A hook is an object which engages students in the context of the problem. It might be a newspaper story with a provocative headline, an intriguing image, or a poem. Often, the hook does not contain the problem itself or clues to directions to take within a problem.

What is a trigger?

A trigger is an object (usually text) which contains indications of how to attack the problem by suggesting possible lines of enquiry or research methods.

What is a scenario?

A scenario sets the context for the problem. Often, it tells the students what role or stance they should take when solving the problem (e.g. you are a group of research chemists, you are theatre critics, you are an environmental pressure group).

What is a problem brief?

The problem brief is text and objects given to students at the beginning of a problem which contains within it, either explicitly or implicitly, the 'problem' (issue, dilemma, or puzzle) which the students should explore. The problem brief includes an appropriate combination of hook, trigger, and scenario materials.

Some models of PBL exclude an explicit statement of the problem, believing that the first action the students should undertake should be identification of the problem. In other models, more guidance is given about the direction that groups should take.

Some practitioners advocate making learning objectives known at the beginning of the problem, but most let students identify learning needs during the problem, guiding the students where necessary to cover content.

What are learning objectives?

Learning objectives or outcomes are distinct from a syllabus in that they define what students are able to do rather than what the instructor will have 'covered'. Learning objectives are statements of what a learner is expected to know, understand, and be able to demonstrate after completing the module. The module assessment should be designed to measure the extent to which the learning objectives have been achieved.

The problem was chosen by combining various suggestions by the teaching teams after a brief description of the nature of a PBL problem. It was developed with the help of recent graduates working over the summer vacation. In its first implementation the problem was staged as given on the right.

Note that the problem asked for some experimental work supported by theory (to provide the scaling-up of the model) and some simple computing. Students in semester one have not yet studied a high level computing language.

This implementation can be described as a 'thick sandwich' model of PBL: lecture-based learning is switched off for a period and the PBL activity is switched on. Other features of the PBL structure were developed à la carte:

A Good PBL Problem
Writing a PBL problem is quite different from writing a problem for a work sheet or assignment. However, the task is easier if one bears in mind the essential characteristics of a good PBL problem. [Ref 5]

Engaging An effective problem must engage the students if it is to encourage and promote a deep level of thinking and understanding. To this end the problems may contain a *hook, trigger* and *scenario*. The *hook* is probably the first thing the student will read, and is designed to engage the students interest. The *scenario* defines the point of view the students will adopt, and the *trigger* ensure students keep to the required learning objectives. All problems should have a *real world* setting.

Multi-Stage The problem will often be multi-stage and require students to make decisions using scientific reasoning and enquiry. Students should be able to justify their decisions and conclusions. If the problem is multi-staged, it will encourage students to think more deeply and to investigate valid assumptions about the physical world.

Complex It is often said that a PBL problem should be 'complex'. In physics, this can be misleading if complexity is misunderstood. We spend considerable effort constructing problems that are simple enough to illustrate fundamental principles clearly. Complexity means at least two things: that students learn to make these simplifications themselves in order to learn to construct tractable models of the real world, and that these problems are contextualised so that obtaining the 'right answers' has 'real-world' consequences.

Open Ended If a problem has a closed solution, students tend to focus on obtaining that solution in order to gain full marks. Open-endedness allows the problem to be explored from a variety of different viewpoints, so that the significance of the solution and the process of reaching it become equally important.

Covers Content Content objectives from the course must be incorporated into the problems and often form the starting point for problem writing. The use of *triggers* throughout the problem text will keep students close to the desired learning objectives. Overall, problems must challenge the students' ability in order to develop higher-order thinking skills. *Bloom's cognitive taxonomy* [Ref 6] may be a useful guide to the cognitive levels activated by various student activities.

Desert Island Rescue Problem
You are the crew of cargo plane carrying goods for PB plc, a large industrial wholesale company. Whilst travelling through a storm your plane is forced to make a crash landing on a small isolated island. Most of the equipment on the plane has been damaged by the landing and only a few rudimentary components remain useable. Air traffic control knows you are missing but does not know where you are. You therefore need to build some kind of rescue beacon. *[Students are provided with a list of equipment salvaged from the plane. The list includes two rescue beacons but no power sources.]*

First Stage Brief
You begin to explore the island. Your survival situation doesn't seem too bad: there is plenty of fruit and seafood to hand and the climate seems balmy with a pleasant sea breeze to keep you cool. Water was a problem at first but you've discovered a type of vine which yields fresh water when cut. You're left with the issue of being rescued. How can you attract attention? If only you could find a way to power those rescue beacons …
Presentation: Power generation proposals

Second Stage Brief
Wind power seems the most viable method of powering your beacons. You work on finding out whether you can make anything from the salvaged materials. Your attempts to keep a fire going on the beach are failing due to the damp climate. You begin to tire of raw seafood and fruit, but can't find anything else that is palatable.
Presentation: Designing and Building a Test Device for the Beach

Third Stage Brief
There is little wind on the beach where you have landed, not enough to power either of the beacons. In efforts to find alternative sources of food, you attempt to scale the mountain to the north. The ascent is too difficult to complete with the equipment you had with you, but you noticed that the wind was strengthening as you climbed. Could the mountain be a good place to site your beacons? You return to camp and make some rudimentary climbing gear out of the water vines. Send a team up the mountain to find out the wind strength, while the rest of you work out how your 'beach device' will perform with a stronger wind.
Presentation: Preparing for the Mountain

Fourth Stage Brief
It's time to take your beacons up the mountain. The ascent will be tough going and you only have the energy and ropes to climb up twice. Conditions on the summit are such that you can only spend about quarter of an hour there at a time. You will have to leave your beacons there running unattended day and night until you are rescued.
Demonstration: Do your beacons work?

Fifth Stage Brief
Your beacons are running, but sporadically. You realize you may have to look for a different and more reliable power source if you are to make the most of your chances for rescue. But there is good news: looking out from the summit of the mountain, you see a modest river running to the north. Some freshwater fish would be a very welcome change of diet, and it looks as if there is a waterfall and pool. A wash would be nice, too. Hmm…running water.
Presentation: Crash Survivors Tell of their struggles to Attract Attention

students worked in groups of eight; support was provided by floating facilitators, both academic staff and postgraduate students. These were all new to PBL; they all undertook a facilitator training session of one afternoon. Students were introduced to PBL in a short initial session together with a written briefing. At the end, short group presentations were assessed together with group reports. Evaluation of the project was conducted by an external assessor.

PBL experts will spot some major flaws in this design. We enumerate some of them here in order to illustrate some of the key features of PBL.

What is open-endedness? The initial briefing given to both students and facilitators emphasised the open-endedness of the problem. This was intended to encourage students to engage with the process of experimental design and to highlight the fact that we did not have in mind a single correct answer. Within the context of a theoretical exercise we might clearly expect students to investigate and compare various sources of power. *However*, within the constraints of providing sets of equipment for ten groups of students some severe constraints come into play. In particular it had been decided in advance that the only viable source of energy would be wind power; after all, Bernoulli's theorem was a learning objective. A sizable fraction of students decided otherwise. Not only was this a tropical island (apparently), but fruit was explicitly said to be available and sea water was clearly plentiful. So acid batteries (involving numerous requests to the laboratory staff for lemons and metal strips) were obvious solutions to the students even if they had not been to the problem designers.

Actually, the lemons do not work, but you have either to try it to see this or have an expert knowledge of lemons. In a theoretical PBL exercise some students in a group could be guided to a deeper study of electrochemistry, while others were steered towards a back-up plan involving wind power. This would extend the learning objectives into possibly unforeseen but nevertheless useful and valid territory. Within a resource- and time-constrained laboratory, this is not possible, and the problem must be designed to exclude un-workable explorations.

How can a PBL problem be staged? The use of staging of a PBL problem, whereby students are given a number of sub-problems, provides both guidance and a means by which a schedule can be indicated or imposed. The problem with this example is that laboratory time has to be supervised (for safety reasons) and students cannot therefore work in their own time. In addition there may be tight deadlines by which students must be prepared to use equipment that has limited availability, in this case the wind-tunnel. The approach used in this pilot project was to have facilitators identify those groups who were 'on schedule' and to have them report out to the class at crucial points. There are several problems with this. One is that it has to be motivated by making it part of the assessment, which does not work well towards the later stages because groups who have already presented know they will not be asked again. Another is that class presentation can be a difficult experience for year one students. The worst however, is that it makes nonsense of the scenario. As soon as we get to the first reporting session the 'real-world' element (the desert island) has been

Writing a Problem

Although writing a PBL problem will depend on the subject area, the following general steps can be used as a guide.

Initial Concepts Choose a physical concept or principle which is taught in the course, then write a homework or tutorial style question which will help students to understand the concept. Once this is done, list all of the learning objectives students should cover by working through the question.

A Real-World Setting Try to develop a narrative around the problem which will give a real life setting for the concepts to be studied. The context might be one in which the answer to the calculations matters to the outcome of the scenario.

Another way to start writing a problem is to collect 'hooks' (news items, pictures, papers etc.) forming a pool of resources from which you can select suitable material.

Structure The problem should be structured so that students can identify the learning issues. This can be done by considering

- What might the initial opening paragraph look like – in particular what will engage the students to begin with (the hook)?
- What point of view or role should the students take (the scenario)?
- What use of language will focus the students on the correct learning objectives (triggers)?
- What initial or numerical information should be contained within the problem?
- How much time should the students spend on the problem and how should it be staged?
- What is the final product?
- What resources might students require to work through the problem – laboratory time, computer work etc.?
- Will lectures be used to support the problem?

Teaching Guide It may be useful to write a short guide detailing how to use the problem and how it fits within the course structure.

Resources It can be advantageous to get the students started by identifying some resources; a few suggested references will help get things moving.

lost. We shall see later how both staging and reporting can be integrated into the problem design.

This brings us to the next issue: *What is the real world?* When this scenario was posed to various experts in (non-Physics) PBL they all thought that it was a very good problem. It isn't. As we have seen, once the groups interact we are no longer on a desert island! But in fact we never were: we were always in a physics laboratory. Or we should have been. Actually, we were never quite sure. This led to some confusion as to what equipment was and was not available: (if the island did not have citrus fruit then what did it have?) Eventually the laboratory staff gave in and went shopping for the aforementioned lemons.) We will return to the pernicious effect this had on the attainment of learning objectives below.

Finally, in the real-world, groups present their findings within the coherent context of the problem, not by stepping out of the scenario.

In order to have a real-world scenario, a problem must give students a point of view, a role, a stakeholder identity. Roles can change through a problem, so a student can experience more than one point of view, but not at the same time. There is sometimes some confusion between the status of a student as student, and as stakeholder. Of course, what we are creating in PBL is an artificial environment in which the student, as aspiring professional physicist, may not yet know Newton's laws, but acts as a physicist in seeking them out.

What is facilitation? Where PBL is introduced partially into a conventional programme the differing expectations placed on students

Models of Problem Based Learning

The term 'model' [Ref 5] is used in PBL in two senses:

To provide a structure for the carrying out of each problem unit (for example the Seven Step model below)

To describe an instructional model (organisation of class sessions etc.) which is treated in the remainder of this box.

The Seven Step Model

The Maastricht Seven Step model was initially devised to provide students with a structured approach to a PBL session [Ref 6].

In this model, students work together in small groups each with individual roles (see Group Roles) following seven defined steps.

1. *Clarify*. The students read through the problem, then identify and clarify any words, equations or physical concepts that they do not understand.
2. *Define*. The students work together to define what they think the problem is.
3. *Analyse*. The students discuss or 'brainstorm' the problem. At this stage there is no prioritisation or sifting of ideas.
4. *Review*. Students now try to arrange their ideas and explanations into tentative solutions.
5. *Identify learning objectives*. The group reaches a consensus on learning objectives, if necessary with the guidance of the facilitator.
6. *Self Study*. Students individually gather information towards the learning objectives and prepare to share their findings with the rest of the group.
7. *Report and synthesise*. The students come together in their groups and share their results. The facilitator checks that the learning objectives have been met.

Instructional Models

The Medical School Model or Fixed Facilitator Model

Problem based learning has been used as a teaching technique in medical schools throughout the UK and US for some time. This model is used to instruct trainee doctors in medical biology and chemistry in the context of clinical cases.

The students are split up into groups of about 8-10. The tutor is assigned to each group to guide the students through their discussions of the problem.

It is the responsibility of the students to organise their time so that the group meets regularly outside formal tutorial sessions, and functions efficiently.

Typically in the Medical School model there is little or no class time. The work is done by the students in their groups and with the tutor.

Floating Facilitator Model

The facilitator moves around from group to group listening to the students and probing their understanding. Where it is not possible to use a fixed facilitator it is advisable to use a group size which is limited to four or five students. Groups of this size also help improve student accountability and provide scope for participation for all group members.

In this model, some class time may be devoted to group reporting. It may be appropriate to give mini lectures on certain topics. Time can also be spent in debates and class discussions.

The Peer Tutor model

Undergraduate peer tutors can be used to guide the progress of individual groups and ensure that student discussions are demonstrating a reasonably deep level of knowledge. It may be best to have some "scripted questions" for the peer tutors to use. This will give some control over the direction of the groups and ensure some uniformity of experience between groups. The peer tutor model is therefore a close relation to the medical school model

Since the peer students already have experience of the PBL process, they can serve as a role model for students who are unfamiliar with it. The peer tutors can also provide valuable insight to the course leader on how well each group is working, and identify any problems.

Large Class Models

PBL can be implemented in large classes, for example where only a lecture theatre accommodation is available or when there is a limited number of additional facilitators.

In this model, the role of the course leader will be to:

- ensure that problems given to the students are discussed
- prioritise learning issues
- ask the students to report on the results of their discussions
- encourage students to share resources
- ask suitable questions to ascertain the level of knowledge obtained by the students

present disabling disjunctions that inhibit learning. This is particularly true in the laboratory context, where the tension between the traditional demonstrator role and that of facilitator arises in an acute form because of the fact that laboratory work must be completed in the allotted time. To cite a specific example, in the pilot project it was assumed that all students would be able to build a simple CR circuit on a circuit board:

PBL FACILITATION: Frequently Asked Questions

What is facilitation?

Facilitation is the method by which the tutor, group leader, or teaching assistant promotes the learning, process, and cohesion of the PBL group. People who perform the process are usually called facilitators, but some prefer to use a different title (such as tutor) while still facilitating the group. Here, we will use the word facilitator to avoid confusion.

Students who have had a lot of experience with PBL may well need little facilitation or can self-facilitate, but this is not true for most groups. In general, a facilitator should ease the group's progress through a problem not by giving the information needed away freely, but by enabling the group to get the best out of the discussion time spent together. Most models of PBL have more time where the students work on their own, so the time they spend with a facilitator is valuable for guiding the problem, picking up areas or learning paths that the students may have missed, reviewing the significance or relevance of their research, and keeping to task.

Is facilitation difficult?

Many descriptions exist of what facilitation involves and how to do it well. Facilitation is often thought to be both the key to PBL and one of its more difficult aspects. Facilitators use their experience of interacting with students to promote a 'learning environment' within the group. Success will be dependent on confidence in the group situation and understanding of what is important in promoting group work.

Does a facilitator have to be a subject expert?

Several PBL experts say that being a good facilitator is more important than being a subject expert. Even some medical schools use non-expert facilitators. However, most opinion seems to suggest that enough subject knowledge to understand the potential of the problem in hand is desirable in a facilitator.

Sometimes, having subject knowledge can actually be a problem: experts are more likely to guide the group straight to a solution without exploring the problem fully and can be prone to turning the PBL session into a 'mini-lecture' after a student asks a direct question or if the group seems 'stuck'.

Does the way one interacts with students have to change to become a facilitator?

A frequently heard PBL maxim says, 'Be the guide on the side, not the sage on the stage'. Moving 'to the side' involves relinquishing a certain amount of control (but not responsibility), talking less frequently, and listening to what the students are saying to each other.

Imagine a good tutorial group session. It is probably one where the group arrives prepared, asks the tutor and each other lots of questions, and discusses complex points with each other. The students demonstrate their engagement in the subject, and the tutor enjoys watching understanding grow and links being made. Perhaps the tutor makes provocative comments to widen the discussion, or asks unexpected open-ended questions which raised deeper issues. This is the type of atmosphere at which PBL facilitators aim – most lecturers have probably already experienced and enjoyed it before.

What does a facilitator do while sitting with a group?

The facilitator watches how the group is working and checks that every member is included; that everyone understands what has been decided; that previous knowledge or experience, perhaps from outside interests or reading, is recognised and shared; that difficulties are not developing within the group; and that everyone understands appropriate behaviour.

Sometimes, a facilitator may spend long periods of time without needing to say anything. This time can be used to make (mental or written) notes for process assessment, if this is one of the facilitator's duties, and to think about what feedback can be given to group members about interpersonal and communications skills.

What if a student says something which is incorrect?

Lecturers do not check the lecture notes that students have written to make sure they are correct and demonstrate an understanding of the relevance of the key points you made. PBL facilitators watch over the learning in their PBL groups at first hand – but does that mean that they must jump in and correct a student if they say something which is wrong? Usually, a facilitator would be more inclined to see whether any of the group members disagree with the incorrect statement, and if not, would challenge the group with questions so that they go back a step and explore where the wrong assumption occurred.

What if a group has difficulties working together?

Sometimes, students will turn to their facilitator for help with conflicts within the group. In general, it is better to prompt the group to deal with conflicts at an early stage, rather than let them continue. Frequently, asking the students to review the ground rules they set up for working in the group will be enough for issues to be brought forward and discussed. Students will probably realise that their process marks, or personal development marks (if given), will be enhanced by a mature approach to differences of opinion, character clashes, and conflict resolution.

Promoting and praising a calm, professional attitude in students will be beneficial in the long term. PBL aims to introduce students to real-world issues, and these include working with people they do not like or who do not seem to work as hard.

What if a group gets stuck?

'Stuckness' is a common state in PBL, and should not be feared. Acknowledging that one is stuck can be a difficult thing to do at first, so students may become silent, fearing to say that they can't see what they should be doing. Later, students should be armed with a variety of experience-gained techniques to overcome the feeling of 'stuckness', for example:

- Returning to the problem statement or triggers
- Brainstorming (perhaps drawing a concept map or making lists)
- Thinking of questions to ask experts
- Re-tracing their path to the current 'stuck' position, to see whether any alternative paths or even mistakes can be identified
- Approaching the problem from a different angle
- Reviewing their assumptions and perhaps modifying them

A facilitator may suggest any of these techniques if the group seems unable to move on: but make sure they have been given time before intervening.

this turned out not to be the case. With a theoretical problem it would be possible to set what was required as an exercise to be completed for the next group meeting. In the laboratory the only immediate solution appears to be to show how it is done. This in itself does not vitiate the philosophy of PBL. But repeated session after session PBL is perceived by students simply to be an inefficient way of delaying telling them what they need to know. Conversely, acting in a demonstrator role, facilitators tend simply to respond to requests for help rather than being proactive in promoting the work of the group.

What is a group? Our idea of a group in this context is that it brings together experimental, computational and theoretical skills to solve the problem. At this level this was not how the students in the pilot project saw it. They were confused by the multiple roles in the PBL group, and those students not directly involved at the laboratory bench at any one time tended to not be involved very much at all. The student 'logs' revealed that their meetings, where a facilitator was not present, were very unfocussed and the minutes of these meetings were at best sketchy. Much more help was required in defining for students the various contributions required, which, of course, creates a continuing tension with any open-endedness.

How are learning objectives set? The learning objectives should be embedded in the statement of the problem. The nature of the problem here was unhelpful. No-one on an island with a crashed plane thinks about keeping a laboratory notebook and estimating errors! It was as if all the previous laboratory training was forgotten and students went back to what we would call 'Blue Peter' science. The sole focus became getting the rescue beacon to work by trial and error, as a group of as yet untrained laymen well might.

Formation of Groups

A PBL group usually consists of three to twelve students. Some practioners prefer odd numbers to discourage subdivisions. Class numbers and resources will be an important factor in deciding the group size and the instructional model.

The groups themselves may be chosen at random or intentionally. Most instructors avoid allowing students to choose their own groups because friendship groups rarely work well. Many instructors (although not all) avoid too great a disparity in ability between group members. A carefully set problem will enable all groups to achieve some core learning outcomes. Some instructors use learning style tests (e.g. ASSIST [Ref 8]) or personality tests (e.g. Belbin [Ref 9]) to form groups of complementary skills and talents. A variety of backgrounds and abilities can ensure that each student has something to offer the group.

Ground Rules

In order to have groups functioning efficiently, it may be useful to establish a set of ground rules to be agreed by the group. Drafting these rules can be a formative group activity at the start of PBL. This may be particularly helpful for students who are new to collaborative learning.

Group Roles

Many PBL models include a formal statement of roles within groups, which can be used to structure group discussion. Some typical roles in groups include the following:

Chair. The chair keeps the group moving forward and helps to finalise strategies to solve the problem. The chair also helps to ensure that everyone is involved, and that each member of the group has a task to do.

Researcher. Researchers are responsible for recording research, summarising, and peer tutoring.

Scribe. The recorder or scribe keeps records of assignments to be done and strategies which have been chosen to solve problems, as well as ideas and issues the group has discussed at meetings.

Author. Authors are responsible for writing or preparing the final draft of any material to be handed in.

Timekeeper. The timekeeper is responsible for keeping the schedule to enable the group to meet deadlines.

Other roles appropriate to a physics environment are:

- *Accuracy checker*
- *Safety officer*
- *Experimental designer*
- *Experimenter*
- *Technical Editor*

Other roles can be invented or adjusted to suit the class and the problem. If roles are used they can be rotated. They can also be assessed, at least formatively.

How is PBL assessed? PBL offers a natural opportunity to assess process (obviously group skills, but also presentation, research, time-management and other personal skills) as well as content. Many implementations use peer-review or peer-marking to assess the value of individual contributions, but in this case it was felt that the students were too inexperienced to use this approach effectively. Here the process was observed and marked by facilitators according to a set of criteria. Unfortunately inexperienced facilitators find it difficult to contribute to group discussion and recall a complex set of marking criteria, especially in dealing with large groups. Staff marked the working beacon (if it did) and group presentations on their work. The content was tested as part of the standard module examination.

The group presentations were very boring and took up a large amount of staff time.

Assessment situations do not provide good opportunities for formative feedback, so it is not clear how much untrained presenters learnt from their presentation. Presentations simply for marks scarcely reinforce a real-world context and can easily run away with

PBL ASSESSMENT: Frequently Asked Questions

Can traditional materials and methods be used?

If the syllabus has remained the same, it may be possible to continue with similar exams. However, it is more usual for PBL students to be assessed by a range of activities which cover formative, summative, process, and content assessment. Sometimes, PBL will be assessed by traditional methods until it has been proved to cover the learning objectives (that is, after one or more runs). After that, assessment would be modified to reflect PBL objectives.

Many practitioners argue against a purely recall form of examination question, others recognise the value of demonstrating standard solution techniques. Often PBL examinations will be 'open-book' or focus on problem-solving.

How can I convince students that they are learning?

Students who are accustomed to lectures often think that if they are discussing, making something, planning how to do some research, or doing something fun or interesting, they are not actually learning. This can have a negative effect on student motivation. Interim quizzes, questions from 'experts', and peer tutoring can reinforce and demonstrate learning. For example, in a two-week PBL unit, students might individually be required to take a short multi-choice content based quiz on subject matter from the current problem. This quiz would be marked and given back instantly (perhaps online) but would not form part of the final assessment. At the end of the second week, a very similar quiz could be given, and this time the marks would count. The idea is that students are shown clearly the content which they as individuals are expected to know. The questions must be pitched so that students do not feel the need to spend the second week revising for the test – they should be confident that the information will be covered by a good solution of the problem in hand.

How can individual and group marks be balanced?

Students are often worried that being in a 'bad' group will mean that their marks do not reflect their personal achievements. It is important to have some element of individual assessment, but also to encourage students to take responsibility for their group work and to work to solve any group issues they may have. Individual marks can be gathered from a variety of methods, including self-assessment, peer-assessment, statements of personal contribution, personal logs or diaries, individual test or exam results, personal development units etc. Factors which might influence the choice of methods are student workload (if already they have several writing assignments, adding a personal log may be too much), maturity and experience of students, number in year group, marking workload, and timing (during PBL or leave until the exam time).

How can reflection be encouraged?

Individual reflection on the learning process is often included as an important element of PBL, deepening learning, encouraging self-directedness, building confidence, and promoting personal development. Assessment methods can be one way of encouraging reflection, for example by asking students to complete a carefully worded questionnaire about their personal progress. There should be some room during the group's time together for discussing how the group is working. This might best be done with a facilitator, unassessed, and will give the group a chance to identify potential problems, and to plan how to keep on track. Eventually, this time can be used to introduce useful management skills, such as risk assessment.

A simple method is to ask students to complete a 'personal log' which details their learning and their thoughts. For short PBL assignments, this log could be guided (give them three questions and expect a paragraph on each) and a one-off activity. For longer units, a different question could be given out each day. Logs or diaries can help provide individual marks, can be useful in monitoring the success of a problem, and for early identification of 'issues' within a group. However, log writing is a skill which may need some help developing in students before it becomes a habit which students regard as useful.

How can the marking workload be controlled?

Here are some strategies:

- Be open-minded about types of student output and assessment methods. Is a poster quicker to mark than an essay? Can good use be made of post-grad facilitators?
- Avoid assessing the same thing twice or more. If the criterion is 'makes a valuable contribution to discussion board on WebCT', then after, say, two check marks have been made against Student X's name, stop marking.
- Have clear guidelines and forms.
- Assess different skills each time. If the class is doing several PBL units, it is unnecessary to assess the same skills each time. Perhaps, concentrate on group work in one unit, then on communication, then on planning, and so on.
- Fit the assessment methods to the group size. Be aware that class activities such as presentations take longer than planned, especially when giving or asking for feedback.

What is the final output of a PBL unit?

Final output material can be very varied: report, exam, presentation, web page, news item, poster, lab script computer program, flowchart, technical manual, outline/plan for a book, abstract for a paper, film script, poem, raw data, a physical or mathematical model; the list is practically endless, but only a few will be suitable for your units in your courses.

Designing your assessment plan can help identify suitable output ideas. Again, you can save time and effort (yours and the students) by not assessing the same thing twice, and by being realistic about the time and workload that creating and marking the output will take. Also take into account that the endpoint output is usually a group effort: is your chosen format capable of having contributions from each member? Will individual contributions be credited?

If you are introducing a new style of endpoint, try to give the students some practice, or have exemplars available. For example, students can find their first presentation in front of the class daunting. By watching other students, they easily pick up what is bad/good/boring/interesting/impressive. Their own presentations quickly rise in standard – it's more efficient than trying to run a 'how to do presentations' workshop. For the practice or interim presentations, the tutor would give constructive feedback immediately but would not mark the presentation. The final presentation however, would be marked, perhaps including a component for presentation skills.

Peer marking of endpoints can save staff effort in collating results and teach students a useful skill. One system is to have three students rate the first group, a different three the second, and so on until everyone has marked and been marked.

staff time to little effect. One approach is to observe and mark individual presentation skills in need-to-know situations (on a group-to-group or group member to group member basis) up to the point where the individual demonstrates the required level of competence. For this problem the presentations were subsequently abandoned and replaced with a written group report.

Standard recall examinations tend to undermine PBL through a conflict between the learning objectives and the assessment. Content is probably better assessed through problems. For this problem a computer-based multi-choice test was introduced to give an element of individual assessment.

How is PBL evaluated? Many accounts of successful PBL problems fail to mention the iterations of the development process required to get to the final result. Evaluation, and modification, is usually key to successful problems and the review process should be built into the resource model. External evaluators can be useful if they can elicit comments that might not otherwise be forthcoming, although for this problem we found that in both circumstances students were very willing to make constructive

Methods for Process Assessment

Group Roles

One model is to define group roles and team working very clearly: reduce everything to a set of bullet points. The facilitator then completes a form with checkboxes or a 1 to 5 grading system e.g. 'Did the Chair ensure that each member had a say in the discussion?'. The students are given the list of criteria and know they will be marked for reaching set standards. In some cases, students are involved in defining group roles, rules, and standards.

Pros:

- This method has the dual purpose of teaching group work while providing a relatively quick way of assessing process.
- It can be used for a variety of problems.
- Students become accustomed to this method and like the individual feedback and feeling of progress against standards.

Cons:

- Takes work to set up correctly.
- Is too detailed to work in large year groups.
- Can give the impression of 'over-assessing'.
- Is too complex to introduce on short-term or one-off PBL activities.

Fixed facilitator observation

Fixed facilitators can quickly pick up a good idea of how the group functions. They are ideally placed to note who contributes what and how much. They also have the time to write a more detailed report on the group, or a paragraph on each individual.

Pros:

- With the facilitator being present all the time, the students do not 'act' in front of him or her.
- The facilitator sees the whole process and so is well placed to assign marks.
- The facilitator will already be communicating with the group, so the feedback process is natural.

Cons:

- No comparison can be made between groups by facilitators because they are each assigned to one only.
- Personal issues are sometimes magnified, students may be concerned that they are not getting a 'second opinion' or 'the best' facilitator.

Floating facilitator observation

With one facilitator looking after several groups, he or she can make brief notes or use a scoring system to record impressions of group work throughout the problem. Criteria might include timekeeping, working to plan, group dynamics, professionalism, or productivity. Systems like tallying (make a mark when a good example is observed) or a variation from average mark (give the group 5/10 unless obviously good or obviously bad practice is observed) can make the process efficient and unobtrusive.

Pros:

- Facilitators can compare groups.
- Groups can be marked to the same standard.
- Limits staff effort required to produce a process mark in a large class.

Cons:

- Some evidence may be missed.
- Facilitators may spend a substantial amount of time ticking boxes.

Endpoint process assessment

Groups will have kept records of their progress such as minutes, lab notes, research diaries. These can be collected in and marked at the end of the PBL unit.

Pros:

- Facilitators can concentrate on facilitating, not assessing.
- Students are not worried by tick marks being made while they are talking.

Cons:

- By the time it's handed in, it's too late for feedback to be useful for the current problem.
- It increases the writing workload on the group.
- It increases the amount of marking of written work (documentation of this type can be very difficult to mark, even with good guidelines).

Self- or peer- process assessment

Students mark themselves and/or each other on how well they contributed to the group. This can be part of the 'Group Roles' method – given that good guidelines and forms are written, students become capable of marking themselves and others. These methods are most successful when introduced into a pre-existing PBL structure after students have developed some group responsibility. Often students will become self- and peer-critical, showing readiness for this sort of method.

Pros:

- Forces students to reflect on their contributions and the group's strengths and weaknesses.
- Reduces workload on staff.
- Can be performed online reducing the effort of collating marks.

Cons:

- Initially, students are usually very wary of peer assessment.
- Some students will always mark themselves down, others will always be blind to their own faults.
- Personal issues can creep into peer reviews.

suggestions for improvement (and, encouragingly, this first time round only a handful thought that PBL should be abandoned).

Surprisingly, the problem can be rescued. We give on the right a revised version of the problem, which was used the following year to address the same learning objectives much more successfully (as determined by the same external evaluator). Since other aspects, which we shall detail in a moment, were also changed, this is not a clear-cut test of the effect of a problem statement, but, from observation of the more coherent student reaction to the problem, we are confident that the reformulation was significant.

Some of the other changes needed will have been readily identified by experienced PBL practitioners. Floating facilitation does not work with such large groups because the facilitator cannot engage with all the members. With groups of four the workload for each group must be scaled down. The advantage with an experimental problem is that all of the group members get to do the hands-on practical elements; the disadvantage is the greater demands on equipment. The scaling down involved assigning different parts of the problem to different groups who then had to check each others' work and then get together to exchange information. This mode of 'presentation', which can be formal or informal, is less threatening than a presentation to the whole class, and is more valuable because it serves a role within the project.

On the other hand it was not feasible to increase the time available for academic staff training without alienating them (although re-running a training session with the same staff is of course cumulative over the years). The research-oriented academic staff involved would engage with 'staff development' for up to half of half a day. The role of the academic staff, who were used as expert consultants, was separated from that of the graduate facilitators, who were paid to attend a full facilitator training session. Nevertheless, it has been difficult for graduate students, familiar with the laboratory demonstrator role and relatively new to PBL to adapt to become effective facilitators. And a huge disadvantage of running PBL alongside traditional components to the laboratory is the similar difficulty the students have in adapting. The approach finally adopted in this implementation was to embed some of the main learning issues explicitly in an expanded statement of the problem stages. It is still not clear if this is a compromise associated with the thick sandwich model that could be overcome either with better facilitator training or in a more wholly PBL environment.

We conclude that to integrate laboratory work successfully within PBL the 'real world' scenario has to be set within a physics laboratory, or a similar location, and that the resource constraints must be built into the scenario from the beginning. Where there is an established practice of demonstrator assistance within the laboratory this should be maintained, despite the tension with the normal practice of PBL facilitation. If students cannot work in laboratories out of hours there is little scope for providing missing skills within a PBL problem. This contrasts strongly with

CROSSWINDS ARE CRITICAL

Another incident this week serves as a reminder for pilots to consider crosswinds on approach to land. Bob C's Puffin Aerosport suffered minor damage after a gust of wind affected the aircraft on landing. Bob was approaching runway 27 (due west), with air traffic control reporting wind from the north west at 21 knots. The Puffin is rated for crosswind components up to 15 knots, so Bob went ahead with his landing, only to be caught by a gust on touchdown. The plane veered onto the grass at the side of the runway and bent an undercarriage leg. The airport emergency team arrived at the scene quickly, but Bob was unharmed and able to exit the aircraft unassisted. He intends to have the Puffin flying again within three weeks.

This is the second incident this year involving crosswinds. Pilots are advised to read the operating manuals for their aircraft to determine crosswind limitations and operating procedures. When on approach, monitor the wind information given by air traffic control and keep an eye on the windsock to assess gusting.

Asked if anything was being done about this state of affairs a spokesperson for Otherton Airport management said that they would be pleased to receive ideas for a safety beacon, but that this would have to get CAA approval.

Otherton Airport Problem

Can you build and demonstrate a crosswind analyser in the form of a light beacon that activates when gusts of wind reach a particular minimum speed? Your experimental design should be based on the following: a small turbine charging a circuit that powers an LED. You will work in groups to make and test a model.

There are two initial aspects to consider for the model: (i) the relation of the wind speed to the output of the turbine; and (ii) the design of the circuit. Some of the necessary theory will be dealt with elsewhere in the course and some you will need to research during the laboratory sessions.

Finally you will have to consider how the model can be scaled from the laboratory test (using fans to generate a low wind speed and an LED to represent the beacon) to measure real crosswinds. You will be asked to submit a report to the airfield management for CAA certification.

theoretical PBL problems where students can be directed to private study, but it is not a fatal problem if likely skills deficits can be identified in advance. Large groups are impossible to manage in a laboratory situation, but even with smaller groups it is important for novice PBL students to have at least an outline management plan of the group time to be provided for them (such as the Maastricht seven stage model). The students in this study certainly found it difficult to make effective use of the three-hour laboratory sessions. In other institutions where PBL has been introduced into a physics laboratory, as far as we are aware, this has been within an existing PBL environment. The perception of PBL as an exception within the overall programme certainly made the task here more difficult. It is interesting to note however that these students found their experience in their subsequent second year PBL much more rewarding in terms of physics content, which they attributed to being familiar with what was expected.

Even more pleasing is the acceptance of PBL (now a 'known known' rather than a 'known unknown') amongst the academic staff, who have taken on board the restructuring of the options laboratory work as PBL, and who have assisted in the development of an overarching problem-based structure to each of the second year core modules.

Thus, while we can make the learning curve less steep, it may be that student difficulties with the introductory sessions of an integrated approach are likely to be a feature of this type of programme design.

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Composite Case Studies

Composite Case Study: Option Module

Scenario

Dr Brown had taught a second-year option for several years using three lectures and a tutorial each week for twelve weeks. He was a popular lecturer with the students and the course generally ran successfully, with the majority of students passing the final exam. There were forty students on the course and increasing student numbers and pressures on staff time meant that the tutorials, which used to be for groups of four, now contained ten students each. Two of the tutorial groups were led by post-graduates, and two others by Dr Brown himself. Discussion questions for the tutorials were given out a week in advance and Dr Brown prepared model answers to help the post-graduates lead their tutorials and give feedback on students' work. Dr Brown had used a similar structure in most of his lecture courses, but had done some background reading into alternative teaching methods in HE, which had led him to consider changing the course. He had been reflecting during the past year about what he really wanted from the course. He felt that he was under pressure to supply content (which he achieved) but that in many ways that content was separated from any useful context. He decided that problem-based learning offered the opportunity to bridge this gap and to improve the quality of teaching and learning on the course.

Motivation to change

Dr Brown felt that his teaching had reached a plateau. Students chose his option course out of interest in the subject, but that interest did not translate into lively tutorial discussions and the 'feel' for the subject which Dr Brown would like to have communicated.

Dr Brown often felt that the students did not take advantage of the tutorial time to ask questions (perhaps out of shyness) but instead just wanted to sit and have example questions run through on the board in preparation for the final exam. The lack of two-way communication also made it difficult for Dr Brown to gauge how well the students were digesting the course material. His concerns were confirmed by exam marks which showed that although the lectures covered the material adequately and students could answer straightforward questions well, they were not reaching as deep a level of understanding as Dr Brown would wish.

Constraints

Dr Brown had control over course content, but the course had to be assessed using the existing style of end-of-term exam, in order to demonstrate that content had not been reduced on the course. The staff time for the course could not increase, with a maximum of five teaching hours a week for Dr Brown and a few hours of time for post-graduates. Room changes would be possible.

Dr Brown would be free to organise his students as he wished, and with no equipment to worry about, he chose to have eight groups of five students. He knew that a deaf student who was currently in the first year would probably choose the course, so he had to ensure that his changes kept the course suitable for all students. He wondered whether PBL, or indeed any kind of group work, offered a suitable learning environment for students with special educational needs and decided he would have to ask for advice.

Management of change

Dr Brown talked to colleagues and received cautious support for his proposed change of teaching method. He noted that his progress would be observed with interest.

In the existing course, Dr Brown had always tried to introduce examples of how the field related to real applications and thought that he already had ideas for several problems. He set aside three weeks over the summer to concentrate on writing new course materials. He also looked carefully at the syllabus to see whether any changes were needed, but decided to keep changes to the minimum in order to avoid seeming to lower the standards.

One of his previous areas of concern was that the students found some of the mathematical techniques difficult, even though they had been previously introduced in the first year 'maths for physics' course. One of his criteria for evaluating the success of the change was therefore to see how well future students coped with the mathematics. His other key measure would be exam results which, as the exam content and format would remain the same, offered an opportunity for direct comparison with his former teaching method.

The rooms used for the course previously had been lecture theatres. Now that the students would be working in groups, Dr Brown requested flat rooms with movable tables and seating.

Thinking about how he could best use the staff time available, Dr Brown decided that he would use one post-graduate instead of two, and re-allocate hours so that the course ran for four hours each week, with himself and the postgraduate present for each of the four hours. He had a particular post-graduate, Sam, in mind who he had seen developing a good rapport with students in the first year lab, and who seemed to be a naturally engaging and thoughtful teacher.

Problem development

During the summer, Dr Brown managed to develop six two-week problems. Four were relatively easy to write, being based on existing ideas, but the final two were a struggle and he felt these might be weaker than the others. He had also found it difficult to cover the entire syllabus and had tried to pack content into the problems.

Writing the problems (especially the more difficult pair) had taken longer than expected, and Dr Brown was glad he hadn't left the task to the last moment. Dr Brown employed Sam to help develop the problems and found it useful to have someone to write the student materials.

Sam suggested that the problem materials should be available online via the university's virtual learning environment (VLE) which the students had used in a previous course to submit work. Dr Brown was keen to try out the VLE but as the start of term approached, he wondered whether too many new ideas had been added at once.

Assessment methods

With no choice but to keep the existing assessment scheme, Dr Brown realised that with an end-of-term exam as the only assessment activity, the students might not feel obliged to engage with the PBL process. He decided to try to overcome the lack of formative, group, and process assessment by giving as much feedback as he could during contact hours. He enlisted Sam's help with monitoring activity on the VLE and being available to the students electronically outside course hours to give feedback and support for group work.

Pitfalls

Dr Brown had identified several areas where he could forestall risks, but his preparation leaves us with some questions:

- Dr Brown has not tested his problems with real students, so he has no experience of whether the problems contain too much content in not enough time. Will the problems 'work'?
- Are Dr Brown and Sam prepared for their roles as facilitators? Have they concentrated on problem development and overlooked other preparation?
- With six two-week problems in a twelve-week course, it seems that students have been given no time to ease into PBL – have they the existing skills to cope?
- The students are comfortable with the VLE, but have used it under different circumstances. Did Dr Brown underestimate the work and time involved in integrating the VLE as a key method of communication between staff and students?
- Dr Brown intended to find out whether PBL would be suitable for a student with a hearing impairment. Documents relating to provision for students with disabilities contain standards and general guidelines, but do not offer practical advice for classroom situations. Will students feel that group work is fair when working with students with special educational needs?

Outcomes

After two years running his option course using problem-based learning, Dr Brown was pleased with the results. Even though he had not identified attendance as a problem in the past, it was clear that students felt more motivated to turn up to each session now and seemed engaged and busy. The biggest improvement had been in interaction between Dr Brown and the students, and between the students themselves. Although some areas of the course were still perceived as 'difficult' it was now far more likely that students would approach him or Sam for help, and also more likely for him to spot struggling students at an early stage and give them extra support.

End of year exam results had improved slightly – not an overwhelming leap in marks, but it at least proved that the course was covering the content. However, students had remarked that they now did not like the difference between the discursive questions asked in class and the formal questions they were given in preparation for the exam. Also, some students who performed well during the course still did not do as well as expected in the exam, giving a poor record of their achievements and progress through the course.

Dr Brown's predictions of which problems would run most smoothly had been wrong. One of the problems he had been most confident about did not flow so well in the classroom. It was difficult to pinpoint why this was so, but students seemed to need strong guidance to follow the path he had felt was the obvious one. Dr Brown admitted that it was difficult, as a subject expert, to view with a student's eye the options and challenges a problem presented. He was pleasantly surprised to find that one of his 'problem' problems actually turned out rather well. It was placed late in the course and by then, the students were comfortable attacking the problem and were generally organised enough to cover a wide range of content.

The first two problems seemed too content-rich, leading Dr Brown to plan to make some future changes lightening the first problem and making it more of an introductory experience.

The time Dr Brown had spent on providing a context for the difficult mathematical techniques produced good results. During one of the problems, the students derived an equation which looked difficult to solve, and most did not recall that they had been taught a suitable technique to handle it in the first year (having had no use for it at the time they had found it abstract and impenetrable). When reminded of the technique, they had applied it to the equation and produced the results they needed to continue. The second time the technique was required, most students used it successfully without question, and spent more time interpreting their results than in worrying about the maths. In the exam, several students chose to answer a maths-heavy question which would have been generally avoided in the past.

Dr Brown had spoken to the deaf student, Tia, and her personal tutor prior to the start of the course. He found that most students in her year had become used to being thoughtful when communicating with Tia and that she did not envisage any problems with working in a group. While the course was running, Tia's group functioned better than the average, perhaps helped by the care with which they shared information.

Guidelines and requirements for provision for students with special educational needs

Special Educational Needs and Disability Act (2001) Part IV Disability Discrimination Act

HEFCE 1999/04 Guidance on base-level provision for disabled students in higher education institutions

QAA for HE Code of practice for the assurance of academic quality and standards in higher education, Section 3: Students with disabilities - October 1999

The VLE aspect had turned out to be more difficult than expected. The students' previous experience of the VLE had not been good, leading to a cautious attitude to the software. The first time the course ran, the VLE was not well used so that when important information was released via the VLE, some students did not pick it up and spent a few days without direction. Dr Brown realised that the VLE would have to be made integral from the first day of the course, with an introductory session, support, and monitoring to ensure that each student was in the habit of using the VLE. This was tried out the second time the course ran and improved the students' use and acceptance of the VLE.

Preparing the staff for problem-based learning also turned out to be as vital as preparing the students: both Sam and Dr Brown realised that their performance as facilitators the second time around was far better than the first time. Both felt more confident, more able to predict the behaviour and progress rates of the groups, and also better at asking 'leading' questions. The course had seemed like hard work the first time, but was far more enjoyable for both Sam and Dr Brown the second time around.

Dr Brown knows that Sam (who found the experience very useful and more interesting than other tutorial work) will not be available to help any more and that another post-graduate will need to step in. In the best case, Dr Brown would like to have a student who had actually taken the course perform a facilitation role, but he would have to wait for a home-grown post-graduate. For the next year, he would spend a little time over the summer training his new assistant, perhaps involving her in tweaking one or two of the problems.

Dr Brown and his Head of Department are happy to continue the course using PBL. Other members of the teaching staff have noticed that Dr Brown's current or ex-students seem more interactive and engaged than the students who have not done any PBL. The PBL skills and attitudes seem to be useful in other courses and this is seen as an indicator of the success of the course.

Cost-benefit analysis

Costs	Lecture-based Course	PBL course
Development		
Time	Dr Brown can't state how much time it took to develop his lecture course: he thinks it took about two weeks originally, but he has made some changes most years.	Dr Brown: 200hrs (1st summer) 50hrs (2nd summer); Sam: 80hrs. Dr Brown envisages that the problems require one or even two revisions before settling, but also thinks that he would be willing to replace problems if he had interesting ideas in future – he is already makes notes for potential problems for another course.
Resources	About the same	
Implementation		
Time	5 hrs/wk staff teaching. 1 hr/wk staff marking. 2 hrs/wk post-graduate tutoring. 2 hrs/wk post-graduate marking. Tutorial question setting and model answers: Dr Brown drew questions from a set he had developed with the course.	4 hrs/wk staff teaching, 4 hrs/wk post-graduate. VLE support: (average) 2hrs/wk staff, 2hrs/wk post-graduate. Cost of post-graduate support increased but would not need to increase further if more students took the course. With a smaller class, Dr Brown could manage on his own. The time spent on the VLE was actually spread over the week in small chunks - Dr Brown and Sam would log in once or twice a day to answer queries etc.
Resources	Lecture Theatre 3hrs/wk. Seminar room 4hrs/wk. Photocopies (notes etc.).	Classroom 4hrs/wk. Access to PCs outside class hours Students print their documents using print cards or home printers.
Assessment	Exam design and marking: the same.	
Benefits		
• Improvement in student responsibility for learning even outside this course. • Feeling of satisfaction for Dr Brown that his course is being taught in a way that shows why the subject is important and interesting. • Slightly improved exam marks. • Improved links between knowledge: for example where and how to apply maths techniques. • Staff time spent marking was replaced by time spent interacting and giving feedback via the VLE. Dr Brown felt that this was a more productive and flexible use of his time. • Department able to monitor the introduction of PBL without committing to wider changes among the teaching team. • Students gained more experience of applying their knowledge (without lab work) than a lecture course would permit. • Students are given the opportunity to explore the subject and to integrate new knowledge into their perception of the subject area in a meaningful way. • Students and teachers feel able to discuss the subject with enthusiasm and understanding.		

Composite Case Study: A single event

Scenario

The Physics Department in Otherton University currently uses a mixture of lectures, laboratory sessions, directed reading, and project work throughout its portfolio of physics degrees. The Department has modified its teaching strategy over the last five years to reflect its commitment to student-centred methods. A vital part of the first year course is the induction phase during the first term, when students develop the independent learning skills needed throughout their courses.

Motivation to change

At the last curriculum meeting, it had been suggested that students could be given a better introduction to group work skills at the beginning of the first year. It was felt that by encouraging the students to reflect on the way they work together in teams, later group activities would start and run more smoothly.

Two members of staff, Dr Green and Dr Salmon, volunteered to organise a half-day skills session on group work, with a small laboratory component.

Constraints

To fit in with the existing timetable, the session would run for three hours on a Tuesday afternoon and would take place in the first year general laboratory. The session would be run in the second week of term by Dr Green and Dr Salmon, who would both be busy over the summer and had limited time for preparation. Equipment would not be a problem as the first year laboratory was well equipped, and it was not envisaged that the activity would require any additional outlay.

Management of change

Dr Salmon was keen to use problem-based learning for the group skills session. PBL was an obvious choice because it allowed group skills to be developed and practiced, as a natural way of working through a problem. Furthermore, the students would be meeting PBL later in their course, as several modules were problem-based, so this session would be an ideal introduction. Dr Salmon, who ran one of the PBL modules, said he could draft some ideas for a problem before the summer vacation started. Dr Green, on the other hand, had never used PBL before. He was not certain that adding what he saw as an extra degree of complexity to the activity would be productive. He agreed to try PBL but had concerns that the PBL activity would not suit all students (see box on right).

Problem development

Dr Salmon had several ideas for possible problems already forming. Knowing that Dr Green was somewhat doubtful about PBL, Dr Salmon decided to ask Dr Green to choose which of the ideas would be used. In addition to group skills, which could be introduced and thought about during any one of the problems, each of Dr Salmon's ideas involved some additional learning outcomes in the shape of lab skills.

Dr Green was surprised that Dr Salmon felt that more than just group skills could be emphasised in the time available, but was happy with several of Dr Salmon's ideas. One was chosen, and Dr Salmon spent a few hours writing up the materials.

Assessment methods

Throughout the induction period, each first year student kept a portfolio which detailed the techniques and learning outcomes of each activity. Although not counting towards their degree, the final mark for the portfolio counted towards their first year mark. For a three-hour induction session, students could earn a maximum of 10 credits, but how these credits would be allocated was up to the course convenors. Dr Green and Dr Salmon wanted to concentrate on the group work element, and to give marks for group function and individual contribution towards the group. They agreed that part of group work was 'getting the job done on time', so decided also to give each group marks for completion. Aware that with twelve groups (each of four or five students), three hours, and just two members of staff, there must be a straightforward and fast assessment process, Dr Green devised the assessment grid shown below. Dr Green and Dr Salmon would each assess six groups.

Group :						
Task Completion	**No** [0]	**Nearly** [1]	**Yes** [2]			**Group Mark**
Group Function	**None** [0]	**Some** [1]	**OK** [2]	**Good** [3]	**Excellent** [4]	
Individual Contribution	**None**	**Some**	**OK**	**Good**	**Excellent**	**Total Mark**
Name:	[0]	[1]	[2]	[3]	[4]	
Name:	[0]	[1]	[2]	[3]	[4]	
Name:	[0]	[1]	[2]	[3]	[4]	
Name:	[0]	[1]	[2]	[3]	[4]	
Name:	[0]	[1]	[2]	[3]	[4]	

PBL and learning styles

Data gathered using the ASSIST questionnaire (see www.ed.ac.uk/etl/questionnaires/ASSIST.pdf) during Project LeAP's pilot PBL studies were used to form groups of students with similar learning styles. The performance and attitudes of these groups were then followed throughout their PBL experience. Initial results suggest that although intuitively PBL should suit deep learners more than surface and strategic learners, in fact no measurable differences were found.

PBL is notoriously difficult to study from an educational research standpoint, and Project LeAP is a development rather than research project. It is very difficult to reduce variables so that individual factors such as gender, ability, and age can be isolated. Sample sizes were too small, with too many independent variables for effects to be visible.

Pitfalls

Dr Salmon is confident that the activity will run smoothly and prove useful to the students. Dr Green has his doubts, but is hopeful of being proved wrong. What will happen? We wonder whether the following issues have been adequately addressed:

- The first year lab is described as ‘well equipped’, but how often have all fifty students been performing the same experiment all at once? Will there be enough copies of the experimental equipment?
- Has Dr Green underestimated the time it will take to perform assessment, given that the two staff members also have to facilitate groups who are new to PBL?
- Indeed, are ‘floating facilitators’ (i.e. one facilitator looks after several groups at once) ideal for a session designed to encourage group skills? Would it be better to have someone sitting with each group for a longer period of time, in order to gain a feel for group function and to help it along?
- Has Dr Salmon managed not only to convince Dr Green that PBL will work, but also that Dr Green can be a facilitator? Is it easy for one member of staff to ‘tutor’ a colleague to change his or her teaching style? What if Dr Green’s concerns are transmitted to the students?
- Has Dr Salmon tried to pack in too much content into too short a time, bearing in mind the inexperience of the students? Should learning objectives be constrained?
- Has the notion of ‘open-endedness’ been defined for this problem? Can students ask for additional equipment? Can they leave to look something up in the library, or do they have internet access in situ?

Outcomes

One of the most difficult areas to predict when first running a PBL activity is how much time the students will take. With a longer problem, facilitators have room to even out timescales and even adjust the problem itself by adding new material, for example, or providing a little more guidance. However, with a shorter activity, there is no room for adjustment. It is very counter-productive to end an activity of this sort without completion, so it is often better to be generous with the time allowed.

We would expect that students meeting PBL for the first time would experience some feelings of confusion – not knowing where to start or exactly what was expected. However, by placing the event so near the beginning of the students’ university experience, these feelings could be minimised: it is often the students who have become comfortable with a routine of lectures and traditional laboratories who find greatest difficulty when faced with PBL for the first time.

Ideally, it is advisable to cut down the number of ‘first-times’ in any implementation. Here we have three: it is the first time the problem has run, it is the first time the students have experienced PBL, and it is the first time that one of the facilitators has experienced PBL. To offset this, Dr Salmon is experienced in writing problems and facilitating. If he can ‘mentor’ Dr Green in preparation for facilitation, Dr Green will have an advantage over those that have to learn without the benefit of others’ experience (see PBL Facilitation FAQ in the previous section).

Turning to the students’ viewpoint, an activity of this nature should be more engaging than a traditional skills session. Trying to think abstractly about working in groups is not as easy or as much fun as having a physics problem to solve and thinking hard not just about *what* everyone is doing but *how* and *why* the group can work well together. If Dr Salmon has balanced the problem appropriately, the students should have time to reflect on their groups’ performance, and their own role in the group, in a ‘real’ working environment. This will be something they can build on throughout their degree.

Cost-benefit analysis

Costs	Traditional skills session	PBL session
Development		
Time	If this activity had not included lab work, the development time would be similar to a traditional approach, although many traditional skills sessions rely on pre-prepared materials such as videos, reducing the time needed to develop the session.	Dr Salmon spent additional time designing the lab equipment list. The two members of staff spent several hours discussing how the session would work. Dr Salmon may have been able to develop the session faster by working on his own, but in this case it was expected that the activity was ‘owned’ by a teaching team, not an individual.
Resources	Development of this short session would require very few resources in either case.	
Implementation		
Time	This was constrained to be the same as usual: 3hrs x 2 members of staff.	
Resources	Ordinarily would not happen in the lab, so would require only paper-based materials and AV aids.	A few items of lab consumables were bought to top up stocks. The activity required lab technicians’ time to set up and clear away.
Assessment	The activity had previously required a short piece of reflective written work to be produced by each group. This required about 15 mins to mark, or about 3 hours of additional staff time in total.	All the assessment was designed to take place within the session itself.
Benefits		
• Students learnt or reinforced knowledge and lab skills whilst learning group work skills. • Group work was demonstrated in a real-life situation. • Students were better prepared for later modules, especially those requiring problem-solving in groups.		

Composite Case Study: Problem Classes

Scenario

Dr Silver, Dr Lemmon, and Dr Rose have recently joined a rather traditional, research-oriented astronomy department. All three have been given some teaching tasks, lecturing either in core areas or options. Dr Lemmon already has ten years lecturing experience, but comes from a small department which is struggling to maintain student numbers, and so is used to dealing with twenty or thirty students rather than the more than one hundred students who face in him in his new lecture course. Dr Silver and Dr Rose are new to lecturing. Whereas Dr Rose is looking forward to the experience, Dr Silver is not as enthusiastic, regarding teaching duties as secondary to her research. She is, however, interested in developing skills among students who are potentially going on to research. All three new staff have been introduced to Dr Grey, their departmental mentor, who will be available to them to discuss any queries they have and to help them to 'fit in' to the department.

Motivation to change

Dr Grey was looking forward to welcoming the three new members to the staff. In his opinion, the department would benefit from some new ideas and some younger faces. He felt that although the department attracted high-quality students and was praised for its results, there was a tendency towards thinking that no changes should be made and that no adjustments were needed in syllabus or teaching style. Dr Grey believed this was short-sighted and the department ran the risk of being suddenly out-competed by other physics departments who were working harder to attract the diminishing number of students who wanted to study physics at university.

Dr Grey wondered whether he, a current colleague who had similar views, and the three new staff could together begin to make some small changes towards a more flexible and targeted teaching strategy. With proven success, these small changes might become an accepted part of the departmental culture, and more wider-ranging changes might then be possible.

Dr Grey proposed to introduce changes in the problem classes which were a feature common to each lecture course within the department. Usually, the students were given four or five 'problems' each week, and the solutions were explained at a one-hour problem class after they had been marked and returned.

The questions set had always been of the 'end-of-chapter' type. Dr Grey suspected that students solved the questions by pattern-matching to things they found in their lecture notes. He believed that students who obtained high marks for the problem class questions often did so without strengthening or deepening their understanding of their lecture notes at all. He also believed that the problem classes did nothing to prepare students for their later project work. Dr Grey often saw students completely stumped when they first came across a problem in their project work which differed even slightly to those in their lecture notes or textbooks. At this point, many students would give up and ask him to solve the problem for them, rather than try to investigate an alternative method of working. Surely the problem classes could, and indeed should, help to develop these skills?

Constraints

Dr Grey was aware that each individual lecturer had only limited control over his or her teaching. Assessment, timetables, and laboratories were all predetermined, and no further allocation of resources would be available. Most importantly, any changes which were made would have to be approved by the HoD in advance and must, from the start, be shown to have no negative effect on the students' marks.

Management of change

Dr Grey and his colleague Prof Peacock decided to re-write some of the problem class questions as 'proper' problems. They had both read about problem-based learning, and saw that by introducing some of the principles of PBL, they could turn 'end-of-chapter' questions into more engaging problems. Rather than attack every single question over the three courses with which the team was involved, they decided to introduce the idea gradually by giving one 'adapted' problem per week, along with three of four traditional ones. This was proposed and agreed upon when all five staff met together to discuss the idea.

The HoD was interested in the plan, and supported the changes after hearing the proposal and the reasoning behind it. He felt that there was no reason not to try the idea, but said that he would be listening to students' reactions carefully.

Problem development

The work of adapting the problems was given mainly to the new staff members, each of whom would be expected to spend a number of hours preparing their teaching. As all three were given a comprehensive set of notes for the lectures, writing the problems would be a good way of familiarising themselves with the courses. Dr Grey and Prof Peacock agreed to review the problems and would themselves be leading the problem classes.

Assessment methods

As the problem classes counted towards the students' degree, the way the new style of problem was marked was discussed carefully. The new-style problems were seen as more difficult than the original ones, but were also asking for more than just a correct answer. It was felt that the marking scheme should reflect these points. Dr Lemmon believed that the students should be expected to collaborate on the problems (many already worked together to answer the other questions) but bringing group marking into the problem class assessment from the beginning was seen as impractical for two reasons. First, the students were not used to group working and group assessment in this sort of setting, so it would be difficult and inefficient to formalise groups just for the sake of one question per week; second, the HoD had been keen to keep assessment as comparable to existing schemes as possible in order to monitor the impact of the changes.

Pitfalls

The proposals here are rather subtle and do not represent a large-scale change in teaching method. We see this as a low-risk but high-potential activity. However, there are a few possible pitfalls to avoid:

- Do all five members of staff share common expectations and a common understanding of PBL? Will Dr Silver feel that developing problems is a good use of her time?
- When problems are created by one person and run by another, the author has to make clear in supporting documentation what the problem covers, which directions it may take, and also any further avenues which it opens for discussion. Do the new lecturers understand that a problem is more than just a statement?
- Can individual assessment of one hundred students realistically be expected to include a 'process' mark? Will the assessment scheme continue to be the summative process that it was in the traditional problem classes or can a formative element be introduced?
- It is not clear whether the 'adapted' problems are compulsory or optional. It sounds as if they are placed last in the list of question each week. Having noted that the 'adapted' questions *look* more difficult, will students simply avoid them? Is the additional weight of marks enough to encourage students that they are worth the effort?
- With one hundred or more students in the year, Dr Grey and Prof Peacock each lead two one-hour problem classes of twenty-five students per week. Will there be enough time to go through the traditional problem and extract the important points from the 'adapted' problems? Will students be able to work on the problems in informal groups without supervision?

Outcomes

Writing a series of PBL problems is often a task that is very difficult at the beginning, but becomes easier with practice. There are also signs that problem-writing comes more naturally to some people than others – it is hard to generalise, but wider teaching experience and varied personal interests seem to be factors that increase PBL creativeness. With three people engaged in writing a large number of problems, we expect that the output would vary widely from person to person. There may be some re-distribution of tasks to suit skills, with roles such as the 'ideas person' and the 'materials author' appearing.

It would be beneficial if the students who attempt the 'adapted' questions are encouraged to discuss their results in the problem classes. This is a good opportunity to show that sharing methods and approaches, even where the solution has not been reached, can be very useful. Class sizes of twenty-five may be too large for this to happen, but Dr Lemmon's small-class experience may be of use in this situation.

We imagine that students involved in these problem classes will be able to convince Dr Grey that they are understanding the material and are becoming able to adapt and expand their knowledge in ways which will benefit their later project work. We think there is little risk that the HoD will see a drop in student performance or perceived quality of the course. We would be surprised if students who successfully engaged in solving the 'adapted' problems did not feel some added confidence for their exams.

Cost-benefit analysis

Costs	Traditional problem classes	PBL problem classes
Development		
Time	This depends on whether a suitable stock of questions are available. Usually, a bank of questions is developed over time, not over one summer.	Writing 24 short problems from scratch would be time-consuming, but here the staff are adapting or 'PBL-ising' existing problems with pre-defined learning outcomes. 24 x 2.5 hrs = 60 hrs divided between three staff members.
Resources	Possible purchase of books with good ideas for problems.	None needed.
Implementation		
Time	2 hrs each per week for classes for two members of staff.	It might be found (especially if further traditional questions are replaced with PBL ones) that smaller classes are more beneficial.
Resources	No change.	
Assessment	20 hrs marking (usually given to post-grads).	The same, although depending on the complexity of the marking scheme for the 'adapted' problems, the markers may need new guidelines and a little more time.
Benefits		
• Deepens student understanding. • Reduces 'pattern matching'. • Improves students' preparedness for project work. • Is an easy way to bring the benefits of PBL into a traditional curriculum. • Makes problem classes more fun for staff and students alike by avoiding running through model answers and by promoting discussion of alternative ways of solving problems.		

Composite Case Study: Whole Degree

Scenario

The Physics Department at Middleground University has a good research profile but is failing to recruit students to physics degrees and relies on service teaching to science students for its student numbers. This is under threat as other science departments feel the pressure of declining enrolment.

Motivation to change

Current recruitment to level 1 of the three year degree is hovering around 20, down from three times that number only a few years ago. Mindful of the Aalborg experience in the cognate discipline of engineering, the Head of Physics, Professor Stern, has been persuaded to redesign the physics curriculum from the ground up, around problem-based learning. Dr Mull, who has shown more interest in teaching development than some of his research-oriented colleagues has been chosen to champion the change. While many colleagues are unconvinced, Professor Stern has found enough support to form a team to redevelop the level one courses; if this is done successfully and is effective in the use of staff time, he will insist on the change being taken through to subsequent years.

Constraints

Dr Mull insists that development time be made available by rationalising some of the now poorly attended option modules and that there should be some funding for external consultancy and evaluation, and for staff development. Although the senior staff refuse to forgo any share of their now declining research allocation, Professor Stern has managed to obtain some University development funding. He uses this to attend a PBL summer school in the US and to visit various departments, mainly engineering departments in the UK and Europe, that have changed to PBL.

His colleagues want to introduce PBL gradually into the curriculum, and to delay the full implementation for at least four years. Dr Mull knows from his consultations that this would be a mistake. The co-existence of PBL and lectured modules with no rational grounds for the difference apart from staff predilection creates disenabling tensions in students. Delays in implementation lead to endless re-arrangement of the curriculum without progress towards development of problems (called the ‘walking kidney effect’ by designers of medical syllabi because the time is used in committee meetings to re-assign the difficult and unwanted task of teaching the kidney). The decision is therefore taken to keep just one full year (and a summer vacation) ahead of the student entry.

Management of change

Dr Mull set up teams for each module, with the exception of the laboratory work, which was to remain unchanged initially. The idea was that the teams would have ownership of their problems, but would not have the difficult task of developing practical projects without experience of PBL. Both of these arguments turned out to be mistakes. The autonomy of the teams ceded control of the timetable for production of materials, so that a lot of time was wasted later in trying to extract materials reasonably in advance of the last moment when they were needed. As a consequence, the decision also yielded control of the overall quality control of the material, some of which ended up lacking the real world open-endedness of PBL. The retention of the standard practicals created even more of a tension between the menu-driven approach to laboratory work and the theoretical material than previously, and missed the opportunity to integrate experiment and theory.

Problem development

Nevertheless, the teams found the opportunity to start from a clean sheet extremely energising, and entered into the general discussions, if not the actual details of suitable problems, with considerable enthusiasm. There were some initial fears that parts of the curriculum were too important to be left to PBL, but these were overcome as staff entered into the development of what students would actually be asked to do. The were also fears that it would turn out to be too difficult to teach some areas of physics by PBL, but once they had got started it was agreed that the level one syllabus should not be a problem - even including wave mechanics and mathematical methods.

Dr Tan had long found the teaching of mathematical techniques a chore. He had reflected on the fact that other skills, such as presentations and teamwork could be taught in interesting contexts and wondered if the same might be true of mathematics. Professor Hands was appalled at the suggestion. He recalled an abortive attempt some years ago to teach mathematical techniques alongside the physics, which had ended up with the students confused about both and quite unable to generalise the mathematics outside the context in which it had been taught.

Dr Tan was not convinced. He was sure the problem lay with the type of context in which the mathematics was set. This should involve familiar physics and pose a problem that would gain student interest. He recalled a colleague in chemistry who taught vectors from the problem of calculating distances between atoms in molecules and wondered whether this could be extended. Professor Stern took the brave decision to let him make the attempt incrementally.

The students underwent an extensive full week induction. The fixed facilitator model was adopted, largely based on the engineering and medical school models, with regular ‘tutorials’. A number of lectures were retained to explain difficult points as they arose in the problems. Because students learnt as they went along, an extension of the teaching year was made possible by a reduction in the period previously set aside for revision.

Assessment methods

The fixed facilitator model lends itself readily to continuous assessment of both process (how well the groups tackle a problem) and outcomes (how they succeed). Less talented students can often do well on the former without necessarily achieving all the higher level outcomes. This can relieve the burden on final examinations, in particular the pressure brought about by modular structures to over-examine. Thus, a significant amount of staff time has been saved by constructing questions that cross subject boundaries and reducing the overall number of papers particularly in year 1.

Pitfalls

We expect that the second level could prove difficult as it involves some less committed staff members. However, as the first year settles down it will be possible to use the then more experienced staff in second level and to put some newer staff into level 1. We feel that some of the practices are unlikely to be scaleable to significantly larger numbers of students.

We anticipate that successful recruitment will require a revision to the PBL model but the time-consuming development of problems will not have to be redone.

Outcomes

What have the outcomes been? Examination performance has actually improved without adjustment to the standard of the examination, although some of the regurgitative aspects have been substituted with more problem oriented questions. Retention rates have improved. As yet there is no marked increase in recruitment.

Cost-benefit analysis

Costs	Lecture-based Course	PBL course
Development		
Time	Preparation of traditional lectured-based courses differs widely from lecturers who do no more than glance at the subject matter for a few minutes to those who produce meticulous PowerPoint slides over a few hundred hours; from staff who chose a few exercises from the book to those who carefully hone their own ideas.	Probably not significantly more time was required to develop problems than would be needed for an ab initio lecture programme, although there is a steep learning curve which appeared to lead to little production of useable materials in the initial phases. Time is required to develop facilitation timetables and assessment procedures, but again no more than for a wholly new traditionally taught programme. HoD involved significantly in driving the development in a way that would not be required for traditional teaching.
Resources	The years of staff development that go into 'improving' lecture-based teaching should be counted here.	Popular science material can be a source of interesting problems and is often not held in University libraries. Staff purchased some books for problem development. There was also a need for staff training in problem development.
Implementation		
Time	With 20 students in groups of 10 and a fixed facilitator model the contact time was surprisingly similar to traditional teaching even though in the start-up phases there was a tendency to greatly over-provide facilitated sessions. A rethought out model might be required for larger classes. The abolition of separate remedial maths classes was a bonus.	
Resources	Tiered lecture theatre largely not useable outside lectures. Separate computing areas are also required.	Availability of flat classroom space presented difficulties; required the use of laboratory space for teaching. Each group was provided with a wireless laptop and a data projector was purchased for group presentations. Classroom space can also be used as student work areas.
Assessment	Traditional exams.	Fewer examinations; reduced marking load.
Benefits		
• Increased student engagement; fewer absences. • Increased retention and completion rates. • 'Students much more interesting to teach'. • Embedded transferable skills. • Integrated laboratory work.		

Composite Case Study: Audit and Accreditation

If one is looking for reasons not to think about PBL, then programme accreditation is often considered to be a 'banker'. Sometimes this is a genuine fear. Professor Beak is experienced at audit panels and accreditation boards and he has indeed seen examples where a single PBL module creates destructive disjunctions in the expectations placed upon students. Often heads of department are happy enough that this does not threaten a whole programme, may even be unaware of any difficulties, and may even be promoting the PBL module as the evidence for curriculum development (which might otherwise be thin on the ground). Sometimes however an audit visit to a department that has partially adopted PBL is the scene of a battleground between the PBL zealots and the fifth columnists. These visits Professor Beak particularly enjoys.

Under the guidance of their enthusiastic HoD the staff at Middleground University have been (more or less) persuaded to invest in PBL. So far the first year of the programme is taught by PBL and it is about to be rolled out to year 2. But all has not gone well.

The Department had initially experimented with some optional courses taught by PBL. These had generally been successful, except that some students had complained about the workload. These complaints could be dealt with simply, by referring to the credit scheme, which defined the expected number of student hours for each module.

Embedding PBL in the core teaching, where it would not just be in the hands of a few enthusiastic staff, was another matter. Typical was the fear that students would emerge from the problems not having covered vital information, or not having dealt with it at the appropriate depth.

HoD had given staff little time to prepare for the changeover to PBL. This was deliberate. It had forced staff to get on with problem development from the beginning and not waste time debating the PBL philosophy. However, the learning curve associated with problem development had been particularly steep. Many staff had found difficulty with the notion of student roles as stakeholders. They felt that it was artificial to regard the students as other than students. They also struggled with ill-defined problems (confused with problems that are not-clearly worded) and triggers, learning issues ('wouldn't it be simpler just to tell them what I want them to know'?) and matching problems to learning objectives (the solution should not be downloadable from the internet). Thus much of the time to prepare for PBL had been spent on discussing problems that were subsequently abandoned.

The Head of Department was aware that PBL does not forbid (except amongst some purists) the use of lectures where appropriate, but had found constant intervention in the planning process had been required to ensure that the planned lectures would not provide bookwork solutions to the PBL problems, and that proposed facilitated sessions did not turn into lectures. The audit documentation showed that staff had attended problem-writing sessions and sessions for facilitator training. Nevertheless, while many staff were willing to suspend judgement, and none would disagree in public with HoD, some were privately hostile. This had opened the process to being undermined by staff incitement of students, and cast a shadow over the accreditation process.

At the audit meeting Professor Beak was able to refer the staff to their own audit documentation. There they had all signed up to a list of fifteen closely argued ways in which the PBL approach benefited students. At the audit panel he took the opportunity to rehearse this list with the staff representatives. The professor observed that he had never come across an equivalent list of advantages for the traditional lecture-based approach as an educational strategy. As expected the panel looked closely at the physics content of the new programme. Some more advanced material had been omitted and some topics were less developed than previously, but student work demonstrated a breadth of knowledge and problem-solving experience commensurate with more traditional courses. The audit panel was pleased to congratulate the Department on its initiative and in particular those staff who were working to make it a success.

In his report Professor Beak noted how teething problems in other institutions in introducing PBL had been overcome in time, particularly in developing problems that would persuade students to engage fully with the learning objectives and not respond in a minimalist and superficial way. He assured the staff that, where problems occurred, what was important was the response of the Department to student and external evaluation; the students were fully aware of this, and were supportive of the process. Professor Beak was also able to re-assure the staff that the smaller amount of material being covered was appropriate, and that, more important for the purposes of audit and accreditation, was the meaningful embedding of professional skills within the curriculum.

Accreditation was approved.

Experiences of Problem-based Learning

A Note to Students about the Use of PBL in Learning Physics

George Watson, University of Delaware

Greetings from the University of Delaware! We have been using problem-based learning in introductory science courses here for more than a decade. Our students often ask "Why are we using PBL?" and you may be asking the same question. I would like to provide you with the same three rationales that I report to my physics students.

Learning is more enjoyable with PBL

At some point in your study of physics you will encounter a task similar to the following problem:

A 1.5g object moving at 2.5 m/s collides with and sticks to a 2.5g object moving orthogonally at 2.0 m/s. What is the velocity of the resulting mass?

With no real context for this scenario, you may not see the relevance to the world in which you live. With a bit of context, as follows, the importance of the concept of linear momentum becomes clear:

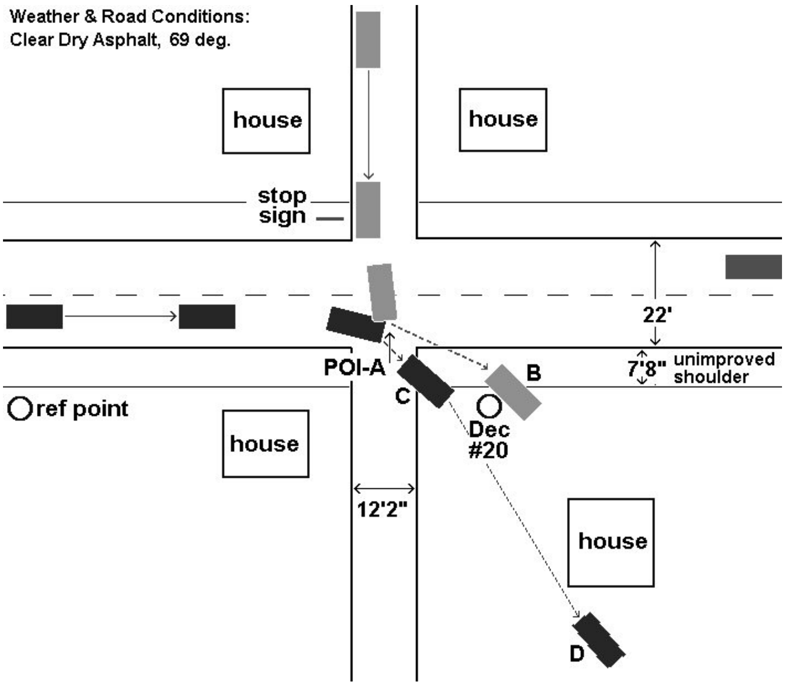
A 1500kg car travelling east with a speed of 25 m/s collides at an intersection with a 2500kg van travelling north at a speed of 20 m/s. Find the direction and magnitude of the velocity of the wreckage after the collision, assuming that the vehicles undergo a perfectly inelastic collision (i.e., they stick together).

[Serway and Faughn. 3rd ed. College Physics, Saunders, 1992.]

However, the thought process and numerical manipulation involved in solving this context-rich problem is parallel to the first example. The mass and velocity of each vehicle is completely specified and the type of collision is fully defined. Please compare the above scenario to the PBL problem below:

Last Friday a frantic call was received at the local police station. There was a serious automobile accident at the intersection of Main Street and State Street, with injuries involved. A police officer arrived at the scene ten minutes later and found that two cars had collided at the intersection. In one car, the driver was unconscious and in the other car both driver and one passenger were injured. After the emergency vehicles departed with the injured, the officer's responsibility was to investigate the accident to make a determination of which driver (or both) was responsible. The resulting sketch of the accident scene is stylized below – what more do you need to know to determine blame?

[Based on "A Day in the Life of John Henry, A Traffic Cop" by Barbara Duch. The Power of Problem-Based Learning, Stylus Publishing, 2001.]



As with most good PBL problems, not all the information needed to solve the problem is included in the opening scenario. For example, you will need to know the make and model of each vehicle so that you may research the masses. And most certainly, on the way to a final determination of blame, you will learn and apply the conservation of linear momentum [a main learning objective of this problem] to establish whether one automobile failed to stay stopped at the crossing street or the other automobile was speeding down the boulevard.

Our experience with using PBL in undergraduate science courses is that students like you find a good PBL problem more engaging and more motivating than the standard fare. You enjoy working in groups, brainstorming items for investigation (we call them learning issues), and defending your solutions to other groups as well as to your professors. In the research we have done on PBL at the University of Delaware we find two results that stand out clearly: 1) students enjoy learning with this format and 2) students feel more confident in their learning as a result.

PBL helps you learn 'how to learn'

Fundamental physics concepts are timeless, of course, but their application to real-world settings and new devices are rapidly changing. The rate of generation of new information in the scientific and technical sectors is truly staggering. Information becomes outdated rapidly and is updated constantly; much of what you will need to know in the workplace following graduation has not been generated yet! Thus identifying when new information is needed, where to find it, how to analyze it, and how to communicate it effectively are essential skills to learn during your undergraduate studies. An important result of PBL is that while problems are used to identify what to learn, the process of learning "how to learn" is also developed. This method of instruction helps you develop skills important for success both in your undergraduate education and in your professional life following graduation.

Effective learning is much more than memorizing information to answer questions on examinations. "Learning (is) a process that culminates in the ability:

- to ask the right questions and frame good problems,
- to acquire information and evaluate sources of information,
- to critically investigate and solve problems,
- to make choices among many alternatives,
- to explain concepts to others (both orally and in writing), and
- to generalize to new situations." [Ref 1]

Using PBL you learn how to learn and learn more deeply than is typically the case in courses focusing on more superficial acquisition of information and assessment through regurgitation of simple facts and calculations.

Critical skills for the workplace are developed with PBL

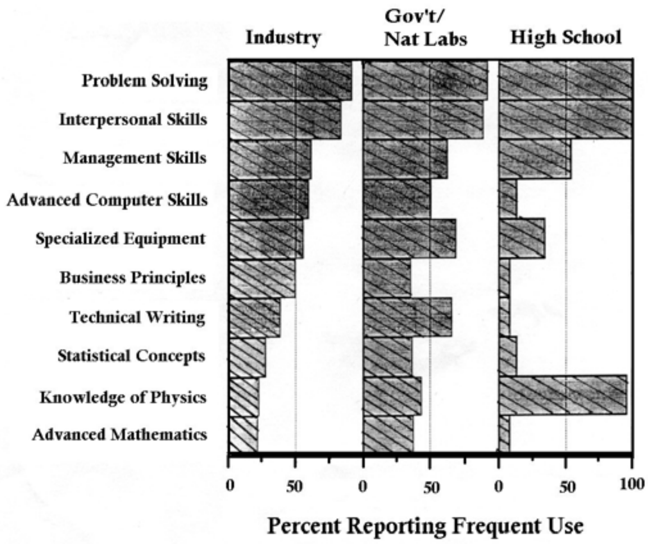
Finally, what do employers want to see from new graduates entering the workplace? Business leaders regularly identify the following characteristics they seek in university graduates: High level of communication skills; ability to define problems, gather and evaluate information; good teamwork skills and the ability to work with others; and the ability to use all of the above to address problems and find solutions in a complex real-world setting. [Ref 2] The chart below presents self-reported skills used frequently by physics bachelors in selected employment sectors: industry, government laboratories, and high school teaching. [Ref 3] I do not mean to imply that knowledge of physics is unimportant, but rather to indicate that other skill sets are frequently used and highly valued in the workplace. Not surprisingly, problem solving is a skill that is often used in all sectors, and good physics majors are universally known to possess highly refined skills in problem solving. Note also the high ratings for interpersonal skills. Where can you develop these skills in your university work? Problem-based learning provides an excellent format for learning communication and teamwork skills that are critically important in the workplace.

Conclusion

I hope that you enjoy the use of PBL in your courses and that you realize the benefits that I have mentioned. Best wishes for success in your studies!

Acknowledgements

In my personal development in using PBL and my writings about problem-based learning, I am deeply indebted to my University of Delaware colleagues in the Institute for Transforming Undergraduate Education, particularly Deborah Allen, Barbara Duch, Susan Groh, and Hal White. In my course syllabi (example listed below), I have borrowed liberally (and often verbatim) from the writings and syllabi of Deb, Barb, Sue, as well as Betsy Lieux, to support my use of PBL in the classroom.



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[Ref 2] *Quality Assurance in Undergraduate Education: What the Public Expects*. Wingspread Conference, Education Commission of the States, Denver, CO. 1994

[Ref 3] American Institute of Physics, Education and Employment Statistics Division, 1994 Sigma Pi Sigma Survey of "*Skills Used Frequently by Physics Bachelors in Selected Employment Sectors, 1994*".

Institute for Transforming Undergraduate Education at the University of Delaware
www.udel.edu/inst/

Problem-Based Learning at the University of Delaware
www.udel.edu/pbl/

Silicon, Circuits, and the Digital Revolution
www.physics.udel.edu/~watson/scen103/colloq2000

A Light Introduction to PBL

James Collett, University of Hertfordshire

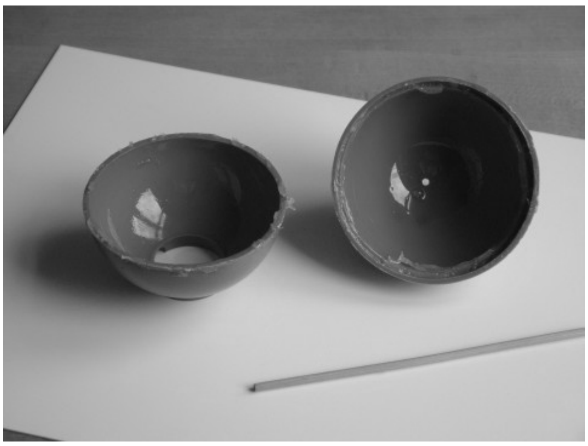
Background	
Class Size:	~ 30
Duration:	1 - 2 hours per session
Level:	various

A wonderful sense of the excitement of PBL is conveyed by Ed Purcell in his article New Practical Physics (Purcell 1997 Am. J. Phys 65 (8)). Purcell organized his seminar group students into small groups of two or three and posed them a stimulating problem such as: 'Is there turbulence in the cardiovascular system?' The rules of the game were that the students were to use what they knew, had to try and work out anything they needed, but were directed not to look things up. Purcell saw this as a way of widening their physics education to tackle problems of astrophysics, geophysics or engineering, areas of applied physics that they would otherwise be unaware of. A not dissimilar group is also described in Alan Lightman's engaging novel 'Good Benito' (Lightman 1995 *Good Benito* Bloomsbury Publishing Ltd.). In both cases, however, it is clear that the students are from a traditional fast stream. One of the benefits of PBL however is that it often reveals important qualities in students – latent talents that might otherwise remain hidden and unacknowledged in a course with traditional assessment. Perhaps the lesson to take from Purcell and Lightman is the joy of just thinking up a problem and then giving it your best shot with limited resources, be it in the lab or classroom.

Light PBL is a way to get a taste of the stimulation of PBL courses without needing to plan a whole course based around it. Many practicing physics teachers have such elements in their courses; we will discuss here some examples where the use of a simple experiment enhances the student's intuition in tackling a challenging problem. Sometimes too, we have to forgo the instinct to pose problems too precisely. Easier as these are to assess, they ask less of a student than more open-ended problems in which the students must decide on the line of attack. Consider an example that would perhaps fit nicely into a Level 1 course: a wax mould for a candle is filled with water and then allowed to drain. How long will this take? To set this in context, we usually mention the water clocks that were employed in ancient Athenian Law Courts because the ultimate goal of the exercise is to calculate the shape of the draining bowl of water that gives rise to a constant rate of fall of the water surface. This design allowed the lawyers to readily assess the length of time they had to make their points. The first part of the problem is to ask the students to make their best estimate of the draining time from the mould. The idea is to rely on intuition rather than any 'quick & dirty' estimate. The water in the mould is then drained into a cylinder and the fluid level filmed – either a digital video camera or a series of digital stills allows the drainage rate to be easily measured. Now the students can be let free on the calculation of the expected drainage rate. This involves modifying the standard treatment of draining water from a cylinder familiar from most fluid texts. Understanding how to make this modification and seeing it in practice will be the basis from which the students work out the water clock problem. The important point is that direct observation of the water level in this case and the calculation that follows give the student the pleasure of a direct comparison between a simple experiment and a piece of theory they have worked out for themselves to explain it. The students can decide how to correct for the 'flat top' caused by the large hole in the upper hemisphere of the sphere, or investigate different-sized drainage holes or different fluids. The graphs are rather instructive and can lead to interesting discussions on the effect of viscosity on the flow rate and the way this dependence changes as drainage proceeds.

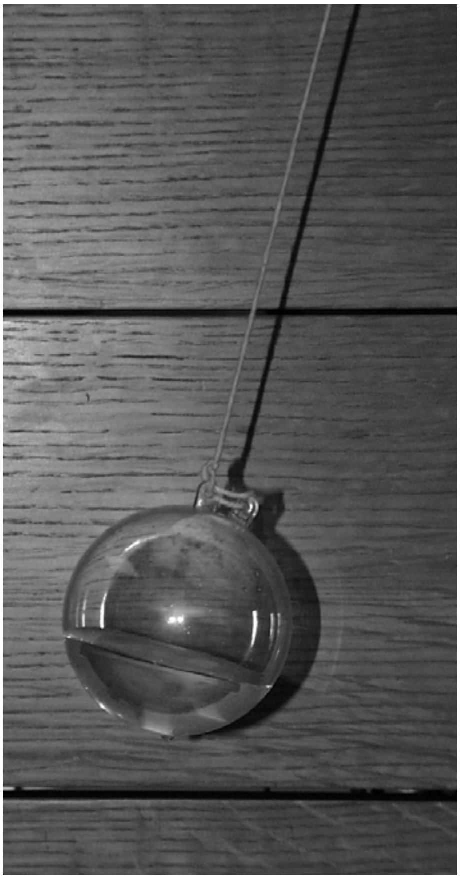
Another nice example is the following. Where should dust gather in a space ship? If this problem is set in this spare form, students may make little progress. So we preface the problem with another simple experiment. An acrylic sphere is part-filled with water and used as the bob of a pendulum. The students are asked to place their bets on the water surface tipping to one side or the other of the sphere or staying

The wax candle mould (shown below separated into two hemispheres to show the small drainage hole)

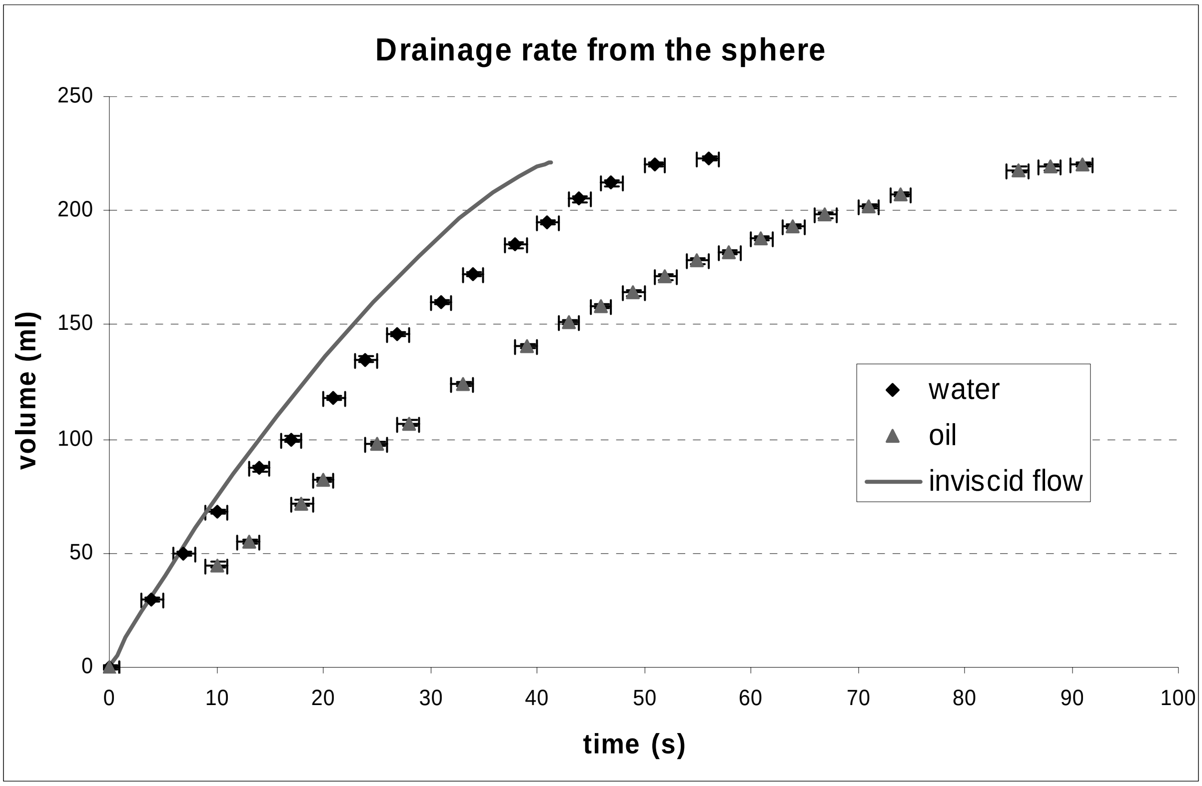


normal to the supporting thread. It is unusual not to find a range of opinions. Once the experiment is done and the final possibility is found to be the true state of affairs (see the figure below), the students appreciate better that the fluid is in freefall along its trajectory and there can be no pressure gradient in this direction. After exploring the case of a free-falling lift, we can ask what difference is caused by the minute variation in the acceleration due to gravity from the top to the bottom of the lift. Now the students are ready to return to the spacecraft and work out these tidal accelerations there – the force field that will determine where the dust will settle.

One of the nice benefits of these 'kitchen sink' experiments is that the students tend to look on them as open fresh territory. We suggest a contrast with a traditional physics experiment that has attached to it a very concrete outcome. Students are honed in to those observables that lead them to the answer. They are accordingly less likely to observe the general nature of the phenomenon in hand. A nice example to illustrate this uses the acrylic sphere again. Partially filled with water, the sphere is suspended from a wound rubber band and released. The rise of the fluid surface up the sphere is impressive, and students can watch to see how the fluid surface changes shape and note the propagation of small surface waves as the spin speed and direction change during the oscillation. Investigating the effects of changing rotation, and the unusual shape of the vessel gives renewed life to the classical problem of a cylinder of fluid in uniform rotation.



The water level in an oscillating pendulum



Problem-based Learning Physics Course in the Dublin Institute of Technology

Dr. Brian Bowe, Dr. Robert G. Howard, Dr. Siobhan Daly and Dr. Cathal Flynn
School of Physics, Dublin Institute of Technology, Kevin Street, Dublin 8, Ireland.

Background and Rationale for Change

In July 1999 a small number of lecturers in the School of Physics in the Dublin Institute of Technology (DIT) started investigating the feasibility of using more student-centred learning approaches in physics education. In 2001 the Physics Education Research Group was set up to carry out research to inform curriculum development and teaching and assessment practices. In the same year members of this group engaged in collaborative action research in order to design, implement and evaluate a first year physics problem-based learning (PBL) course.

The pedagogical reasons behind the move to PBL included concerns over students' approaches to learning and their conceptual understanding. Physics education research has shown that physics students may not developing the conceptual understanding to become adept problem-solvers (Hake, 1998; Knight, 2002; Van Heuvelen, 1991). This research has shown that students will not develop understanding of the conceptual nature of physics simply by solving quantitative problems even though physics education tends to rely on this assumption. It was envisaged that PBL would encourage students to adopt a deeper learning approach (Marton and Saljo, 1997), increase student motivation and hence engagement in the learning process, and help students to develop the skills necessary to become self-directed learners.

Although the reasons for changing to PBL were mostly pedagogical, as mentioned above, there were other factors that influenced the School staff. It was felt that an approach was needed which addressed staff concerns regarding student motivation and ability. Another reason for the change to PBL was due to the increased emphasis on the development of key skills, including group, presentation, communication and problem-solving. Inherent in the PBL approach is the development of all these skills along with others such as the ability to critique information and evaluate one's own work.

Development of the PBL Course

There were a number of pedagogical questions that needed to be addressed before beginning the PBL curriculum design process. For instance, the issues of content coverage, subject integration, and the integration of practical work had to be decided upon before any learning outcomes could be determined. The issue of content coverage was widely debated among the staff members in the School of Physics and it was evident from the discussion that the move to student-centred learning with the emphasis on conceptual change would need a dramatic shift in attitudes and perceptions. However, it was accepted that the PBL course could not "cover" the same quantity of material as its predecessor, the lecture-based course, but it was also accepted that what the students learn and what is "covered" can be radically different. On the issue of the integration of practical work, it was decided not to integrate the practical work initially but to use the year to devise ways in which this could be done in subsequent years. Since the initial development, the PBL team have developed and integrated a problem-based learning laboratory programme into the course (Howard and Bowe, 2004).

Background	
Course	4 Year Degree in Physics Technology
Year PBL Introduced	2001
PBL	1st and 2nd Year – theory and practical
Staff Involved	5
Number of Students	20 approx
PBL Group Size	4-5 students

The staff team decided against integrating the topics within physics and so kept mechanics, optics and so on, separate from one another. The reasons for this stemmed from the fact that these students were inexperienced in PBL and some of them had no prior physics knowledge. Physics education research (McDermott and Redish, 1999) has shown that students enter higher education with many misconceptions and the educational approach must allow the students to see the errors in their understanding before they can begin to develop conceptual understanding. The staff team believed that in order for students to restructure their conceptual understanding (Posner et al., 1982) it would be essential to keep the number of new concepts introduced in each problem relatively low. As the students progressed through the course the problems would become more integrated and realistic. Essentially these problems can be viewed as concrete scenarios that, by striving towards a resolution, students could develop an understanding of abstract concepts.

The staff team began the PBL curriculum development process by determining the aims, objectives and learning outcomes of the course. These not only included the learning outcomes associated with physics but also the learning outcomes associated with the development of key skills such as group, critical thinking, presentation and problem-solving. Once this extensive list was completed the assessment strategy was developed, which ensured constructive alignment (Biggs, 1999; Cowan, 2002) between the assessment methods, teaching strategy and the learning outcomes. Prior to the development of the PBL course only summative tests and examinations were used, so significant changes had to be made in order to ensure compatibility with the PBL approach. The purpose of the assessment strategy was not only to ascertain what learning outcomes each student was achieving, but it was also to encourage, diagnose and help students learn and develop. Therefore the assessment strategy developed for the PBL course was primarily formative in nature but with summative elements.

Each student's individual contribution to the group process is collaboratively assessed. A complete set of assessment criteria was developed and includes such things as their level of contribution, peer-teaching, questioning, and completion of assigned tasks. These criteria are negotiated with the students at various stages throughout the course. Based on these criteria each student is given a mark by the tutor for their contribution supported with both positive and developmental feedback. The student is also required to assess his or her contribution to the group process and award a mark based on the same criteria. The students keep a reflective account of their contribution and use it to justify their mark. A similar process is also used to assess reports and presentations.

To augment the feedback process a WebCT on-line learning resource was developed, which includes course information, calendar, links to other physics sites, simulations, quizzes, tests and communication tools, such as chat. To assess the students learning individually, there are three tests during the academic year in the form of online multiple-choice questions. There is also an end of year examination that is open book and involves the testing of the students' abilities to problem solve and their understanding of the physics concepts.

The students work in groups of six, with a roaming tutor observing the process and acting as facilitator. The students are presented with approximately one problem per week and have two, two-hour PBL group sessions to work on these with a tutor present plus a two-hour session without a tutor. At first the idea of a physics problem with no one correct answer or solving strategy inhibits the students' learning. The process seems very chaotic and confusing to the students but it is only by working through this that the students develop a real understanding of the subject. It is only after the students have had a number of group sessions that they begin to evaluate the problem in terms of prior knowledge and experience. During these brainstorming sessions the problem scenario becomes clearer allowing them to evaluate what knowledge and skills they will need to solve the problem. For each problem they delegate roles of chair and recorder before they begin the problem.

Initially the students use the "four columns" (Barrows, 1980) technique where they list the facts, ideas, learning issues and tasks. However as the course develops the students develop their own strategies based on the four columns.

The students are given regular tutorials on some of the theory or problem-solving tools they will have learned by solving the problem. The purpose of this is to re-affirm the knowledge the students have gained and to give the students confidence in themselves and the teaching technique. It also affords them the opportunity to assess their learning and evaluate their learning needs.

An induction program was developed in the School of Physics which introduces and explains the PBL rational and philosophy, the teaching methodology, assessment strategies and the learning resources which are available to the students. Further workshops are arranged throughout the year to deal with group dynamics and assessment.

Example Problem

The following is the first problem students are given upon entry to the first year (introductory physics) of the physics course:

Your group have been asked to take over an emergency situation at the Irish Train Control Centre. As none of the staff there have any special training, there will be a terrible accident with high casualties unless you can find a solution to their problem. On entering the Centre you are informed of the following: There is a passenger train on the track which has a serious engine fault. The train has eight carriages with 200 passengers. The driver cannot control the speed so it is travelling at a constant velocity of 30 ms^{-1} in a north-east direction. This train has only 9 km of track left. You can communicate with the driver but he has no control over the engine. However there is another engine (engine only) on the same track 600 metres behind the uncontrolled train. You can communicate with this driver and he has complete control over the engine. You can assume that the 600 metres is the distance from the front of one train to the back of the other. The track between the trains is straight as is the remaining 9 km.

At the moment the two trains are travelling at the same speed. An engineer in the Centre informs you that if the train behind were to catch up to train ahead the trains can be remotely connected together. The leading engine can then be switched off. Then the train behind can be used to stop the other train. However the connection has to be made when both trains are travelling at the same speed.

Outcomes

An evaluation strategy that concentrated on the students, their knowledge and their skill-based learning outcomes was developed. This strategy included a comparative evaluation of the problem-based learning course and a parallel lecture-based course (Bowe and Cowan, 2004). In short, the course achieved its initial objectives in improved students' motivation and engagement, conceptual understanding and student retention. The students found the course to be fun, interesting, challenging and motivating. The following are excerpts taken from the student evaluation forms in answer to the question what students like about PBL:

…."having fun learning"

…."learning from each other"

…."don't fall behind as everyone is constantly learning"

…."it is more effective and enables you to remember better"

…."you have to interact and so cannot be lazy"

…."the real-life problems are more interesting and challenging"

The major advantages of the problem-based learning course are that the students develop the ability to learn independently and in groups, develop key skills and the ability to contest and debate. It helps the students acquire ownership of their learning experiences by giving them more control over the learning process. It also offers the students the chance to engage with real-life problems and helps them see the ambiguity that may exist in real life situations. It helps develop the ability to critique information and allows the students to make sense of the material in their own way by integrating newly acquired knowledge with prior knowledge and experiences.

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Laboratory PBL at the University of Sheffield

D J Mowbray, C N Booth, C M Buttar, University of Sheffield

Introduction

The Department of Physics and Astronomy in the University of Sheffield has conducted a preliminary investigation of the problem based learning (PBL) approach in its first year physics teaching laboratory. This laboratory class starts with training in basic laboratory skills, moves on to a number of short (single afternoon) experiments, and concludes the year with group projects lasting 5 weeks. For these, students work in groups of five. It was decided that the best way to experiment with PBL-based work was to introduce a couple of group projects based on these ideas for a small number of students. The standard group projects provide an experience of team working and an opportunity for students to explore a topic in considerably greater depth than is possible in normal laboratory sessions. The group projects are also considerably more open ended than the experiments encountered previously and may involve material that the students have not yet met in their lecture courses. For the PBL-based projects clearly defined topics (Fourier series and the use of complex numbers in LCR circuits) were chosen that required an understanding of material that had not been covered in the lecture courses. The aim was to investigate if these concepts could be taught using a PBL approach.

Implementation in the first year teaching laboratory

Two topics were chosen for PBL projects. These both concerned topics which the students would not have covered in any depth in their Physics lectures. The students therefore had to obtain relevant background theory as well as learning how to apply it. The two topics chosen were:

- LCR circuit
- Fourier analysis

The LCR circuit project was chosen as AC-circuit theory had been dropped from the curriculum. (This has since been put back into the syllabus but is only briefly covered.) The aim was to ensure that the students developed some knowledge in this area of AC-circuit theory and had practice at constructing electrical circuits. This topic also provides a good example of the application of complex numbers. Complex numbers are covered in depth during the first year maths courses although the present application is not covered.

The Fourier analysis project was chosen to given students practical experience with Fourier analysis before they met the mathematical treatment in the 2nd year ‘mathematics for physics’ course.

Project development

The LCR project was designed by Dr. D. Mowbray. The main part of this project was concerned with the design, measurement and simulation of a resonant LCR circuit with a resonant frequency of 10kHz. Students had to make a choice between a series or parallel circuit and then use a limited number of resistors, capacitors and inductors to achieve the desired resonant frequency. Measurements were made of the voltage and phase response and also of the effect of different degrees of damping on the Q of the circuit. A final question required the students to design a circuit for a specific application with a well defined resonant frequency and Q-value.

The Fourier project was also developed by D. Mowbray. This project consisted of a number of tasks. These included (i) researching the theory of Fourier series and computing the series for a number of simple wave forms (ii) simulating the Fourier series for square and saw-tooth waveforms using Excel, (iii) measuring the frequency response of a 10kHz low-pass filter and then using this filter to analyse the frequency components of a number of periodic wave forms (iv) using the known response of the filter to produce simulations of the experimental results of part (iv), (v) using a computer based oscilloscope and FFT system to analyse the frequency components of sounds produced by a sonometer and other musical instruments.

Material for students

The students were given a task list for each project – these are reproduced below. In the case of the LCR project they also received photocopies of the theory from a text book (Duffin). In the case of the Fourier project, they were encouraged to find material through the web.

Assessment

The projects were assessed using the standard methods for the group projects. Students were required to submit individual project reports and to make and present a group poster.

Views of students

As well as the standard anonymous questionnaires completed by all students at the end of a module, students’ views on the projects were also obtained through interviews with an external evaluator towards the end of the project.

Despite introductory material given to the students, they did not appear to have a clear view of the aims of the problem-based aspect of the project. Many felt they would have liked more direction or instruction, rather than being asked to obtain so much information for themselves. They also felt that a more structured approach would have been beneficial. The fact that the topics studied were not integrated into the first year syllabus was also seen as a drawback. Some felt that less was learned because they did not see the relevance of what they were doing, while others were more positive, realising that by asking their own questions, and then attempting to resolve them, they had a better understanding of the material.

Overall, despite many reservations, all students felt there had been some benefits from the problem-based approach, and that they were better prepared for when the relevant topics came up in second year courses. They also felt that it was considerably harder work than the other “traditional” group projects!

Students found the Fourier project difficult. This was partly because the project consisted of a number of different parts and partly as it was based in mathematics. However there has been some subsequent student feedback indicating that it had indeed helped the students to understand the Fourier theory covered in the 2nd year ‘mathematics for physics’ course.

The students found the LCR project easier, and felt it had a more clearly defined goal.

Views of staff

The LCR project ran very well. The students appeared to understand clearly what was required, worked well together and completed all of the tasks within the four allotted sessions. A number commented on the fact that they felt that they had a clear understanding of the physics by the end of the project.

The Fourier project ran less well. Students were concerned about the open-endedness of the project and the lack of clearly defined goals. The use of the low-pass filter to analyse the Fourier components of a wave form is made complicated by deviations from an ideal behaviour, particularly the frequency dependent phase shift. Analysis required the students to vary the frequency of the wave form which they found slightly confusing. The complications with the filter made simulations rather difficult. Ideally a better and/or different filter is needed i.e. a tuneable bandpass filter. However despite these problems it was felt that students had gained some understanding of the concept of Fourier series (and some admitted to this at the end of the project). As a second year tutor I have received on more than one occasion the following response from a student when discussing Fourier series (taught as part of a semester 1 maths course) ‘Yes I understand the concept of Fourier series because I did a project on this last year’.

Conclusions

The LCR project worked well and the majority of students appear to have gained a reasonable understanding of the physics and maths involved. Although the Fourier project also succeeded, but at a lower level, it could undoubtedly be improved. A more structured project appears to be necessary and a modified method of experimentally determining the frequency components of a waveform is desirable.

Using Visual Basic for Applications in PBL

John Atkinson and James Collett, University of Hertfordshire

Background
Computational Physics – A case study within this module 'From Random Walks to Planetary Orbits'

Class Size:	~ 15
Duration:	6 sessions: 3 - 4 hours per session
Level:	3

One of the aims of PBL is to prepare students better for the workplace by giving them experience in tackling problems that require collaborative work, strategic thinking and encourage innovation. If the medium of the PBL sessions also provides a marketable skill, the sessions have added value. The course described here was embedded within a one year Level 3 module on Computational Physics. The module seeks both to teach computational methods in a variety of environments (Maple, Matlab, Fortran or C have been employed in the past) and expose students to interesting physical problems that extend core areas of the curriculum met at earlier levels. These can vary from year to year so that there is no sense of a compulsory curriculum within this module.

This course used the Visual Basic for Applications (within Excel) which is widely used outside of science and therefore of great benefit to undergraduates who may end up in a variety of commercial jobs. It has the great merits of being easy to pick up (particularly through the recordable Macro facility) and having pre-defined objects and graphical interfaces. The course attacked some interesting problems in dynamics: some varieties of random walk (including self-avoiding walks and walks with reflecting barriers); the spinning motion of an irregular asteroid and the search for habitable zones in a binary star system. The sessions had no formal teaching in the sense of a prefatory lecture. The students had worksheets to learn the nuts and bolts of the programming language and then tackled some rather open-ended assignments. An example is given below.

You work for RoboSecure, a company which manufactures automated and robotic security devices. One of your products is a robotic mouse which is designed to record and monitor movement in an industrial environment.

A client approaches you for help. He owns a large refrigerated warehouse which houses meat products that are suspended on hooks from an overhead gantry. He has found that the meat is being tampered with and suspects an animal is entering the warehouse late at night.

The warehouse has a rectangular floor space of size 20 m square. You should program two mice to perform a two-dimensional (lattice) random walk starting in the centre of the warehouse. If a mouse reaches a wall it blindly keeps trying until a clear path is found (i.e. it no longer hits the wall). Both mice carry a web-cam and transmit the data back to a computer in the warehouse office. If one of the mice does not send any data back to the computer (e.g. if it breaks down, or gets "eaten"), the other mouse is alerted and goes directly (i.e. in a straight line) to the place where the last signal from the other mouse was transmitted.

Your company manufactures three types of robotic mice. Each type of mouse travels at a different speed; the three speeds are 1 m/min, 2 m/min or 3 m/min. Each model can also choose to take a step length of either 1 m or 2 m. Given that the mice would operate over a 6 hour period each night, investigate the average time taken by the second mouse to arrive at the point of breakdown. Describe how different mouse models give different results and summarize the advantages and disadvantages of different combinations of chosen speeds and steps lengths.

Credit will be given for: a well-written working program; a clear description of how the program works; an analysis of the output of your program in a form suitable for the client. You should ask yourself what the client needs to know and answer these likely questions in a clear non-technical fashion.

Whilst the general response to this assignment was fairly good, it was the very last requirement – tailoring the outcomes of the work to the client's needs – that proved problematic. No student considered the benefits of including an executive summary and most information that was presented in what might have been useful tabular form was rather hard to digest quickly. A student's response might be that this is not physics and that no exemplars of good practice had been given. Exemplars are all very well, but how often in a commercial environment, particularly when working in a new project area, do they exist? The facilitator made just this point and indeed pointed out the benefits of learning this lesson in an environment when the cost was not high – there was a small weighting on this first assignment for this reason.

The second assignment was simpler in this sense because the focus was on the numerical technique (finding eigenvalues and eigenvectors) and physics (working out the moment of inertia of a non-symmetric body).

You are a member of the modelling team for Axon International, an aerospace contractor. Axon International has been asked to ensure that an International Space Station will be a stable platform for scientists conducting experiments in space. The space station consists of mass modules made by different companies that are assembled into a network structure ('the station') in space. Your team are asked to work out how the space-station will spin if hit by a piece of space debris or small meteoroid. To do this, your job in the team is to work out the moment of inertia tensor of the space station and find its principal moments of inertia.

You must write a VBA program that takes the masses and positions of the modules and works out the components of the moment of inertia matrix in network *coordinates. You must then work out the eigenvalues and eigenvectors of the matrix and return these values to the rest of the team.*

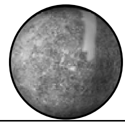
The details of the initial station are given below. You can assume that each module can be treated as point mass and that the modules are linked to each other by very light tubing.

Credit will be given for: a working program that successfully reads in the parameters of all the modules and returns the correct values for the principal moments of inertia and gives their directions; a program flexible enough to be used for a revised version of the space station (i.e. NASA may, at a later date, want to attach more mass modules); an explanation of the pro's and con's of the space station having high or low moments of inertia. There is no fixed answer; think of as many possibilities as you can, given the environment of the space station.

		Network coordinates		
Module	mass	x	y	z
Living quarters	2	5	4	0
Lab	4	0	0	1
Fuel tanks	2	0	2	0
Communications module	2	1	2	*2*

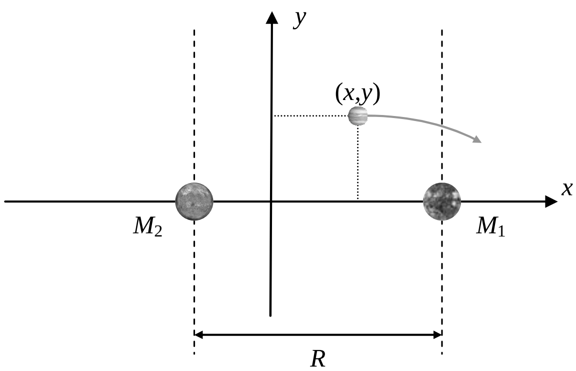
The students found this a much easier exercise and in a sense it has less PBL content. However in accompanying classes, the students went on to investigate the stability of the spinning space station when subjected to small impacts and there was a good deal of exploratory freedom in this. We believe this was a very good way to teach Euler's equations – a difficult subject for undergraduates analytically but much easier with a visual and computational tool to gain some intuitive feel for the motion. For their final summative project in this course, the students had to pull together several of the techniques they had learnt (e.g. orbit integration). The investigation was designed to test the student's ability to devise a successful and intelligent work strategy. The assignment had a fixed goal but the strategy for securing that goal is left to the student. The students are given a collection of fictitious binary star systems – an example is given below, together with an abbreviated form of the assignment briefing.

You must write a code that calculates and plots the orbit of the planet for given starting conditions. The system parameters are the luminosities and masses of the two stars, their separation, the albedo of the planet and the initial position and velocity of the planet. These parameters should be input via a User form. Your output should include a graph of temperature against time along the planetary orbit. Evidence of a logical and systematic search for a habitable planet in each system should be provided. A habitable planet, for the purposes of this exercise, has a surface temperature in the range 273 to 373 K for a time-span of 10 years. Note that this prescription is purely for numerical ease. If you find an orbit which enables the planet to be habitable for a time shorter than 10 years, make a note of the parameters. You should describe how you decided upon your method of search and you are encouraged to include a good sample of your results (i.e. not just those habitable planets).

Planet Name	**Hurst** 
Albedo	**0.2**
Mass Star 1 (M⊙)	**1**
Mass Star 2 (M⊙)	**1.1**
Luminosity Star 1 (1026 W)	**1**
Luminosity Star 2 (1026 W)	**1.2**
Separation (AU)	**10**

This was an interesting exercise and the outcome was very positive, although we ran one surgery to help identify stubborn numerical bugs that would have otherwise hindered completion of the project. One of the dangers of this exercise is that the students become so interested in the outcomes that they spend a disproportionate amount of time on it. Certainly one or two of the submissions were of this kind. Again, the physics that had to be picked up in order to make progress included topics that are often not well assimilated in traditional lectures e.g. motion in non-inertial frames.

The students felt this course had been tough and asked a lot of them both in terms of time and concentration. Nevertheless, they did appreciate they had learnt marketable skills and would be better prepared to face a new computational challenge where their knowledge base was modest.



The planet orbits in the combined potential of two stars in a binary star system. The stars rotate about their common centre of mass in circular orbits

Teaching Thermal Physics through PBL: a case study

Paul van Kampen, Physics Education Group, Dublin City University

Background
Year: 2003-2004
(2nd Year module's been offered)
Class size: 45
Group size: 4 or 5
Timescale: 12 weeks of 2+1 hours per week
Degree structure: Science Education degree Yr 2 semester 2, Applied Physics Yr 1 semester 2, Physics with Astronomy Yr 1 semester 2.

Introduction: why bother with PBL?

Having taught physics modules in the usual manner: through lectures and standard problem-solving tutorials, I was struck by the students' inability to apply their knowledge to problems similar to, but different from, the ones they have solved in the tutorials. Like most students, mine did become proficient in solving standard problems, as evidenced by their performance in exam questions that essentially only changed the numbers given.

Consider for example the well known problem of an ideal monatomic gas in a cylinder closed off by a massless piston that is able to move freely in the vertical direction. In tutorial problems we would have covered many standard end-of-chapter problems: we would have pushed the piston down, heated the system up, made the gas expand adiabatically, and the students would have calculated changes in pressure, volume and temperature with great abandon.

However, applying what to me looked like a trivial departure from a known problem can turn a routine problem into an intractable one to a large number of students. If the gas was heated by a laser shining through a glass piston instead of a Bunsen burner, a large minority was unable to get started on what was an otherwise identical problem. If the tutorial involved solving p for given n,T,V using the ideal gas law, then solving n for given p,T,V proves difficult for a small number of students. Giving the piston mass and asking about pressure before and work done during expansion was an unpleasant experience for the class, and for me, too.

It took some time, and some courage, for me to realize that (i) by widely accepted standards, I was doing a good job as a lecturer, and (ii) the students were, by and large, hard-working and not any less talented than one may reasonably expect them to be. They were able to master complex routine tasks such as calculating the change in temperature or the work done in adiabatic expansions – as long as they could follow an algorithm, a large number of steps to be taken did not seem to present an impossible obstacle. As stated above, any departure from even a simple algorithm however can prove to be an insurmountable difficulty. The evidence seemed to point to a flaw in the delivery of the module.

On reflection, in the delivery of my module I had, unconsciously, put huge emphasis on covering the entire syllabus, and training students to solve problems by algorithm. The person who learned most from the module was me: I learnt new ways of looking at thermal physics, got more fluent in solving standard problems, and conveyed this information as best I could. I arrived at a paradox – as I got better at presenting and organizing the material, the students' brains needed to do less and less.

When I learned about PBL, one aspect struck me most: the total emphasis on the student and the learning process, not on the lecturer and the teaching process. My paradox was resolved instantly.

Getting PBL to work

PBL in its pure form treats teaching and learning as a problem-centred, student-centred, collaborative, integrated, interdisciplinary process with students working in small groups on open-ended problems rooted in real-life. Lectures and often formal exams are abandoned and learning revolves around tackling problems. In this case study, the PBL method is not integrated, because it is implemented in just a single module; it is not truly interdisciplinary, and the problems are somewhat more well-defined and structured than in pure PBL. However, the focus for learning remains on solving a problem; the students acquire the appropriate principles and concepts to arrive at a solution under guidance of the facilitating staff. Information is easily accessible through literature and the internet, but in some cases a limited amount of data is given to the students, for instance if essential information was hard to come by prior to mastering the physics vocabulary.

Resistance to alien teaching strategies is not restricted to teaching staff; a fair amount of resistance can be expected from students, too. It is therefore important to start with a problem that serves to convince the students that PBL is worth their while. It would be an opportunity lost, if not counterproductive, to give an overview lecture extolling the virtues of PBL. We devised a real-life introductory problem for them, which essentially asked them to explain why PBL is worthwhile. The students are asked to put themselves in the role of the teacher, and consider that perhaps teaching would be better if the students got actively involved. They're pointed to PBL as a possibility and are asked how they would convince their students that PBL can be a much more exciting way of learning science. They are also asked what difficulties they would anticipate, how they would try to avoid these, and how they would assess group work.

This strategy works on many levels: students complete an admittedly non-physics research project on a subject they hadn't heard of, thus reducing that barrier for the first real physics problem. They think about how they would like their groups assessed, and the level of agreement between independent groups is astounding. Some groups voice strong opposition to the concept; this provides a good opportunity to show the teachers' openness to discussion and willingness to listen to counterarguments, as long as they are carefully thought out. In the end the class will agree on a form of assessment that is quite close to what the teacher would have hoped for. It is essential though that the learning process is rewarded, and superficial knowledge is not. Some students may struggle with elementary math; others with translating a real-life problem into a tractable mathematical problem; others still with physics covered in earlier modules; and many will find the thermal physics concepts difficult. What should be graded are the strategies they develop to tackle their problems, their willingness to think about their own misconceptions and skills they need to acquire, and their ability to work as a team. How much they actually learn is clearly correlated to all of these points, but should be a secondary consideration when grading.

Introductory problem

What constitutes a good physics PBL problem? It is important to link the question to the students' existing knowledge, whether acquired formally or not. It is crucial that the first physics problem is one everybody can relate to, and that it seems "relevant". For example, we opted to discuss the thermal insulation of a house as the first physics problem.

Relevance alone does not a good PBL problem make. A question like "Explain why double glazing keeps the energy bill down" is not a good PBL problem: it may seem open-ended by virtue of its loose formulation, but it is still in essence an end-of-chapter question with a right or wrong answer. Instead, we formulated a problem in four parts that gets students to think about the physics before jotting down equations. For example, the problem tells students that on a winter's day the heating system breaks down suddenly, and are asked what factors determine how quickly the temperature will decrease.

In the second part of the problem, students are guided towards thinking about conduction, convection, radiation and Newton's Law of cooling. They're given a reason to calculate how long it will take for the temperature to drop below a certain value. It matters little that the criterion is whether a goldfish will die; what does matter is that the problem is relevant. In order to solve the problem, students have to estimate the indoor and outdoor temperature and the rate of heat loss, look up the temperature below which goldfish will struggle, and so on. These determinations should not be viewed as an unnecessary distraction from the "real" physics, but rather as a way to guarantee progress at the early stages of tackling the problem.

The problem ends with students calculating U and R values for thermal insulation; emphasis is placed on the role "dead air" plays as an extra layer of insulation (as does, for example, hair or fur), and determining how a warmer house affects the swing of a pendulum clock (i.e., thermal expansion is dealt with). Further problems include heating a hot-air balloon, operating a refrigerator, and a semi-experimental task on heating and cooling dominated by radiation by silver and black objects. In this problem, students are to determine relative values for the emissivity after devising a sensible curve-fitting procedure.

Assessment

In the first year of running this module (minus the experimental/computational problem), the impact was greater than expected. The students really took to it, and got a lot out of the module. In the second year described above, there are still many positives to record: students do engage with the material, see how physicists model real-life problems, etc. Many of them are still enthusiastic about PBL; but for some, the experience proved difficult. Group dynamics appears to be the deciding factor here; where in the first year all students were determined to overcome some of the difficulties they had, in the second year two groups out of ten did not function as well as anticipated.

One case was solved relatively easily: it was a case of one student consistently failing to show up, and the other three were OK with doing a little more work themselves. They were rewarded for their efforts by a few bonus marks in their grade. In the second case, relationships were tense mainly due to immaturity problems: one student was quite vocal when he got frustrated with temporary lack of progress, and this had a bad effect on one of the more timid members of the group. The students in this group still learned a lot, but the experience was almost certainly not as pleasant as it could have been.

Acknowledgements

The development of this PBL module would not have been possible without the assistance and input of Eilish McLoughlin, Caroline Banahan, Michael Kelly, Eoin O'Leary and Rebecca Tracey.

Reference

A more detailed description of the implementation of this module can be found in:

P. van Kampen *et al*, Am. J. Phys. **72**, 829 (2004).

PBL Induction

Sarah Symons, University of Leicester

Induction: is it necessary?

When students first meet PBL, it is highly unlikely that it will be the first time they have worked in a small group. However, previous group work experience cannot be assumed to provide a complete grounding in the skills and attitudes necessary to gain the most from PBL. Most practitioners agree that some time set aside for induction or group-forming activities is desirable if the students have no prior PBL experience.

If no introduction to PBL is given, various group behaviours and student attitudes have been observed. Generalising, these break down into typical reactions (which seem to be independent of age, academic experience, discipline, or other factors):

'I'm confused, I don't know where to start and I haven't been told enough to solve this problem.'

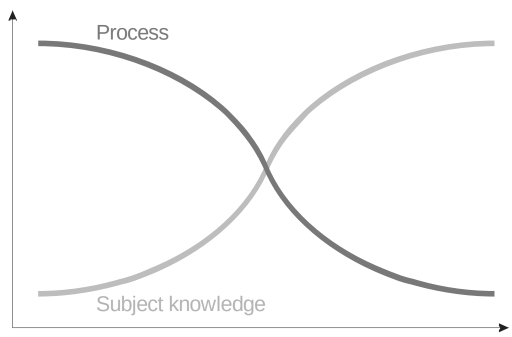
'This is a waste of time, just tell me what to do and what I'm supposed to learn.'

'Where is the physics? I don't see how reading this story gives me any subject knowledge at all.'

or

'I don't want to work in a group: I would do this faster on my own.'

Thoughtful and engaging induction activities can help reduce or overcome these reactions, however there is also another compelling reason to include induction, especially when PBL activities will form a substantial part of the students' timetable. Thinking about the balance between learning the PBL process and allied skills, and learning subject content, PBL students begin by spending more time learning 'how to do PBL' than learning content (see graph below). At this stage in their PBL experience, the amount of subject content that they can cope with in any one problem is quite low. Too much expectation of new knowledge acquisition can lead to the problem being found 'too hard' and feelings towards PBL becoming negative. However with time, experience, and practice the amount of content in each problem can be increased, with students reaching productive activity faster and with less time devoted to process skills. As a result, facilitator contact time and the amount of direction given explicitly in materials can be reduced. Given that students will usually need time to reach a stage when their content learning becomes efficient, it makes sense to defer assessment activities, treat the early stages of PBL as induction, and start with light problems which encourage skills development, engagement, and reflection.



With experience, students spend less time on process and more time gaining subject knowledge
(Adapted from a slide by Prof J Cooper, University of Manchester)

Background	
Year:	1st Year
Class sizes:	4-80
Group size:	4 or 5
Timescale:	1 hr up to 1 week
Staff:	1 academic + suitable number of post-grads

Types of induction activity

At Leicester, we have tried several types of induction activity with varying degrees of success. Induction activities can be ranged in a roughly ascending scale of length and sophistication.

None

For a short (an hour or an afternoon) activity, induction is usually not necessary. This works when the problem is pitched correctly for the students' capabilities and when there are enough experienced facilitators to spend time with each group. We have used this method for open day activities with pre-university students and workshops with teaching staff who had no prior PBL experience, with between eight and forty individuals and one to three facilitators.

Written and oral briefing

As a first attempt in first year labs, with PBL seen as a small part of students' future activities, we attempted to set out our expectations for students in a briefing document. The document was given out in addition to the problem statement and schedule, and contained details of how we imagined students would divide their time, the assessment criteria, and a few comments about the nature of PBL. We supplemented this with a short introductory talk at the beginning of the first lab session which drew students' attention to the most important points.

As an induction strategy, this is the quickest and easiest method short of doing nothing at all. It had the advantage that students had a document in their group packs to which they could refer at any time during the two-week activity. However, it failed to reduce the students' anxieties about an activity which was viewed as being very different to 'normal lab'. Students did not approach the problem seriously at first, and time was wasted while they settled down.

Although the initial PBL session was a single two-week problem, the students went on to do three further PBL problems in their first and second years. Induction was then realised to be an activity which deserved more time.

Half-day introductory activity

Setting aside two or three hours for PBL induction allows several aspects of group work and process to be explored while working on a problem that can have more than one stage.

In our experience, our first year students want to work on physics problems right from the start, but others (at DIT, for example) have had equal success with non-physics tasks, beginning with puzzles as ice-breaking activities. This approach is especially useful if students have not met before.

In the time available, a problem can be structured to include thinking about group ground-rules, investigating group roles, seeing the value of sharing out tasks and reporting back information to the group, working to time and target, and producing a simple outcome.

We found that this sort of activity was effective in forming groups, and improved student understanding of aims and responsibilities significantly when compared with the briefing document it replaced. As this activity occurred near the end of the students' first term, however, several students commented that they felt it was an interruption. They would have been happier spending the time doing some assessed work.

Series of short activities

As an alternative to a single induction event aimed solely at PBL, we also tried a pair of PBL-based induction activities which replaced existing skills sessions in the first few weeks of the first year. The skills introduced (which included group work, experimental design, error analysis, and documentation) were a basis not only for PBL sessions but also traditional lab and problem class work. Each activity took one afternoon and included some experimental work. An example of one of the problems called 'UltraKleene' is shown below.

Although this induction programme took extra time to develop and run compared to the PBL-only induction activity, it turned out to be the most effective in terms of time spent versus outcome. The problems contained more than enough physics to placate the most ambitious students, but were engaging and fun. Students gained experience without being spoon-fed, and staff were pleased that the skills sessions illustrated clearly the importance of concepts such as error analysis with which students often find difficult to engage in the abstract.

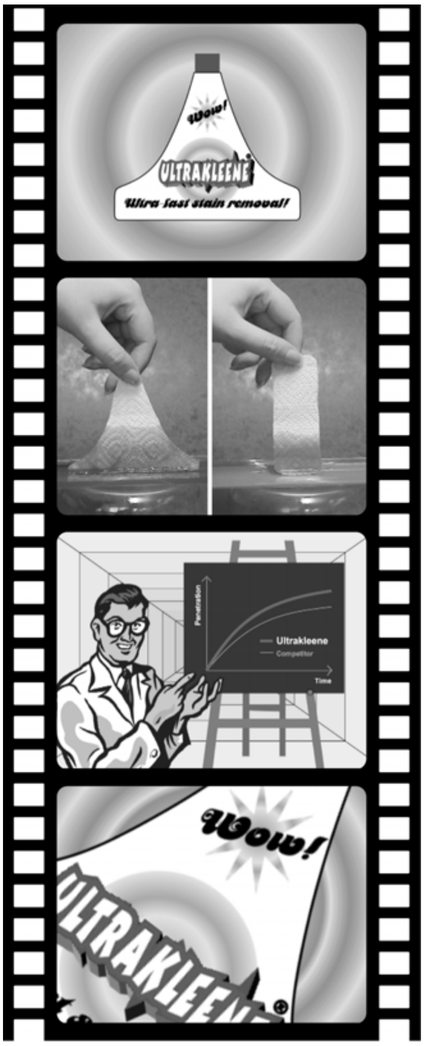
The 'UltraKleene' problem was also used successfully as a facilitator training exercise and part of the Interdisciplinary Science induction week (see next section), showing that problems are often adaptable and re-usable.

An induction week

Where PBL forms the major part of a students' degree, initial activities are significant in establishing the atmosphere of the degree and forming students' opinions of their new working environment. For Leicester's new Interdisciplinary Science degree, which is taught wholly by PBL, induction week for the first students was seen as a critical time, bursting with opportunities.

A varied and interesting programme of events was planned, reflecting the wide range of people, places, methods, ideas, and practices which the students would encounter later in their course. In common with physics students, it was important to lay the foundations for good practice in scientific method, experimental procedure, and communication. The programme included a half-day group skills problem with plenty of discussion, interactive presentations by members of staff, the 'UltraKleene' problem, and a field trip.

Although the whole week was great fun, the amount of thinking, bonding, and learning which went on (both in the students and in the staff!) was impressive. I felt that we had given the students a useful and memorable start to their degree, and was by the end of the week really looking forward to watching their progress as they began to attack longer and more complex problems.



UltraKleene

UltraKleene is a new stain-removal fluid that the manufacturers say is more penetrating than its competitors. The Advertising Standards Authority has received several complaints about the claims made in UltraKleene's advertising campaign and has asked your laboratory to look into the matter.

The ASA have already informed UltraKleene Corp. that their marketing claims are under investigation. The company has responded by sending a lab report supporting the assertions made in the advertisements. Your task is to form a supportable opinion as to whether the representations made in the UltraKleene advertisement are fair.

Carry out your investigation and prepare your response in the form of a brief outline of a letter to the Advertising Standards Authority.

You will be given:

- a video of the advert under investigation
- letters of complaint received by the ASA
- the report supplied by UltraKleene Corp.
- an extract from Len Fisher, 'How to dunk a doughnut: The science of everyday life', BCA, 2002, (p1-21)
- a sample of UltraKleene, a sample of a rival product, and equipment including containers, a retort stand, some ruled blotting paper, a ruler, and a clock

Using a problem strategy

In each of the induction activities outlined above, our main goal was to prepare students to work on problems. In practice, we often want students to work under several reasonable and real-life-like constraints, for example:

- within the time available
- with a professional attitude to the work and to colleagues
- with consideration of safety of people and equipment
- with output of the required standard of detail, format, and accuracy

However, we also demand *learning*. How can we use induction to embed useful habits in students that will ensure that they learn efficiently, cover all of the learning outcomes that we attempt to design into the problems, and develop the group and individual learning skills which are the reason why we choose to use PBL?

Many PBL practitioners advocate the use of a 'model' or 'process' – a path which students should follow in order to work through a problem. The most widely known example is the Maastricht Seven Steps method mentioned in a previous section. We decided to introduce a similar strategy during induction to provoke thought and reflection about the relationship between problem-solving and learning. We did not intend to enforce its use during assessed problems, but several implementers do require groups to stick to the pattern for a longer time.

The strategy we worked through with the students is shown below. Some of the details and terminology are simply from choice or convenience, but this custom design contains characteristics which are perhaps fundamental to PBL, whether stated explicitly or embedded in the problem design or facilitation. The two most important, in my opinion, are:

Identifying the gap between what knowledge is needed and the knowledge that has already been gained. This is made explicit by students when they summarise or locate the problem and list their existing knowledge. The generation of learning issues then follows naturally. Ranald MacDonald informally defines PBL as 'a learning method where students identify the need to learn something'. This need drives engagement with material, promotes deep learning, and gives the student responsibility for and control over their own learning.

Iterating the process, ensuring that targets are met and learning objectives are covered. In short activities, it is sometimes not possible to spend time reviewing work and reflecting what progress has been made and the next step that might be taken. In a developed PBL scenario, however, problems will be too complex and embedded learning issues too large to be covered in one journey from A to B. Investigation and reflection take time and problems which can be solved in a single gulp will not satisfy students for long. Iterating the *process* of course does not imply that the students do the same thing repeatedly. It is an effective tactic which allows students to reach an appropriate depth of knowledge over a wide enough topic area.

The problem strategy itself was used as a basis for discussion in the Interdisciplinary Science induction week. Students were asked to make a habit of reflecting on the way they were learning and problem-solving. The students thought that the strategy could be particularly useful in overcoming difficulties such as being stuck or seeming to be going round in circles. By being asked to review the strategy, the students began thinking about their own learning processes, and staff gained an insight into the new students' learning attitudes and experiences.

A Strategy for Problem Solving

Locate the problem
What are we being asked? What is the issue here? What are our targets?
Existing knowledge
What do we already know? Does anyone in the group have experience of this? Have we done anything before which can help us?
Identify learning issues
What do we need to know? What must we learn in order to understand this? What skills do we need to complete the task?
Course of action
How can we find out? Who do we need to consult? How shall we divide up the tasks? What sources of information can we use? Can we test something by experiment?
Enquiries and/or experiments
This is where the work takes place!
Share results
Getting back together as a group and bringing the newly acquired knowledge and skills together. Summarising fresh information for the group.
Theorise
How can we apply what we know to the problem? Are there useful links between what we have brought back? Has a new angle emerged? Are all our results consistent?
Evaluate progress against target
Have we achieved what we need? Do we need to do more? What can we learn from the process of working on this?
Report (or repeat the process if necessary)
Produce the endpoint of the problem – the 'product'. For more complex problems, or further tasks, or if the group is 'stuck', repeat the scheme to make further progress.

Conclusions

Induction activities which we have tried have developed towards a policy of using PBL to teach PBL. This is not surprising. Many people, including our own students, have noted that you cannot understand what PBL is or how to do it without actually doing it. PBL is also the natural home for skills development, making it the ideal induction activity not only for itself but also for other non-PBL activities.

Designing and running induction programmes is a similar process to designing and running ordinary PBL, and should not be seen as something which can be left to chance or thrown together at the last moment. By setting the stage for PBL, these activities are fundamental to a successful outcome.

A PBL programme at DkIT

Tony Lennon, Dundalk Institute of Technology

Context

Where: Dundalk Institute of Technology (DkIT) is a college of 3,500 students on the east coast of Ireland, exactly halfway between Dublin and Belfast.

Why: As part of an internal review within the Department of Applied Science it was realized that the overall retention rate of students, like a lot of third level colleges, was a matter of concern. It was further acknowledged that the students were studying physics because they had to! The students were more interested in their core subjects of biology and chemistry as they were typically aiming for a qualification in Food Science, Environmental Science or Chemistry.

As part of the review surveys of the employers to determine what they wanted from the graduates had been performed. The employers wanted:

1 Team work skills.

2 Problem solving skills.

3 Quality systems knowledge.

And much further down the list…

.. Technical skills.

In the past, attempts to solve the employers' skills set requirements had been made by adding courses like communications, in addition in the subject Quality Control the students were lectured about the necessity of teamwork, however the students were not given the formal opportunity to practice the theory.

Problem Based Learning was believed to be the answer to these issues as it would solve the required skill set problem and provide a student centred learning environment that it was hoped the students would enjoy.

How: After one of the departmental review meetings this author said in passing to Dr Breda Brennan that PBL and Physics were a marriage made in heaven. Dr Brennan, a biologist who had just completed a period as head of the DkIT Learning Support Unit, had written a proposal for funding within the hour. Senior management accepted the proposal for commencement in the next academic year.

Having attended the necessary training and workshops, including the LeAP project summer school on drafting problems, a group of 20 PBL problems were devised covering the whole syllabus. It took the whole summer to draft the problems and update the equipment.

As scientists it would have been preferable to run a controlled experiment to determine which method of teaching was preferable. However, as it was deemed that for possible legal reasons it would not be possible to split the class, it was decided to run the whole 1st year physics course as PBL.

It was decided to run 2 hour sessions and each problem was to last 2, 4, or 6 hours. The students would be taught all other subjects using the traditional teaching methods. One change made from the examples that had been examined was the decision to integrate the PBL and laboratory sessions. All PBL sessions would include those necessary modifications.

Background	
Year	2003/2004. First year students
Students	48 at start of year
Group Size	2 classes with 3 subgroups of 8
Time Scale	6 hours per week for full year
Degree Structure	3 year ordinary degree – Bologna
Staff	4 teaching staff: Henry Bacík, Ted Hyland, Tony Lennon, John Walters. Titular head Breda Brennan

Physical Constraints

Only one physics laboratory was made available for the project that had 3 benches in it. This automatically set the number of groups to 3 and with 24 students in each class this meant that there were 8 students per group. This was too large since the groups were changed after everybody had been Chairperson, Scribe, and Reader. This size of group and the physical size of the laboratory benches meant that the volume of the students' voices often became quite loud. This was a problem as we deliberately kept the laboratory door open as part of our attempt to create an open and free atmosphere during the sessions. (During the academic year 2004 – 2005 the group size has been changed to 6 people which is working much better.) Three networked computers were also installed in the laboratory with internet access. Each computer was also fitted with an e-beam system so that the students would have a record of their own work on the white boards.

Assessment Strategy

Assessment drives the whole process. Students are no different to the rest of us. People put effort into what they deem important. If students are not assessed on something they will not put the effort into it. Equally important is that the marking system is seen by the students to be fair and equitable. Changes to the marking scheme were planned but only introduced when students raised issues of equity etc. and were deemed ready for the change. There were three phases and at all times attendance was mandatory.

Phase 1:

- Tutor assess process (feedback only).
- Tutor assess product.
- Marks pro-rated on attendance.

Phase 2:

- Self Assessment of process,
- Tutor assess product and process.
- Marks pro-rated on attendance.

Phase 3:

- Peer Assessment. The Students divide up the marks.

One problem of this marking scheme is how to assess the student's contribution outside the classroom when they are doing their group activities. This year we are considering some fine tuning of the attendance criteria to include the students doing their own role call during group work.

Reinforcement

After every main section of the course we do a short review of the learning issues and we also provide a few tutorial questions to reinforce the material that they have just discovered for themselves.

Outcomes

Since attendance at all PBL sessions was mandatory and directly affected their continuous assessment mark very high attendances were recorded all year (in the order of 87% for those who completed the course in group 1). In contrast in traditionally taught subjects the laboratory attendance is good but lecture attendance is poor. A very strong correlation between attendance and marks had been noted previously.

The lecturers in the other subjects remarked that there were changes in the attitudes of the students in that they were nosier, more confident and asked more questions. This trend is continuing into the second year of the project, so is therefore not just a function of an individual cohort of students. Anecdotally, it can be said that the students attitude to learning has changed, even in traditionally taught subjects there is a spill-over effect.

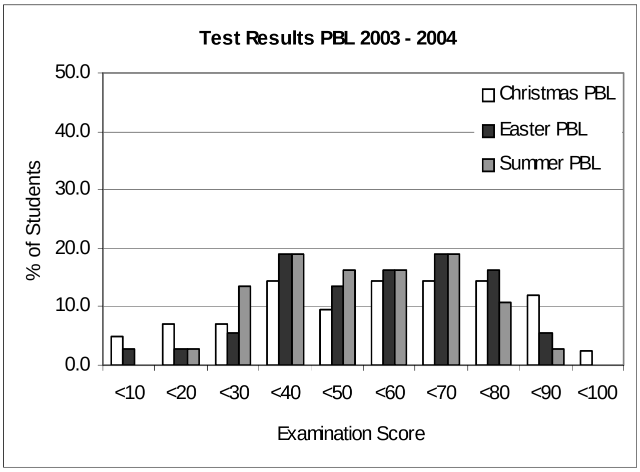
The examinations were set with the same format as previous years so as direct comparisons could be made.

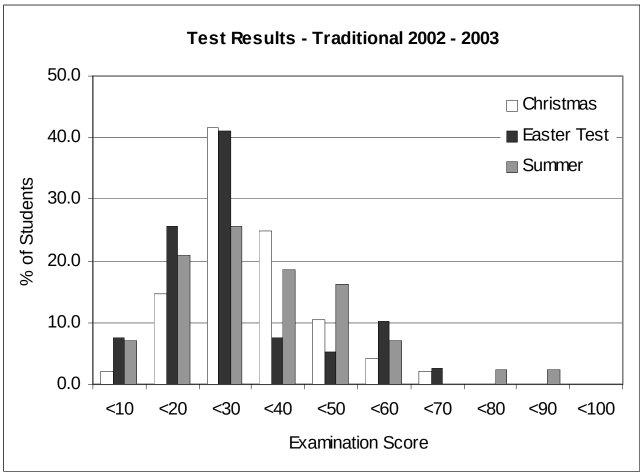
Key points

- These are unconsolidated results and do not contain the autumn repeat results.
- Average mark jumps from 30% to 50%.
- Christmas pass rate jumps from 17% to 67%.
- Easter pass rate jumps from 18% to 70%.
- Summer pass rate jumps from 28% to 65%.
- Final Result (including Continuous Assessment) jumps from 60% to 84%.
- Retention Rate (as applied to Physics) jumped from 43% to 65%.

Raw Data:

Traditional	**Final Result**	**PBL**	**Final Result**
Average	**40.0**	**Average**	**51.6**
Std dev	**13.9**	**Std dev**	**14.3**
Min	**4.0**	**Min**	**20.0**
Max	**72.0**	**Max**	**78.0**
No. Took Exam	43	No. Took Exam	37
No. Pass Exam	26	No. Pass Exam	31
Pass Rate %	**60**	**Pass Rate %**	**84**
No. Registered	61	No. Registered	48
Retention Rate %	**43**	**Retention Rate %**	**65**





Survey

A survey of the students was conducted and these are some of their comments:

"As I am repeating the subject this year I can honestly say this method is by far a better way of teaching than lecture based learning."

"For a person who has never done physics before I find it very interesting and it's a change from long classes."

"It stays in your head because you can look for the information yourself."

"PBL should be carried out in every subject."

Conclusion

In conclusion, students should be allowed to speak for themselves. A separate survey was conducted to determine if the attitude to physics had changed between the PBL group and the control group of the previous year who were now in their second year.

43% of last year's traditionally taught students would like to have had the opportunity to do physics in this their second year.

67% of this year's PBL taught students would like to continue with physics into their second year.

During the first year of the PBL project there were approximately 25% of the students repeating physics. In this the second year of PBL there are no students redoing their physics course.

Two example Science 1 Physics problems from DkIT

Problem Brief
Title: Move it Man!
Previous Related Modules: Linear Motion.
Syllabus area / Module: Mechanics - Circular motion.
Learning Outcomes :
The student can:
- Relate circular motion and linear motion.
- Can use radians.
- Use equations involving angular velocity *r*

Duration of the problem in class contact hours : 4
Materials :
- A conveyor system.
- Strobe.
- Rulers.

How the problem will develop / Staging - where appropriate :
Stage 1: Student will be asked to investigate the conveyor system.
Format of final student product and assessment :
- Formal report.

Conceptual Questions :
1) How would the linear velocity of the belt be affected by doubling the diameter of the idling roller? Justify you answer.
2) With a drive roller of radius 1 m what is the linear velocity of the belt when the angular velocity is 1 radian per second.

Move it Man!
You are working for a food company making small boxes of sweets for elves. These sweets are used to pay the elves. And we all know what happens if the elves are not paid on the 23rd! You are in charge of the packing area and you have just received a new conveyor. There are five interchangeable rollers of 21 mm, 26 mm, 33 mm, 41 mm, and 60 mm diameter.
You have to commission (set up) the new conveyor. The manual stipulated that the angular velocity of the drive shaft must not exceed 10 radians per second. The motor is a Farnell part 650 - 316 and the gear box is Farnell part 650 - 341. Your production line manager has the Farnell Data Sheet. The control system is designed to run at full and half speed.
You have to initially set the speed of the conveyor between 70 and 80 mm per second for the sweet production line to work at all.
Because of the bad pay in DkIT your tutors have been forced to moonlight as the production line managers in the sweet factory.

Problem Brief
Title: Moon Rescue
Previous Related Modules: Move it man!
Syllabus area / Module: Circular Motion.
Learning Outcomes :
The student can:
- Explain the different forces acting on a body in circular motion.
- Perform velocity calculations involved in circular motion.
- Explain escape velocity.

Duration of the problem in class contact hours : 2
Materials :
- String and a weight.

How the problem will develop / Staging - where appropriate :
Stage 1: Handout
Format of final student product and assessment :
- Short report.

Conceptual Questions :
1) What happens to the momentum of the mass as the string gets longer?
2) Are your arms still attached to your body after you launch the beacon?

Moon Rescue
The year is 2025 and your name is David. You are enjoying a holiday on the moon in the Lunar Hilton paid for by your father's company called Goliath.
You have been on the Lunar Induction course which all Earthies have to take on their first visit to the moon. You went out in your moon cruiser and you went around to the far side. Everyone does on their first visit to the moon!
Unfortunately your moon cruiser has broken down but worse again you departed a long way from your logged journey plan.
Because of where you are on the moon your emergency beacon will not be picked up. You have a spare space beacon and a 1000m of space "fishing line".
During the Lunar Induction the first dumb question that everybody asks is "Could I run fast enough on the moon to get into space". The answer is "Yes, if you could reach 2.38km s^{-1}".
- Could you launch the space beacon by hand?
- Is the fishing line long enough?

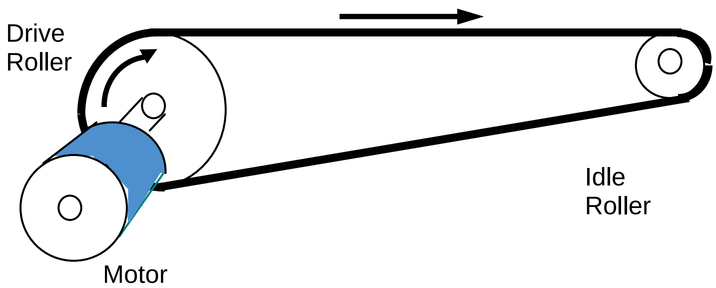


Image-based PBL

James Collett, University of Hertfordshire

Background
Image-based PBL – A Schools Masterclass
Class Size: ~ 60
Duration: 1 session: 2.5 hours
Level: Year 9

The template of a traditional physics problem might consist of: a question; a collection of specific and appropriate data; and some assumed knowledge of relevant equations and their manipulation. Without denying the usefulness of such 'five-finger exercises', as Pippard has nicely described them in the collection of *Cavendish Problems in Classical Physics*, they lay no claim to encouraging innovation in methods of solution or model building, or skill in interpreting or choosing appropriate physical data. Most importantly, they are not used as a vehicle of learning – no-one would attempt these questions without having first been schooled in the appropriate theory. Interestingly the cover of *Cavendish Problems*, depicting a rather involved interference pattern, provides a nice example of an image-based problem. The student has to decide which measurements to make on the image, and interpret the size and shape of the fringe patterns. This is clearly more provocative than a question on a similar theme in which, say, we do little more than insert numbers into a question about Young's Slits. Nevertheless the student is expected to be aware of the conditions for constructive interference, phase retardance etc. so that the problem, whilst challenging, is not a vehicle for learning these physical ideas.

Image-based PBL seeks to use images as the driver for the introduction of concepts. Here, we describe how Year 9 school students were introduced to trigonometry and scaling in a Masterclass in which we wanted to use contemporary applications – recovering information from blurred images, movie-making, spacecraft imaging – as the vehicle for first meeting and appreciating these ideas.

The format of the Masterclass was as follows: the students were given a short talk (~ 20 minutes) on some real examples of image analysis, for example reconstruction of the early Hubble Space Telescope images and rendering CGI characters in films. To launch the students into the idea of looking as closely at an image as possible, we investigated, as a group, two classic slides of paintings: Velazquez' *Las Meninas* and Vermeer's *Music Lesson*. The idea was to elicit suggestions as to how to uncover how the physical dimensions of the rooms, positions of the characters and time of day might be deduced from visual clues in the images. They were then shown how to use the trig and inverse trig buttons on their calculators and their relation to a right-angled triangle. From this point on however, the emphasis was on application. The students sat in groups and tended to work in them naturally but this is not forced, save in the fact that kit was limited so sharing was essential. An image of a shadow from a bridge strut must be used to find the altitude of the Sun. Some students simply drew a construction triangle onto the image, encouragingly circumventing what they have just learnt. To reinforce the lesson learnt from this exercise, students then attempted to work out moon crater depths from their interior shadows and the given altitude of the Sun. They found this quite difficult, perhaps because the cause of the shadow is unclear when a crater is imaged face-on. In another exercise, the students had to find, in the guise of a director of an animated film, how close a miniature character can approach a food tin and still see the entire supermarket logo. This exercise in drawing tangents drew a roughly equal response from those who simply drew around the tin and constructed the tangents to the logo endpoints, and those who drew triangles and applied the trigonometry. Interestingly, in cases such as this, where (the familiar) Pythagoras' theorem can be used, this was much preferred to the new functions. The students had been exposed to Pythagoras' theorem in two dimensions in school and, in the next problem, they needed this and the insight as to how to extend it to three dimensions. A small video camera was placed in an enclosed box directed at a miniature film set. The students could not see inside the box but they could see the view from the camera on a monitor. From this image they had to work out the distances between objects on the set from their two dimensional projected positions and one or two scale references (e.g. small figures in the set). The most challenging question was to work out the position of the camera inside the box. This is possible using a geometrical construction – exploiting the changing elongation of floor tiles as the distance from the camera increases. A simple concept (of projected area) is used to satisfying effect when the enclosure is removed and the position of the camera revealed. A noticeable (and pleasing) effect of students tackling the less transparent questions was the increased discussion and experimentation that resulted. Equally satisfying was that when the students were asked to estimate the volume of the room they were sitting in at the end of the session, they looked for repeated units – floor or ceiling tiles – to use as the basis of their estimate.

In a session of this length, variety is essential. To break from calculation, the students investigated the physics behind their ability to discern small letters in an eye test. They were given a symbol and invited to draw around a washer, keeping the centre of the washer on the boundary of the symbol. The resulting envelope simulates (in a crude way) the 'ballooning' of the symbol by the optical transfer function. By repeating the exercise with different washers, eyes of better and worse quality, or optical instruments of higher and lower resolution can be simulated.

This is very much an entrée into the world of image-based learning: nevertheless it has the virtue of making students interrogate images in a much more critical and analytical way. Since so much of commercial film-making now relies on imaginary or lost visual landscapes, the need to be able to both understand the formation and nature of an image is an idea that is readily marketable to young people. This was one session in a series of Masterclasses and we await feedback on how the students found it relative to other methods of delivery. We have previously run a PBL Masterclass with year 12 students with a quite different structure. Here the students did work in groups with each group representing a Government Task Force. The scenario, which the students were unaware of on starting the exercise, was multiple fragments of a cometary nucleus impacting the Earth over a single day. The team were fed news reports, simulated TV news broadcasts, seismic plots etc. and asked to reconstruct the events that were unfolding before them in the light of information that they had received. The interesting feature of this structure is that the students have the crucial experience of interpreting limited data and see the dangers of over-interpretation. They also see how understanding a physical process can evolve with burgeoning information. The lesson we learnt from this exercise was that our session (several hours) was too long and the scenario too detailed. The students were also perturbed at first by the idea of informed estimation, although we were comforted by feedback that suggested they wished they had done this kind of thing before. A better format might be to release information on a website accessible to schools and use the incremental growth of this archive to stimulate a weekly 'best estimate' in the classroom of what is going on and what will happen next.

A nice example of image-based PBL that can be used at a more advanced level, but with the same philosophy, is the reconstruction of the positions and brightness of light sources in a room from their reflection in a spherical 'Christmas Tree' bauble. On a practical note, we found it best to use transparent acrylic spheres that can be bought from larger craft stores and to silver the interior of one of the two component hemispheres before sealing. This protects the reflective surface and means you have both a convex and concave mirror as required. The problem can be posed in a quite general way – what can we learn from this image? This allows the students free reign to use their own ideas, e.g. measuring pixel intensities, distortions, perhaps constructing and experimenting with the mirrors to gain some feeling for the way they behave. It seems to be generally recognised that the study of ray-tracing and optical instruments lends itself very easily to a PBL approach and can nicely incorporate experimental and computational elements.

Reference

Cavendish Problems in Classical Physics ed. A.B. Pippard, Cambridge University Press 1962

The TV monitor image of the model film studio. School students were invited to find the distances between actors, the ground floor area of the building and the height and angle of the camera.

From end of chapter exercise to PBL problem: Some examples of problem evolution

Derek Raine, University of Leicester and James Collett, University of Hertfordshire

Background
Class Size: Any
Duration: Various
Level: Various

The following example shows four stages in the evolution of a problem from something that might be set as an examination question to a 'hook' for a PBL problem. The first version encourages students to plug numbers into formulae with a minimum amount of thought, while the succeeding versions increasingly engage students in the research process and are more likely to result in deeper learning. (Note that for simplicity some of the quantitative details have been omitted from the statements of the problem.)

Introduction (for versions 1, 2, and 3)
Asteroid 216 Kleopatra has been mapped with Earth-based radar. From the returned signals it has been deduced to have the shape illustrated, similar to a dog-bone or dumbbell. The radar reflections are so strong, it has been speculated that it is nickel-iron rich and it is thought that the bulk of the mass of the asteroid may reside in large metal cores in the knobbly ends of the asteroid. The asteroid undergoes a collision with a small body.

Version 1

- The density of the asteroid can be taken to be 3000 kg m^{-3}.
- You may model the asteroid as a dumbbell consisting of two spheres separated by a rod. Use the *parallel axis theorem* to work out the moment of inertia of each sphere of the dumbbell about the centre of mass of the dumbbell (midway along the rod).
- You can assume that the collision is inelastic and that the asteroids adhere to each other after the impact. The mass and moment of inertia of the smaller body can be neglected after the impact. Use the conservation of linear and angular momentum to compute the motion of Kleopatra after the impact.

Version 2

- You may assume that the asteroid has the same density as an iron-rich meteorite.
- Make a simplified mass model for the asteroid, e.g. a dumbbell or a rod or some combination of these. Hence deduce a value for the moment of inertia about an axis passing through its centre of mass.
- Would you expect the collision to be inelastic or elastic? Stating clearly any simplifying assumptions you make, describe the motion of Kleopatra after the impact.

Version 3

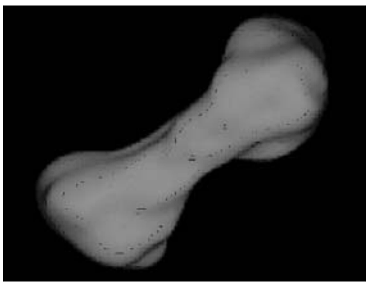
- Make an estimate of the density of the asteroid based on the information above and any other sources you care to use (reference your sources in full).
- Estimate the moment of inertia of the asteroid.
- Describe, as quantitatively as you can, the motion of Kleopatra after the impact.

Version 4

The Daily Planet

Asteroid on Collision Course?

Photographs taken by the Hubble Space Telescope show the first images of asteroid 216 Kleopatra believed to be on collision course with a smaller body. This is thought to be the first time such a collision event has been observed since Comet Shoemaker-Levy in the last century. Interest has been aroused as to what might happen to the asteroid as a result of the collision. Information on the path



of the asteroid is continually updated on the New NASA website.

Palace denies Harry's links with actress

Palace officials today denied rumours that King Charles III had personally intervened in the love life of his son, second in line to the throne. Harry (35) has been photographed with a number of young women recently but rumours of improper

(cont. P2)

The next example (below and right) shows the incorporation of a set of end of chapter exercises into a more meaningful research activity. For the purpose of running this as a real laboratory experiment, some compromises have been made in the given data in the PBL version.

Original Version

(a) A coil of length 10 cm, radius 1.5 cm has 1000 windings. What is its inductance?
(b) Calculate the capacitances for two tuned LC circuits, frequencies 160 kHz and 500 kHz using the inductor in part (a).
(c) A parallel plate capacitor has plate area 10 cm^2 . What plate separations are required to obtain the capacitances in part (b)?
(d) What is the Q-value of a circuit with L = 10mH, C = 1 μF and R = 1 kΩ.
(e) In the tuned circuits of part (b) what is the smallest resistance placed in series that will be required to ensure the two signals are separated?

PBL Version

A sugar factory contains various hot vats of molten sugar at various temperatures. The heating is by high-pressure steam, which is controlled by a thermostatic valve. Surprisingly, in this factory, the system is not fail-safe: loss of electrical power allows steam heating to continue. There is already a warning system to monitor the temperatures, which sounds if the temperature rises too high in any vat. However, quality assurance best practice requires that there be a fail-safe secondary warning system which will remain ON in the absence of any problems and will turn OFF if either the temperature in the molten sugar rises above the preset limit OR is likely to do so as a result of levels of (granular, not molten) sugar, in the bins that supply the vats, which are either too high or too low. The back-up alarm must be simple and non-power consuming so that in the event of a power failure the alarm will still sound. Your management has proposed the idea of using a tuned LCR circuit for this purpose that uses a fixed inductor to pick up an audio-modulated high-frequency signal from a local on-site transmitter, which uses an external power source. It is your job to design the prototype system that will perform this function. For the prototype, take the high temperature warning to occur at 50°C. The sugar level warning can be considered independently.

The final selection[3] (below) illustrates alternative formulations of short problems that can be used in a tutorial or problem class setting.

Original Questions

1. A car starting at x = 50 m accelerates from rest at a constant rate of 8 m s^{-2}.
(a) How fast is it going after 10 s?
(b) How far has it gone after 10 s?
(c) What is its average velocity between 0 and 10 s?

2. A proton moves in a circular orbit of radius 65 cm perpendicular to a uniform magnetic field of magnitude 0.75 T.
(a) What is the period for this motion?
(b) Find the speed of the proton.
(c) Find the kinetic energy of the proton.

3. Liquid helium is stored at its boiling point (4.2K) in a spherical can that is separated by a vacuum space from a surrounding shield that is maintained at the temperature of liquid nitrogen (77K). If the can is 30 cm in diameter and is blackened on the outside so that it acts as a blackbody, how much helium boils away per hour?

4. A glass ball of radius 10 cm has an index of refraction of 1.5. The back half of the ball is silvered so that it acts as a concave mirror. Find the position of the final image seen by the eye to the left of the object and ball for an object at (a) 30 cm and (b) 20 cm to the left of the front surface of the ball.

5. (a) How far apart must two objects be on the moon to be resolved by the eye? Take the diameter of the pupil of the eye to be 5mm, the wavelength of light to be 600 nm, and the distance to the moon to be 380 000 km.
(b) How far apart must the objects on the moon be to be resolved by a telescope that has a mirror of diameter 5 m?

PBL Versions

1. *Speed Kills* The advertising agency making the government information film on road safety currently shows how much further a car braking from 35 mph travels than one travelling at 30 mph. Advise them whether it would be more dramatic to show how fast the former would be travelling at the point where the latter has come to a stop.

2. *Cosmic Rays* Cosmic Rays are highly energetic particles (mainly protons), which impinge on the Earth's upper atmosphere to produce secondary cosmic ray particles that penetrate down into the atmosphere. Explain why secondary showers from lower energy cosmic ray particles are not observed.

3. *Goodbye Oceans* The scenario for the latest Hollywood blockbuster has the sun increasing to the red giant phase giving only a short time to evacuate the Earth before the oceans dry up. Advise the producers how long this might realistically take.

4. *C'est Magnifique* In the 17th century, Anton van Leeuwenhoek created simple microscopes using small glass spheres as simple lenses. With such microscopes he discovered bacteria, red blood cells and spermatozoa, to name but a few.
Explain how large a magnification could be achieved with this equipment.

5. *Flying the Flag* Conspiracy theorists like to speculate that the Apollo moon landings were staged. One of the arguments used states that "the Hubble Space Telescope can image distant galaxies, but it can't see the flag supposedly left on the Moon. Obviously it never happened."
What do you make of this argument?

[3] Developed by Alex Mack and Harmaninder Shergill, Department of Physics and Astronomy, University of Leicester

Find out more about Problem-based Learning

Literature

Selected books:

The Power of Problem-Based Learning: A Practical "How To" for Teaching Undergraduate Courses in Any Discipline Duch, B.J., Groh, S.E., Allen, D.E., (editors) et al Stylus 2001. (Many of the contributors come from a science background.)

Problem Based Learning: How to Gain the Most From PBL Woods, D.R., Woods, 1994 (available from McMaster University bookshop). For other works by Woods, some of which are available online, see **chemeng.mcmaster.ca/pbl/pbl.htm**

An educational research approach to PBL can be found in, for example:

Foundations of Problem-based Learning Savin-Baden M., Major, C. H., Open University Press 2004

Problem-based Learning in Higher Education: Untold Stories Savin-Baden, M. Open University Press 2000

On line

A huge repository of PBL literature citations can be found at the University of Maastricht PBL website (**www.unimaas.nl/pbl**) under 'Publications'. Unfortunately, no annotations are given. The University of Delaware (**www.udel.edu/pbl**) also has an online collection of its own PBL publications. A good round-up of PBL links (including where to find example problems) is given at **pbl.cqu.edu.au/content/online_resources.htm**

The Higher Education Academy Physical Sciences Centre has many useful publications and resources available online at **www.physsci.heacademy.ac.uk** including *LTSN Physical Sciences Primer "Problem based learning",* a *"Teaching a Physics Laboratory Module to Blind Students"* Toolkit, and an excellent "*Employability"* toolkit.

The Project LeAP website – http://www.le.ac.uk/leap

The Project LeAP website offers the opportunity to find example physics problems, many of them tried and tested in the lab or the classroom, to find out who is doing what in physics PBL across the UK, and to meet up and talk about PBL problems, issues, and queries.

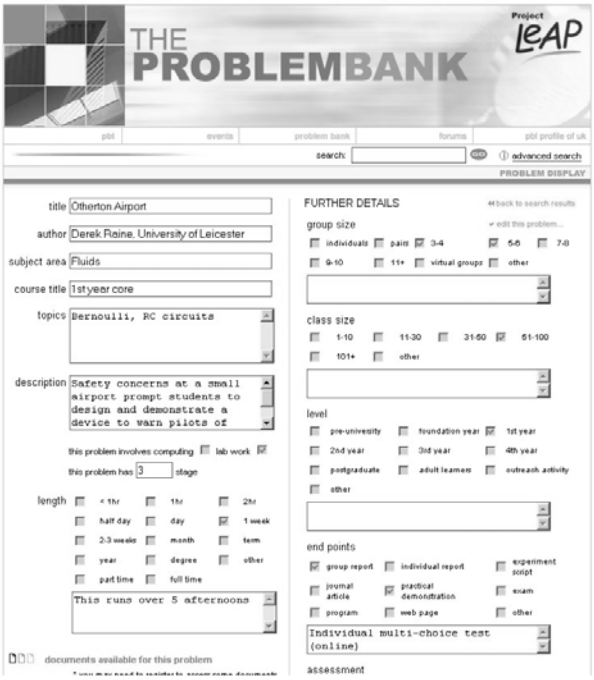
PBL Profile of the UK for Physics and Astronomy

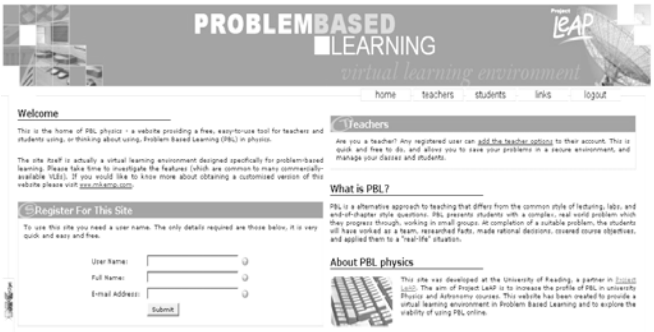
A clickable map of the UK shows where PBL is being used in physics and astronomy. Brief details of the types of activity are given, showing the diversity of implementations which are appearing across the country. Add or update your department's information!

Problem Bank

Aiming to become the world's largest collection of physics, astronomy, and interdisciplinary science problems, the Project LeAP Problem Bank is a searchable database of problems covering many topics, problem lengths, and student levels. The problems are freely available to view, download, and use. To see facilitators' notes and supporting material, register (free) on the site.

The Bank allows you to upload your own problems to share and discuss. The process is easy: just fill in a form which describes your problem, then upload your supporting documents (all common formats are welcome) to the site.





PBL Virtual Learning Environment

University of Reading student Matt Kemp designed a unique virtual learning environment especially for PBL in physics. The Project LeAP PBL Physics VLE is in use as a student learning and communication resource, but guests can also access it to look around, discuss PBL physics on its discussion boards, or even use the instant chat feature.

Register as a teacher to post your own problems, form a group of students or colleagues and use it to communicate and assemble documents ('answers') collaboratively.

Consultancy

Project LeAP has aimed to collate and share experience. To this end, Project LeAP members are available to talk about implementing PBL. Get in touch via the website to discuss your requirements. The service is free to UK institutions until October 2005, time permitting.

Summer School

The Project LeAP PBL Summer School is the only event of its type in the UK. A three-day, residential, annual event, the Summer School is a practical workshop where people involved in Higher Education teaching in any discipline can spend three days discussing PBL, working together to produce problems, and taking part in workshops led by invited experts.

The 2005 Summer School will be held from 11th to 13th July 2005 in Leicester. Visit the Project LeAP website to find out more and for registration details.

Feedback

Project LeAP would like to hear your comments about this Guide and the website. We would also like to know about your PBL experiences and invite you to contact us at project.leap@le.ac.uk.

The Higher Education Academy
Physical Sciences Centre

...enhancing the student experience in chemistry, physics and astronomy within the university sector.

Physical Sciences Practice Guides are designed to provide practical advice and guidance on issues and topics related to teaching and learning in the physical sciences. Each guide focuses on a particular aspect of higher education and is written by an academic experienced in that field.

This practice guide, a product of the FDTL4 LeAP project, provides an introduction to PBL for physics teachers (and others) who want to find out enough to get started.
The guide is divided into four sections. Section one is the narrative of a PBL problem, its implementation and development. This is used to illustrate the nature of PBL, and is elaborated explicitly in the accompanying boxed text. Section two contains 'composite' case studies based substantially on real situations, but drawn together to help make a number of points efficiently. The variety of situations treated here should help readers decide for themselves the cost-benefit analysis of any particular PBL implementation and also illustrates that there are many different ways, both big- and small-scale, of bringing the benefits of PBL into your teaching. The third section is a set of real-life case experiences by invited contributors, many of which include samples of problems. The final section points the reader towards a selection of useful resources.