From Projects to Problems

Symons, S. L., Raine, D. J., and Barker, T.

Department of Physics and Astronomy, and Interdisciplinary Science Centre, University of Leicester, UK

Abstract

This paper draws on our experience of promoting PBL to Physics Departments in the UK and in the development of PBL problems both for Physics and for a new Interdisciplinary Science degree.

It is well-known that in general academics believe that PBL is easier to implement in all subjects other than their own. Also well-known is the still prevalent confusion between PBL and problem-solving and between PBL and projects. In the former case, we provide explicit examples of end-of-chapter exercises that can be developed into PBL problems. This provides a mechanism for gradual evolution from an existing traditionally taught programme to a PBL program, daunting as it is to develop a programme from scratch by this means.

The difference between projects and problems has occasionally been discussed in the PBL literature. For us, it is a matter of scale: projects provide a coherent large-scale context, which sets the scene for PBL problems. In terms of promoting PBL this approach demonstrates how the common end-of-course experience of project work can be generalised to earlier parts of a degree programme. We provide some examples which show how the approach can make manageable the task of creating an ab initio PBL programme.

Introduction

An extended project is a traditional part of the final year in UK physics degree courses. This paper describes the parallels and synergies between this type of project and problem-based learning (PBL) activities, attitudes of staff and

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1 This type of final-year physics project, which usually involves several weeks of research, experiment, and data analysis, will be the type referred to by the word ‘project’ throughout this paper.
students concerning these areas, and descriptions of PBL implementations which complement the project process. The experiences related have been gathered during Project LeAP,\textsuperscript{2} a four-year educational development programme which focused on introducing PBL into the higher education physics curriculum.

A typical project runs over one or, more commonly, two semesters in the student’s final year. A four-year degree programme may contain an additional project in the third year, but usually does not. Students select subject areas from a menu and are supervised by a member of academic staff. Projects usually relate to the supervisor’s research area, and staff typically like to involve some new research for each project. Each supervisor takes on one or two students and students can work in loose pairs (each with their own research question, but using similar techniques) or as individuals.

Projects are assessed based on a final written report or ‘mini-thesis’ which gives details of methods and results. Often, the written report is accompanied by an oral presentation. Project presentations can become social and educational high-points in the final year, having an audience of many staff and students from within the department, and representing an important milestone for final year students in terms of becoming a mature member of the physics community. Further assessed elements may take the form of marking interim reports and giving formative feedback, but in general, process is given much less prominence than content in project work.

Basic staff expectations for projects are that students gain a taste of the research process while applying knowledge and skills learnt during earlier work. For students, retrospectively, projects are often the most memorable experience for graduates and sometimes prove to be vital factors in career decisions.

\footnote{Project LeAP is funded by the Higher Education Funding Council for England under the Fund for the Development of Teaching and Learning, Phase Four, and involved a consortium of physics departments in UK universities: the Universities of Leicester, Hertfordshire, Reading, and Sheffield. Many of the Project’s findings are collated in Raine and Symons (2005).}
Projects have been an embedded part of the physics curriculum for over thirty years. In contrast PBL is newly emerging in this discipline. Can one complement the other?

**Background to investigation**

Attitudes to PBL from the physics teaching community\(^3\) are varied, ranging from highly enthusiastic (arising typically from personal inclination towards this learning style), through interested but unwilling to try (arising from perceived barriers to change), to the view that traditional lecture and laboratory teaching represents a superior delivery method for physics (no motivation for change has been acknowledged). It is in the latter group, unexpectedly, that an interesting qualifier emerges, typically expressed as “I can't see us ever using PBL, although it could be a useful preparatory activity for final-year projects”. This is used in apposition to a perceived flaw in introducing PBL: “Only final-year students have the maturity to work in a project-like structure. To me, PBL resembles projects and is therefore not suitable for earlier years of study”.

A second phenomenon related to projects also emerged anecdotally and sheds an interesting light on this attitude. Staff who expect project students to apply skills and knowledge gained during their previous university study, often have the experience that final-year projects serve to highlight gaps in learning. Supervisors recount experiences of project students struggling with the basics of, for example, C++ or basic thermodynamics which the students ‘learn’ in their first year but only really conquer through the motivation of their project. This implies that project work, instead of using and reinforcing existing knowledge, may prove to be the richest learning experience for a student while at university. It is not surprising that deep learning\(^4\) happens during this activity: the student ‘owns’ the project, knows the context of the work he or she is undertaking,\(^5\) may be part of a larger collaborative team\(^6\) and hence

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\(^3\) Staff attitudes collated from Project LeAP’s programme of ‘Road Show’ visits to UK Physics Departments 2002-2005.

\(^4\) Ausubel (1985).

\(^5\) Vygotsky (1978).

\(^6\) Roschelle (1992).
feel part of the community.\textsuperscript{7} Thus, they develop a different, more mature, 
professional relationship with their role as student physicist. All of these 
factors are shared with problem-based learning. A major perceived difference 
between projects and PBL, the reliance on previously-acquired knowledge, 
may not be as strong as believed. While projects are not couched in the 
framework of PBL, the links are strong enough to suggest that the two 
activities could be mutually supportive within an integrated curriculum.

Is it true that the benefits of project work only occur after several years of 
standard university teaching? Staff attitudes to project work generally suggest 
that students need a certain level of knowledge and technical skill before 
project work becomes accessible and valuable to them. Also, projects tend to 
take a considerable amount of staff time to oversee, due to the personal 
nature of the contact with students, who often work individually. These factors 
prevent projects happening before the final year of study. However, staff also 
recognise that students often struggle with the freedom of projects: the lack 
of constraints in time, level, and (to a certain extent) direction. Some of the 
contact time is usually taken up with time-management issues, such as 
starting too slowly or unevenness in approach leading to panics and hold-ups, 
and overcoming ‘stuckness’ brought on not by lack of knowledge, but by lack 
of clarity of purpose.

Project work is perhaps the most complex process which students undertake 
during their degree, both on an intellectual and professional development 
level. We can identify several areas which may be new to students or 
performed in an unfamiliar manner during projects, where previous use of 
PBL can prepare students for more efficient and rewarding project work. 
These include project management (especially time management), writing 
skills, self-directed research and learning, interaction with others in a (real) 
working team, experimental design, and problem-solving.

The links between most of these areas and the PBL process will be obvious 
and will be common to project work in many other disciplines. An area of 
particular discipline-specific interest is problem-solving.

\textsuperscript{7} Wenger (1998).
Problems in physics

Problem-solving in traditional physics courses generally consists of end-of-chapter-style problems which are used to reinforce by repetition techniques introduced in lectures. In their most basic and familiar form, some context may be given, but the emphasis is on applying the given data to the described situation via a ‘template’ (for example an equation or law) into which the data are inserted and the answer generated. Manipulation of the template is sometimes required. At the end of the problem, a discursive question may be asked. A mark will be given for a right answer, with a wrong answer occurring if a mistake has been made either in inserting the data into the template or in the identification of the relevant template or format. Feedback given for a wrong answer needs only to be minimal (error identification) and throughout, the students' range of choices in approaching the question are (intentionally) very narrow. The discursive question can usually be answered in a single sentence, and students who are only just coping with the material will generally omit answering it. The value of this type of problem is in reinforcement and knowledge checking. For staff, the learning issues from a unit can be addressed individually in clean, targeted problems, and the marking load is acceptable.

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Example of a set of ‘exercise’-style problems from AC theory

(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 cm². 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) What resistance placed in series will be required to ensure the two signals are separated in the tuned circuits of part (b)?

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8 Woods (1994) Ch. 3, p 4. describes this type of problem-solving as 'exercise solving' in order to contrast with the use of the word 'problem' in PBL.
In contrast, the type of problem posed by projects will be ill-defined, unfamiliar, open-ended, capable of investigation in a variety of ways, interwoven with other issues in a complex manner, and/or critical to the success of the project. All of these aspects represent stress factors for project students who may not be adequately prepared to overcome them without significant input from their supervisor. Students may not have met ‘dead ends’ before and may either be unwilling to start an investigation without the outcome being in sight, or may be very discouraged if an approach to which they devote energy proves incapable of conclusion.

Furthermore, project problems may not fall into a well-defined topic, or even into a well-defined process area. The example above draws on knowledge from a particular subject (AC theory) and a defined source (theory lectures). Project problems will require students to combine knowledge from several of their physics modules, mathematics, computing, and laboratory experience. If students’ conceptualisation of physics has remained divided into ‘bins’ instead of forming a network of interlinked constructs, they will find project work much harder than a student who has already made progress towards an integrated understanding of physics theory (either as an individual or as part of the design of the course) which they can call on and add to during their project.

PBL provides a structure, akin to scaffolding, which can introduce a more developed, mature, and life-like problem-solving environment in preparation for project work and, in the longer term, the work or research which a student will perform after graduating.

Methods and models

Most physics departments will not have the opportunity or the necessity for clean-sheet PBL implementations, so the models described here will concentrate on incremental changes within an existing curriculum.

PBL can be introduced into many of the typical activities and fields covered in a physics course. The area applicable to the example above is clearly problem classes (tutorials, seminars, workshops, or worksheets) associated

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9 Wood et al. (1976).
with an AC theory lecture course. In addition, there will be laboratory work which may not (for operational reasons) occur simultaneously with the relevant problem classes.

Problems can be developed by starting from a list of learning issues associated with the course area (for example inductance, capacitance, and Q-values in LC circuits) and identifying scenarios or situations which draw together these concepts. Look for interesting, engaging, or topical applications where students can assume a role, make decisions, or form opinions instead of simply finding an answer. For each idea, problems can be drafted which conform to the implementation scenarios described below.

The following models indicate a spectrum of implementation of PBL in physics. Each model is described briefly, and the key benefits in relation to, or preparation for, final-year projects are noted.

**Model 1: Enhanced problem classes.** In addition to a range of typical problems, PBL-like scenario problems are introduced. These mini-PBL activities are short, theory-only, and will probably be tackled by students working alone. Very little PBL process will be introduced, but the ideas of open-endedness and contextual setting of information can be present. These questions should form a discussion point in class. Tutor roles remain the same as for ordinary problem classes, but should include development in students of discussion skills and confidence in recognising unusual applications of familiar theory.

*Benefits to project work:* Students have more flexibility in adapting problem-solving templates to new situations.

<table>
<thead>
<tr>
<th>Sample mini-PBLs</th>
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<tr>
<td><strong>Heavy air (from ‘Light and Matter’ core module)</strong> People often say in humid weather that the air is heavy. Can this be literally true? Golf is more difficult in the rain for a number of reasons, but is there any affect from the rain on the flight of a golf ball?</td>
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<tr>
<td><strong>Goodbye oceans (Light and Matter)</strong> The scenario for the latest Hollywood</td>
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blackout has the Sun increasing in luminosity to the red giant phase giving only a short time to evacuate the Earth before the oceans dry up. Advise the producers on how long this might realistically take.

**Speed Kills (Dynamics)** 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 braking from 30 mph. Advise them on 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.

**Nuclear Energy (Waves and Quanta)** By examining the binding energy curve, or the mass difference curve, (i) decide if the fission energy depends significantly on the mode of fission and (ii) determine how much more energy is liberated per unit mass by nuclear fusion then nuclear fission.

**Levitation (Electricity and Magnetism)** A Bingo House wants to use an electric field to levitate the ping-pong balls which carry the numbers for the caller. What would you advise?

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**Model 2: Replacement of an existing laboratory experiment with a PBL-like version.** Students are given a scenario where the results of the experiment have consequences and are asked to plan the experimental procedure. They can work in pairs (as is traditional) or groups of around four (larger groups are impractical in the laboratory environment). They are required to document their experiment as usual, but possibly have an additional short task such as describing the results in a press release, or writing a short article about the significance of the experiment. Tutors in this model aim to encourage students’ investigation of the experimental equipment, and should draw out knowledge from students instead of demonstrating correct procedures.

**Benefits to project work:** Students practise experimental design, the pertinence of results, and alternative points of view about presenting physics.

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**PBL version of AC Theory problems (above)**

From: Quality Assurance Division
To: Head of Systems
Re: Monitoring of levels and temperatures in manufacturing process

It has come to our attention that we rely on visual inspection to monitor the sugar levels in the supply vats. In order to ensure a steady supply of sugar to the heaters we need to keep the level
between defined upper and lower limits. This is particularly important as we use only a single low temperature warning system in both the toffee and caramel vats which could present problems if the temperature falls too low from an over or under supply of sugar. This certainly isn’t best practice and risks significant financial losses if we have to interrupt the manufacturing process. Can you get the research people on to this? We need something that will not fail if the power goes.

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**Model 3: Introduction of pre- and post-laboratory sessions based on a PBL model.** Most PBL strategies include a cyclical process of initial contact with the problem, planning, exploration, sharing, and revisiting. Framing laboratory, research, or computing investigations by reflective, process-focused contact time (here labelled ‘seminars’) helps to develop students’ understanding of the concepts behind their work and to use their laboratory
time more effectively. Pre-laboratory activities have been shown\textsuperscript{11} to enhance learning in traditional laboratory schemes, but can also be a natural feature of a PBL problem, incorporating several steps of the chosen PBL strategy. Students work in groups (again, four is a suitable group size) with a facilitator who follows their progress throughout the problem, but several groups can be part of a pre-laboratory seminar session. The activities can be assessed, and pre- and post-laboratory tests or quizzes can demonstrate (to students and staff) progression of knowledge. In the pre-laboratory activity, tutors take the role of a PBL facilitator. As students enter their laboratory sessions (perhaps two half-days, with time for reflection between) well prepared and organized, tutors’ laboratory supervision duties are reduced to safety considerations, dealing with technical and operational problems beyond those soluble in a useful way by students, and being available for discussions.

\textit{Benefits to project work:} Students become habituated to devoting time to preparation of investigations and reflection on results and practices, and also see that tutors will give guidance but not do work for them.

<table>
<thead>
<tr>
<th>A PBL strategy designed for physical sciences\textsuperscript{12}</th>
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<tbody>
<tr>
<td>1. Locate problem</td>
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<td>2. Existing knowledge</td>
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<td>3. Identify learning issues</td>
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<td>4. Course of action</td>
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<td>5. Enquiries and/or Experiments</td>
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<td>6. Share results</td>
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<td>7. Theorise</td>
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<td>8. Evaluate progress against target</td>
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<td>9. Repeat, Report, Reflect</td>
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\textit{Model 4: Integration of laboratory work, lectures, and problem classes.} The PBL problem is introduced at the beginning of a module lasting several

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\textsuperscript{11} Johnstone et al. (1998), Reid (2003).
\textsuperscript{12} Raine and Symons (2005) p. 42.
weeks, and forms the over-riding theme. Traditional elements are all still present, but groups of students apply what they learn directly to the problem, and have identified the need for knowledge before arriving in a lecture. In problem classes, the 'enhanced' problems (from Model 1) deal with sub-areas of the greater problem, while laboratory work (based on Model 3) is devoted to a collaborative exploration of possible solution paths. Endpoints include scenario-based outputs, such as writing from a particular viewpoint and for a given target audience, but core knowledge is also tested in traditional ways, such as standard examinations. Tutors will be facilitators for the PBL process in many of the activities and will monitor and guide students' progress towards final goals. In addition, they will act as subject experts, delivering lectures and answering queries about content.

Benefits to project work: Students see physics as an integrated activity to investigate important, interesting problems. New knowledge is gained for a reason, and a problem which will at first seem beyond solution will be resolved by a process of learning and collaboration.

Model 5: A PBL module. Students are given a PBL problem, which will be progressively disclosed and developed over a period of a few weeks, during which this is their sole activity. Under the guidance of a facilitator, and with visits from 'subject experts' when the need has been identified, the students manage their own time and learning. Core knowledge and skills will be covered by all students, but there is room for personal learning objectives. Group size can vary, with the problem being complex enough for individuals or groups to have different roles and outputs. Assessment is tailored to be an integrated part of the learning environment and includes a mix of content, skills, and reflective components.

Benefits to project work: Students become 'project managers' who work to goals, manage their own learning, converse meaningfully with subject experts, and whose behaviour and output models real-life research work.
for scientific merit. This example covers elements of thermodynamics.

The Johnson Converter (Patent #05-2005)

Inventor: Dr. Philip Johnson, 18 Stokes Road, Truro, Cornwall

Abstract: A device to harness solar energy. The sun heats a chamber of gas during the day which expands, driving a piston. At night the gas cools, and the process reverses.

Description: Every day over 1000 joules of energy beat down on every square metre of the Earth every second, most of it going to waste. The Johnson Converter intends to harness some of this energy, without the use of technically complex and fragile solar cells.

The Johnson Converter consists of a chamber of air – just plain air, so no poisonous gases, no special materials that cost extra money, or can be exhausted and need to be replaced – with a piston to extract the energy.

Essentially, the converter operates like a steam engine, but rather than the piston being driven by evaporating water, it’s driven by expansion of gas due to insulation.

Below is a schematic of the apparatus:

The cycle operates as follows:

Incoming solar energy heats the gas in the chamber, which expands isobarically. The walls of the chamber are fixed, and the piston is pushed upwards.

At night the gas cools and contracts, again isobarically, and the piston returns to its original position.

This cycle continues ad infinitum and a low, but steady, power is extracted by a dynamo.

Claim: It is not anticipated that the Johnson Converter will replace traditional power stations, but with its ease of upkeep and relatively low setup cost, as well as the virtue it has of accessing otherwise wasted energy (and bringing down people’s electricity bills), I believe that they will have a large market. Perhaps the government can be persuaded to give concessions to customers, who will be reducing dependency on fossil fuels, and aiding our efforts to meet the Kyoto Protocols.
Each one of these models has been developed and implemented during Project LeAP, with Model 5 currently being used for an Interdisciplinary Science degree housed within the Department of Physics and Astronomy at the University of Leicester. Model 4 is currently used within first-year core physics modules (taught by teaching teams of three staff plus support from graduate students) and stream-specific\textsuperscript{13} modules in the first and second year (designed and taught by individual members of staff).

**Conclusions and further exploration**

A research programme is being planned to explore further the attitudes and expectations of staff and students starting final-year projects, and, eventually, the impact of prior experience of PBL on project outcomes. It is intended to elicit predictions of student performance anticipated by staff (through the use of interviews) together with elicitation of students’ attitudes to projects \textit{a priori} (by using an inventory). Observations of staff and students will then be recorded as the project process ensues (utilising video analysis). Finally students’ attitudes will be elicited \textit{a posteriori} (again using the same inventory) which together with elicitation of staff reflections (utilising a questionnaire) allow the effects of the projects upon staff and students’ perceptions (particularly of attitudinal changes and of predicted versus actual performance) to be gleaned. Furthermore, these outcomes may be matched against actual project processes, resulting from the video analysis, thus providing important practice feedback. The methodology utilised will be a variant of Grounded Theory\textsuperscript{14} and Case Based research.\textsuperscript{15}

The five models demonstrate that PBL-like activities can take many forms and can be developed incrementally within an existing physics curriculum.

The established benefits of final year projects can be introduced into earlier years in a physics course without completely re-writing the curriculum. In essence, the knowledge-, skills-, and attitude-formation which supervisors see happening in students during final-year project work is exactly that which we

\textsuperscript{13} Degree streams include Physics, Physics with Astrophysics, Physics with Space Science, and Physics with Nanotechnology.

\textsuperscript{14} Strauss and Corbin (1998).

\textsuperscript{15} Stake (2000).
wish to foster in PBL. Introducing PBL into physics at an early point in the curriculum is not only a natural way of preparing students for project work, but, even more importantly, of engaging students throughout their degree course, promoting lifelong learning, and providing useful and enjoyable experiences in the same way as projects have done for graduating students for many years.

References:


