This series of slides provides a short introduction to problem-based learning in higher education. As we will explain, we interpret “PBL” in its wider sense to cover a range of implementations and not just the forms in use at our host institutions. While, given our affiliations, some of the examples are specifically aimed at physics and physical sciences, much of the content is applicable more generally.
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In this first section we shall look at the basic ingredients of the problem-based approach to learning and teaching. Let’s start with an example.
A problem:

It is two weeks away from the end of term. Jean has arranged to see her personal tutor to complain that the rest of her group never turns up to the meetings to prepare their weekly presentations: so she has to do this largely by herself. Just before the presentations the rest of the group will borrow her notes so they can present the material if asked to. Since presenters are chosen randomly and the mark is awarded to the group as a whole, Jean feels that it would be counter to her own interest to withhold the notes. But she resents the fact that the others’ presentations are sometimes muddled because the other group members haven’t understood properly what she has done. She feels that the whole process is unfair and that she should get extra marks for her efforts, while the rest of her team should have marks taken away. She thinks that the assessors for the final session of the module should be told what has been happening, so she does not have to share her work for that session.

As her tutor, what would you do?

The text on the slide recounts an incident in a group work module in which a student reports a problem to her tutor. Please read through the slide and think about what you would do if you were in the position of the tutor.
Your thoughts might be something like this: what is the problem here? On the face of it the student appears to be in a lazy group who are happy to leave her to do all the work because they share the credit anyway. Is this how the course really runs? Do I need to find out more about what students are expected to do in the module, or am I sufficiently familiar with this already? Can I take her proposal that I talk to the presentation assessor directly or do I need to find out what the other students feel?
This is a real story (although the student was not called Jean), so we can tell you what actually happened. The rest of the story is on this slide. Please read it. The research we have done has perhaps led us to a rather different picture of the problem.
As experienced tutors we would approach the problem systematically. We need to understand what the nature of the problem is. In this case the tutor decides to probe more deeply rather than taking Jean’s word (or her solution). This reveals a quite complex problem in group dynamics. To tackle it one might discuss the issue with other tutors. We’ll come back to how we might formalise these steps in problem solving. For the moment, let us observe that asking them to tackle problems like this might be a good way to train academic staff to act professionally as personal tutors.

Follow-up

• Now consider the following questions

- What do you think the problem is?
- Is there anything in your own experience that would help you to resolve this problem?
- Is there anything you need to find out to help solve the problem? Could you seek information from anywhere or anyone?
- Would it be helpful to discuss this with colleagues?
Let us contrast the approach implicit in this example with traditional methods of teaching. In the traditional approach, teaching begins with the delivery of information which the teacher believes that the student needs to know. As a test of the acquisition of this knowledge the teacher may follow the delivery of the information by setting a problem. Problem-based learning begins with a problem which the students must research to acquire the information that the students themselves believe they need to solve it. The tutor is there to guide the research in response to the students' needs.
Thus, the principal idea behind PBL is that the starting point for learning should be a problem, a query, or a puzzle that the learner wishes to solve.
So learning is initiated by a problem. That problem should in general not have a closed solution that is either right or wrong, so that it initiates a discussion in which students can share knowledge. It is a common feature of PBL that students work in groups to promote discussion. Not all of the information required should be given in the problem, so the solution of the problem should require research; thus in solving the problem students acquire new knowledge. Students identify the knowledge that they need, under appropriate guidance. Thus their prior knowledge is not an assumption made by the instructor. And finally, learning requires the active participation of the student.
PBL (problem-based learning) is a student-centred method of teaching in which students learn by investigating real-world problems and, working in groups, seek out the tools necessary to solve them.

This slide summarises what we've just said in different words. Later we'll see a range of implementations of PBL.
Although there are other claims to priority, PBL as an institutionalised form of tuition originated in the McMaster medical school. This was in response to an evaluation of the effectiveness of medical education, to train doctors to be doctors and not professional students. The key elements of the McMaster model are self-directed, self-assessed learning based on a set of carefully crafted real-world problems that take students a step at a time through their medical training. The concept was embraced in the medical schools at Maastricht and Newcastle in Australia with some collaboration on the development of the programmes. From there the methodology spread to professional education more generally, for example in other medically related professions (nursing and midwifery), architecture, law and engineering. In the humanities, PBL has been employed in sociology and related disciplines, particularly anthropology. The uptake in the sciences has been slower, although some chemistry courses have significant elements of PBL and physics has embraced the PBL approach in a handful of institutions.

The spread of PBL has also seen local adaptations of the PBL method and a broadening of the approach to a number of BLs, notably project based learning, context-based learning, case-based learning and enquiry-based learning, wherein the initial stimuli are extended from problem scenarios to more general research questions and cases.

In the next section we’ll look at how effective PBL is and some of the reasons that have held back its acceptance in pure sciences.
In this section we address two questions: the evidence base for PBL in learning theories and the evidence base from practical implementations.
Before we go any further let’s look at the objections to using PBL. We’ll leave aside resource issues, drivers for change etc. for the moment and look at some objections to the process. Then we’ll look at the claims for PBL. And finally in this section we’ll use what we’ve learnt to try to answer these objections.

“PBL is the most significant educational advance of the 20\textsuperscript{th} century” (Boud D and Grahame Feletti G)

[-- But it isn’t physics]

- Objections:
  - Linearity
  - Students don’t know enough
  - Skills (Kolb levels)
  - Coverage (a single PBL problem)
Let’s deal with the external reasons first: Over time we’ve heard that that PBL is something we’d love to do if only we had the resources, the space, better students, less able students, and that PBL is fine in theory but it won’t work with our teaching staff. All of these are true: PBL, just like any pedagogy, doesn’t work by imitation. It has to be adapted, usually by trial and error, to local circumstances. But this is equally true of traditional teaching. (In fact, even within the same institution it is rare for someone to take over someone else’s lecture course without changing it.)
The next objection was the linearity of learning. This is exaggerated. For example, although most physicists think that physics begins with Mechanics, because US textbooks do, in the UK Mechanics is not even a component of some pre-University physics programmes. This does not mean that you can start anywhere. The structure is imposed by the different technical requirements of different areas of physics. So you might think of algebraic physics, calculus physics, complex numbers physics, pde physics and so on. It is not appropriate to teach this skills component by PBL alongside a physics course (or even worse as part of a physics course) – there is evidence that this does not work. Students have to come to the physics PBL with the technical skills they need. This includes not only maths but also laboratory skills. Students cannot be expected to design an experiment to test a physical theory if they do not know what (say) an oscilloscope is. The same applies to any subject that demands a hierarchy of technical skills.

In fact the hierarchy of skills is well known as Blooms taxonomy, or versions thereof. These attempt to systematise the different stages of development of cognition. But they are processing skills, independent of the hierarchy of discipline knowledge.
The next ubiquitous objection is that students do not know enough to tackle a problem so we must prepare them by telling them everything they need to know. We'll see why this is impossible when we come to learning theories (Strictly it's not the telling that is impossible, it's achieving the stated objective through telling.) Problems have to be carefully crafted to develop concepts incrementally, but the new knowing comes from doing the problem not from preparing for it. In fact, the segmented view of knowledge acquisition – acquiring segments at all levels – is the one we practice in the way we stage education through school. We do not forbid students to proceed beyond Newtonian mechanics until they have mastered Hamiltonian dynamics and the KAM theorem.
We can’t cover the syllabus if we have to wait for students to solve all these problems. Actually, if you are not waiting, you are not covering, except in the trivial sense of flipping the pages. You cannot make students learn more quickly by delivering material at a pace: this just encourages a surface approach where student try to identify the subset of what you are supposedly teaching that will get them through the exam.
So let’s assume we want to find out a bit more about PBL. First, let’s look at how it relates to the way people learn. There was a time when there was a widespread opinion that since behaviour is the only observable, learning is related to behavioural change. This implies repetition and reward for actions that are measurable. This approach is relevant to the acquisition of skills, but it is surprisingly easy to see why it is wrong for higher level skills. For example, my computer can read music and reproduce it technically perfectly, in the sense of playing the right notes. Because it does not, in some sense, understand music the technically perfect rendition does not sound much like the performance of a musician. Many experiments have shown how students can be trained to give the right answers in a physics lesson and revert to an Aristotellean world view outside their class. We therefore have to think about how we learn, that is, cognition. Cognitive theories stress the acquisition of new knowledge as a process of extension of what we already know. The most widely known of these theories are Piaget’s stages of development and Vygotsky’s zone of proximal development. As far as HE is concerned Piaget’s important insight is into assimilation and accommodation – the way we fit knowledge of our existing structures and the way we change our structures to accommodate new information.  
http://www.learningandteaching.info/learning/assimacc.htm. That this is best achieved in a social context was emphasised primarily by Vygotsky (http://www.learningandteaching.info/learning/constructivism.htm, http://tip.psychology.org/vygotsky.html) and leads to social constructivist theories. These are anathema to many physical scientists who think that scientific knowledge is objective: perhaps it is, but what we make of it and the way we learn it isn’t, as we’ll see later.
How does this fit into PBL. We begin with experiential learning and this quotation from John Dewey, one of the most influential of educationalists of the 20th century. There is a well-known Chinese proverb that says much the same thing: “Tell me and I'll forget; show me and I may remember; involve me and I'll understand.”

“...careful inspection of methods which are permanently successful in formal education...will reveal that they depend for their efficiency upon the fact that they go back to the type of situation which causes reflection out of school in ordinary life. They give pupils something to do, not something to learn; and if the doing is of such a nature as to demand thinking, or the intentional noting of connections; learning naturally results.”

John Dewey (1916) see http://www.infed.org/thinkers/et-dewey.htm
Here is another comment on passive learning.

... the structure of traditional science courses erects numerous roadblocks to students becoming actively involved in their own learning. Encouraging students to remain in this passive role in the classroom has the further unfortunate effects of promoting rote learning ... and riveting intellectually immature students to a naïve view of knowledge and its acquisition.

From Deborah Allen, Barbara Duch & Susan Groh
The Power of PBL in Teaching Introductory Science Courses
The Boyer commission looked at educational practices in the US Research Universities with a view to improving the undergraduate experience. They came up with ten recommendation of which the three highlighted are particularly pertinent. Research-based learning is a hopefully self-explanatory close relative of PBL, both of which link professional skills and subject material. Cultivating a sense of community will be an important aspect of PBL.
The problem of achieving an integrated curriculum is highlighted by Bransford in this quotation.
What Bransford highlights is that introducing good ideas into a pre-existing curriculum is not necessarily a successful approach. It is important that curricular in general, including PBL curricula, are coherently designed. The educational term adopted to express this coherence is constructive alignment. Let's look at what this means.
Here are some learning environments. The Socratic method is rather labour intensive and requires a Socrates. Apart from that all day one-to-one conversations and a “symposium” in the evening have much to recommend – for wealthy philosophers. The apprenticeship model, represented here by Kepler and Brahe is not dissimilar to the Platonic dialogue. It is of course the preferred method of research training and appears in undergraduate programmes as the final year project. But it is not thought to translate to a mass system, where one sage performing to an audience of 500 is a more cost-effective solution. In fact, why stop at 500. With electronic media it could be 5 million. The problem is that methods of delivery are not neutral with regard to the educational model. The sage on the stage implicitly assumes a delivery mode – old wine into new bottles. Just as the apprentice model assumes the relevant learning occurs through copying the works of the master.
And then we have active experiential learning. How well do these environments align?
Let’s look an example from Physics. The slide encapsulates a lecture and an exercise on the lecture. The equations on the slide are genuine equations from physics, but in an unfamiliar notion. Since any notation will be unfamiliar to the students this gives some impression of how the lecture might appear to them. The exercise is a genuine example (using the same coding) that can be solved on the basis of the lecture. The problem is that it can be solved by anyone with a modicum of patience quite independently of any understanding of the lecture, just by pattern matching. Mildly industrious students therefore receive full marks; how are they supposed to know that they have not done exactly what was asked of them?
The slide shows the non-alignment of the traditional models. On the left we have the categories of alignment: subject knowledge and related skills; prior knowledge and goals; the assessment regime; and the nature of the community. While academic teachers view subject knowledge from the point of view of the professional researcher, students aim to become good students. Professional students are experts in examination technique. This is not generally the required expertise of the professional employee. The teacher assumes a certain level of prior knowledge: without this they would be teaching the same thing over and over and we would never move on. Furthermore the academic teacher sees the goal as recruiting the best students to their research group. In fact, the prior knowledge of students is variable and unformed, and their goals are usually very different. For the teacher, assessment is what happens at the end of the traditional course; for the student it is the starting point. But we do agree on one thing: in terms of a sense of community it’s “them and us”.
The PBL model seeks to change this non-alignment by re-creating the classroom as a coherent model of the professional world.
This brings us back to constructivism. How does information acquire a meaning? There are two requirements: prior knowledge and context.
What is the meaning here? Click on the slide and see when the meaning is revealed.
You’ll find that the symbols acquire a meaning only in context. If students do not own the context, they will not recognise what it is they are supposed to be learning. This means we need tools to diagnose the recognition of the context, not just behavioural traits.
And just in case the symbols were unfamiliar... Here are the more common symbols. The fact that you don’t need this shows how powerful the socially constructed context is.
Collaborative learning in a community is a way of providing a context. Various experiments show the value of collaborative learning. PBL is set up to encourage collaboration.
The slide is adapted from one of the most referenced demonstration of the effect of collaborative learning. The data shows the gain in the score on a concept test on Newtonian mechanics by University students in the US, following a course of instruction, versus scores on the same test prior to instruction. The two modes of instruction are indicated by different symbols. In almost all cases the gains are greater for students working collaboratively.
So much for the theory. What about the practice? The slide shows some of the feedback from students at Leicester to independent external assessors.

- ‘practical learning... it really helped me to understand and apply the theory...I understand a lot more’
- ‘we felt we needed preparation for PBL but, actually, PBL was a preparation for now’ - A 3rd year student after two years with PBL
- ‘you have to learn it for yourself, not by preaching...you have to have the experience before you can see how good it is’
Not every student finds it a positive experience, especially in the beginning. Most students increasingly appreciate the approach as they progress. There are now a number of student guides to PBL that aim to support students undertaking PBL curricular, especially in the initial stages.
A large number of studies have been carried out to try to determine the effectiveness of PBL. There are also a number of meta-studies and reviews that try to put this data together. The slide gives one reference to a synthesis of a selection of eight of these meta-studies which together include a total of around 160 investigations. The majority are in medicine and professional education (including teacher education where the largest positive effects in favour of seem to be found). The results depend on what is measured. The conclusion of these authors is summarised on the slide.
Let’s come back to the notion that teaching pure subjects like Physics in Higher Education is different from teaching professional practice. It is! But we know a context in which PBL works in HE, namely at the postgraduate research level. We can think of PBL as a way of scaling one-to-one postgraduate research supervision to the undergraduate context which provides an alternative to the traditional transformation of a conversation into a lecture. So stick with us for a bit and let’s explore how PBL can be used effectively in HE in general and Physical Sciences in particular. We’ll begin by looking at practical implementation in the next section.

Then we’ll return to the perceived problems with PBL in HE and see if we can address some of them.
You might think that we would start the development of a PBL programme with the problems, but we won’t, because PBL is not just about presenting problems and telling students to solve them. The choice of problems is important, but so is the way they are presented and supported. All PBL implementations have some framework or scaffolding and getting this right for your individual circumstances can involve a lot of trial and error.

There are two aspects to the structure: the support framework, what and how classes are arranged; and the balance between group and individual work.
A PBL programme like any other method of curriculum delivery, is based around an understanding of the rhythm in which students learn. There are a variety of ways in which the learning process can be split into a cycle of stages. The slide shows one of the best known due to Kolb. We turn this from theory to practice when we establish a teaching schedule.
Here’s a simplified version of the learning cycle specific to PBL. The distinctive feature of PBL is that it starts with a problem. Later we’ll see some variants that take advantage of some of the other positive features of PBL but use a different starting point. In all cases the starting point generates a set of learning issues; things that need to be found out in relation to the problem. Part of the design of a PBL programme involves the degree to which these are wholly generated by the student or tutor led. For example, Woods describes a Chemical Engineering module in which the students have access to the learning objectives specified by the tutor to which they can compare their own if they wish. (Ref: article in Bond book) Where the learning issues are student led, the tutor will normally give some guidance on priorities or focus.

The agreed learning issues for the basis for individual research which can then be brought to bear on the problem at the evaluation stage. The cycle is then repeated in the light of the new knowledge.
Some learning issues will be part of the group’s existing knowledge. These should be identified. What is left is then what has to be researched. The group need to agree how this is to be done. There will be some core knowledge that has to be researched by each of the group. They may chose different resources to do this, but they will each come to the next session with this information. There may be some research that can be divided and shared; the group may want to find a number of example of a process, in which case they can take one each. Or there may be some issue that one of the group members takes on as research in order to teach it to the rest of the team at the next meeting. The tutor has an important role in ensuring that the group does not confuse the different aspects of research.

The sharing process occurs at the next meeting. The group members need to ensure that they have a common understanding of the individual core knowledge, and that they exchange information on their separate contributions to the group research. The tutor again has a role here in ensuring that this exchange does take place.
This slide summarises in a different form and expands on what we have just discussed. We can think of PBL as planning, investigation and analysis. We insist on a written plan which is part of the assessment so that the responsibilities for research are clear. With more experienced students the sharing of information can take place without detailed supervision although we often schedule compulsory facilitated classes for this. In the early phases of a programme the reflective aspect is often the most difficult in terms of persuading students to look more deeply than a general article on Wikipedia. The extent to which suitable resources are suggested to students is part of the planning of the programme.
Let’s look at some examples of the way in which this has been put into practice. The most widely known of the PBL structures is the Maastricht 7 steps. Here is the version from the UCD web site. It spells out some of the detail of what is required at each stage.
This is the same Maastricht model as defined in the British Medical Council journal. Note that step 6, private study, requires each of the students to research all of the learning objectives.
This slide shows the structure from the Institute for the transformation of University Education at Delaware with their permission. Here there is some acknowledgement of the division of labour at the research stage. We'll come back to group and individual learning later.
Finally, here is the Leicester model, which provides not the easiest of acronyms. It is adapted to acknowledge that the research stage may involve the execution of an experiment which might have its own LEIC loop.
Now we come to the writing of problems.
Here are some of the things that are known about PBL problems and some of the things we have learnt. Let’s take them one at a time.

In strict PBL a problem should be just that, not a mission statement or an instruction to do something, as one might find in a project. This is relatively easy when there is no pre-defined curriculum, and increasingly difficult the more one needs to cover stuff. In the light of this difficulty a number of variants of PBL have arisen which acknowledge that they are starting from a case (CBL) an enquiry (EBL), or subject to research (RBL) or a project (which doesn’t get its own acronym). If you want to distinguish there is also PPBL (for pure PBL). None of this matters provided that the problem is relevant; that is, provided that it is not just appended to a set of learning objectives in a way that it can be safely ignored. An example might be a photograph as the trigger to the problem of how a camera works. The photo adds nothing to the problem: how does a cameras work?; in fact it just annoys by its irrelevance.
What is a PBL problem?

- Poses a stimulating question
- Based in a realistic context
- Is open-ended and/or multi-pathed and encourages debate
- Complex (cannot be “Googled” or guessed)
- Encompasses several new areas of knowledge
- Gives students a role or point of view
- Requires “professional” working habits
- Engages students

PBL began as a pedagogy for professional education. The whole point therefore was to provide a realistic context for training that would prepare graduates for employment. Professional practice will provide a range of problems from simple to complicated that can form the basis of a structure curriculum, even if some doctoring is required. In the pure sciences it seems to be more difficult. Let’s consider a professional physicist for example. A research physicist will be presented with problems that are way beyond anything that can provide a useful framework for a beginning undergraduate. This attitude arises from a somewhat narrow view of the professional physicist as research academic. Once we expand the horizon beyond the pure discipline one can find many problems in environmental science, biophysics, geology and so on that provide problems in physics at all levels. In the last analysis it may be that one accepts that a realistic context does not mean an actual context. For example, many of the PBL experiments at Leicester use simple equipment that comes up against the signal to noise problem of real life. We could have engineered precision equipment that would get round this, but we prefer to simulate the research environment where the answer depends on some realistic error analysis.
Our next desirable property for a problem, open-endedness, presents another issue. Most physics problems as we currently teach the subject are closed, in that the answer is right or wrong. Educators who do not have any experience of physics have latched on to the supposed fact that while there may be only one answer, there is more than one solution, that is, that problems can be tackled in a variety of ways. In our undergraduate careers we think we came up on just two occasions with solutions that were genuinely different from that expected, and not just a superficially different presentation of the same solution. We do not think there is much mileage in requiring that PBL problems in the pure sciences should have multiple methods of solution, although there are some possibilities in experimental design work. Our approach is to require the problem context to be such that the answer has consequences, for example, where the range of outcomes using different values for unknown quantities might affect a decision. This is also relevant to the obvious constraint that it should not be possible to find the complete answer to a problem on the internet. This can happen if the problem is too simple, which enables students to “answer the question” without engaging in the learning objectives or because it is too close to standard book work.
Many academic staff think that they get the point of PBL as an aid to reinforcement or revision. “They can’t solve that because we haven’t taught them this yet” is a common complaint. Actually, PBL IS a great aid to reinforcement, but that is not the main intention. It is also true that there is only so much new knowledge that can be incorporated in a single problem. But there should be something that students decide they need to learn. This will be the things they remember later. The word several is also important here. PBL problems should enable students to integrate knowledge.
Giving a point of view is important and difficult. Students are not experts, so problems that attempt to provide a role and a point of view by starting “you are an expert in climate change ....” are confusing. Constructing the learning issues becomes a tortuous navigation of the response that “if we were experts we would know that”. Often the source of the difficulty is the problem. Students are unlikely to be researching basic geology if they “work for an oil exploration company” but they might be if they are doing some archaeological research. For the most part we find that most academic staff (and students) are more comfortable if we dispense with the pseudo roles and just treat students as “fellow professionals”, essentially as a research team with a “line manager”. The point of view should be implicit in the problem. If the problem really is to measure the speed of light, there had better be a reason why we should not just look it up.
We come next to the professional aspect of PBL and one of what is for us its main problems. It is very easy for students to tackle problems as amateurs, being satisfied with the first half-relevant thought as the solution. We have found ourselves inadvertently encouraging this by setting problems in contexts where one would not expect to behave as a professional research. (For example, no-one “abandoned on a desert island” makes it a priority to keep a laboratory notebook. One is also unlikely to have a facilitator on the island.) To repeat, the professional context for physics is a research team and we find it best for the problem to keep it so. Of course, the problem should be more straightforward where PBL is used in professional training.
Finally, the problem should be engaging. This is again where a lot of the effort in constructing a PBL programme comes in. We find that students are readily engaged by what they can easily already do, but this defeats the object. (If they can readily do it anyway, what are they learning.) On the other hand, if it’s too difficult it is not engaging. (At least not beyond the initial encounter with the prospect of, say, computing trajectories through gravitational wormholes.) An engaging problem is one that one feels one ought to be able to solve with just the right amount of effort allowed for in the schedule. An engaging problem should also be one appropriate to group work. Two obvious sources of failure are problems which fail to recognise resource limitations, so end up being done by a sub-group, or which clearly lend themselves to horizontal division (each group member learns the statement of half of one of Newton’s laws.)

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<td>- Requires “professional” working habits</td>
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What does a problem look like? “It depends” is the all embracing answer. We’ll see in this section that it can be more than just a question. In this section we’ll start with aspects of setting the problem itself: the hook, trigger and scenario. We’ve already looked at the problem solving strategy. But we may want to include a list of resources and a guide to the facilitator. Our own view is that the assessment should be thought of as part of the problem-setting, not as a bolt-on at the end. We’ll see come back to facilitation and assessment in subsequent sections.
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.
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.
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. Our trigger in the example problem was the instruction to suggest what the tutor should do.
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). The scenario in our example problem was the role of the University tutor.

Since our physics students are unlikely to act as a team of professional theatre critics this is not the type of scenario we use, but it could be appropriate in other contexts.
Here’s an example. You can probably deduce that the learning objective is the Doppler effect and perhaps also how mobile phones work. The example doesn’t specify what the students have to produce – what we call the deliverable – but presumably it would be a written or oral reply to Mr Odicean.
Our next example compares a standard physics exercise with the same learning objects set in a PBL context. The slide shows a typical end-of-chapter problem as might be found in a traditional physics text book. There is no need to study the details. A cursory glance shows that the student is expected to have attended lectures on the material and is no being tested with a problem. This approach is sometimes referred to as problem-solving learning. The problem comes after the tutor has decided what the student needs to know. This is not to be confused with PBL where the problem comes first and drive the learning.

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Example 2

It is not necessary to know any physics to see the point of this. Here is a typical end-of-chapter physics text book exercise:

(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 $L = 10$ mH, $C = 1$ µF and $R =$ kΩ.

(e) What resistance placed in series will be required to ensure the two signals are separated in the tuned circuits of part (b)?
These two slides show the PBL version of the same problem.

The next two slides give a problem with the same learning outcomes:

Melangeur mixing sugar and cocoa into "chocolate paste"

The sugar is well mixed into the liquid cocoa using our Melangeur. Both the sugar and cocoa solid particles are ground down smaller and smaller while more and more fat is released from the cocoa. The sugar/cocoa mixture becomes smoother and remains a thick liquid known as chocolate "paste," now ready for the refining and conching process to follow.
The version we use directs students to thinking about an AC circuit because of the problem it replaces. (In fact, in our version this is a practical task.) One might also use the problem to allow students to explore other ways of measuring the dielectric constant.
Now we have seen what a problem looks like, we’ll look at some of the issues in creating problems for PBL.
Let’s start with some basics that are far less trivial than they might seem. There are important differences between writing problems for students who are taking a range of PBL courses and where this is the first or only PBL course. We cannot assume that students know how to do PBL without training. On the other hand students coming to a course in, let us say, quantum theory, will resent having to spend time initially being trained in group work on an unrelated problem. There are differences in the level of control and investment required for small classes, where the writing will also facilitate, and classes where there will be many facilitators. We have written great interdisciplinary problems that cannot be facilitated or assessed by staff who have different skill sets. Another thing we have found is the necessity to provide students not just with time to do the work, but time to think about what they are doing. In other words to schedule the problems appropriately.

<table>
<thead>
<tr>
<th>Decisions about problems</th>
</tr>
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</table>

<table>
<thead>
<tr>
<th><strong>Who is the problem writer?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>discipline</td>
</tr>
<tr>
<td>control issues</td>
</tr>
<tr>
<td>level of investment</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>What is the course?</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>students (number and level)</td>
</tr>
<tr>
<td>sequencing of course/problems</td>
</tr>
<tr>
<td>time/structure of class</td>
</tr>
</tbody>
</table>
Problem-based learning should be a way by which students learn discipline content. It is very easy to recognise it’s other benefits and to slip into justifying the approach through these. If the aim of your PBL problem is process oriented that can be fine; if the intention is discipline content the problem should support this and should be discarded if it doesn’t. And remember that process skills are cumulative, so you need a global view: beware presentation and report writing overload.
We find it quite useful to document the planning – even if we sometimes only do this in our minds and not on paper. For example, you may well need to know the group size when you write the problem so that it requires the right amount of group effort. You obviously need to know the schedule too. These are things that are not fixed post hoc.
We are often forced to start from learning outcomes because the nature of the programmes requires that certain things are covered. This is the most difficult way to write problems, although we'll give some hints later. Learning outcomes and assessments should be aligned, so now is the time to think about assessment. If you are not using this problem to develop presentation skills, think carefully about why you are using staff and student time on presentations.
The summary tells us the depth of the problem. We have to set it in a way that will elicit this depth of response. Here we will require students to study a derivation of the Doppler effect to solve the problem.
Here's the problem for this learning objective that we met earlier.

Should mobile phone calls be permitted on planes?
The use of mobile phones on planes flying in European airspace has been approved by Ofcom. Is this a good idea?

Surely at the high speeds that planes fly there will be distortion of the sound. A voice will sound faster and more highpitched going towards a transmitter and slower and lower once the transmitter has passed. This is known as the Doppler effect and it might cause the identity of the caller to be confused by the receiver. I don't think they have thought this out at all.

L A Odicean, L Someone in
But a given problem can be used in multiple contexts. These are some for this problem culled from a PBL staff development workshop. The problem could be used in a law class, to introduce mobile phone technology, for marketing (apparently), in a biological context and, of course, for the basic physics of the Doppler shift.
In this section we’ll look in more detail at how standard exercises can be turned into PBL problems. In doing this, we’ll see again how the PBL approach supports deep learning.
Each of these slides shows how students can be given a decreasing amount of information. This not only makes the problem more interesting but aids retention.
Again look at the three ways the modelling task is presented (it is not necessary to read the details):

1. 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).

2. 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.

3. Estimate the moment of inertia of the asteroid.
More on the modelling task:

1. 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.

2. 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.

3. Describe, as quantitatively as you can, the motion of Kleopatra after the impact.
This is one way in which one might present the hook for a PBL version of the problem. It might be necessary to add a trigger to clarify what the students’ roles will be.
This is another example that addresses scientific methodology in a way that should be more memorable than a lecture. We’ve assumed that the problem would be given in stages. There is no commentary for this section.
To the editors of the New York Times:

Several claims have been made to have found the mummy of Queen Nefertiti, the latest of which will be broadcast on the Discovery Channel on Aug 17. We at the University of Delaware have obtained information from sources associated with the programme to suggest that this association is less reliable than is claimed. We plan to carry out our own series of tests for which we would need your support and would suggest in return that you publish our article on or around the time of the broadcast.

Yours faithfully,
Association Sceptical Scientists
University of Delaware
<table>
<thead>
<tr>
<th>Stage One</th>
<th>Stage Two</th>
</tr>
</thead>
<tbody>
<tr>
<td>What questions should you ask about the methods to be used?</td>
<td>What are the full range of methods available? — addresses science knowledge</td>
</tr>
<tr>
<td>Stage Two</td>
<td>Raises ethical issues in science</td>
</tr>
<tr>
<td>Would the methods be acceptable to the Egyptian government?</td>
<td></td>
</tr>
<tr>
<td>Stage Three</td>
<td>Addresses the limits of science</td>
</tr>
<tr>
<td>Could any scientific method yield a definite answer?</td>
<td></td>
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<tr>
<td>Stage Four</td>
<td>Stage Five</td>
</tr>
<tr>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>Should the NYT provide funding?</td>
<td>Raises issues in the funding of science by interested parties</td>
</tr>
<tr>
<td>Should the NYT publish the result?</td>
<td>Raises issues of publication of scientific results, particularly peer review</td>
</tr>
</tbody>
</table>

**Deliverable**

Produce a report with answers to the above questions to be submitted to the editorial committee
Finally, the slide suggests how to find PBL problems. The list is probably not exhaustive. Our experience is that the first few are the hardest; after that one starts to see them everywhere and one can start to be a bit selective in which ones to use.

<table>
<thead>
<tr>
<th>Sources of Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Your current exercises</td>
</tr>
<tr>
<td>2. External sources</td>
</tr>
<tr>
<td>Newspaper articles, news events</td>
</tr>
<tr>
<td>Popular press in the discipline</td>
</tr>
<tr>
<td>Make up a story – based on content objectives</td>
</tr>
<tr>
<td>Adapt a case to a problem</td>
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<tr>
<td>Research papers</td>
</tr>
</tbody>
</table>
A good way of encouraging group work and the exploration of an issue in depth is to give students the role of stakeholders.
Here is a problem from the University of Delaware adapted with permission. The problem centres on the over-extraction of water from the Colorado river.
Here are some of the points made to the secretary of the interior from the Living Rivers Foundation: the full letter, which one would provide to students, contains a lot more information. The letter makes it clear that there are competing demands which cannot all be satisfied.
From the original letter the stakeholders here include the various city authorities and industries in Los Angeles, Phoenix, Las Vegas, Salt Lake City, Albuquerque, San Diego and Denver and elsewhere in the Basin States as well as agriculture, Indian tribes and Mexico. The problem with this is that one might expect the city authorities to be experts on their city governance and not have to research their water use, populations and economies. From our experience this can create confusion as to how the students can set about the task. One solution is to give students the roles of consultants to the various stakeholders who must research their clients’ issues.
This is a stakeholder problem around the issue of global warming.
And here are some of the stakeholder positions.

<table>
<thead>
<tr>
<th>Stakeholder positions will be chosen from the following list:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Oil Industry</td>
</tr>
<tr>
<td>• Car Industry</td>
</tr>
<tr>
<td>• Heavy industry: mining</td>
</tr>
<tr>
<td>• Heavy Industry: manufacturing</td>
</tr>
<tr>
<td>• Heavy Industry: chemical refineries</td>
</tr>
<tr>
<td>• Environmental groups</td>
</tr>
<tr>
<td>• Scientific advisory panel (e.g. National Academy of Sciences)</td>
</tr>
<tr>
<td>• Climate change skeptic (scientist)</td>
</tr>
<tr>
<td>• Solar energy sources</td>
</tr>
<tr>
<td>• Wind energy sources</td>
</tr>
<tr>
<td>• Hydro energy sources</td>
</tr>
<tr>
<td>• Biofuel energy sources</td>
</tr>
<tr>
<td>• Developing countries: Sub-Saharan Africa</td>
</tr>
<tr>
<td>• Developing countries: China/India</td>
</tr>
<tr>
<td>• United Nations</td>
</tr>
<tr>
<td>• Nuclear power industry</td>
</tr>
<tr>
<td>• Coal/gas power industry</td>
</tr>
<tr>
<td>• Aid/ disaster relief agencies</td>
</tr>
</tbody>
</table>
Here are some further examples that lend themselves to stakeholder problems. The first four are non-technical and this might be thought a feature of stakeholder problems. But that is not necessarily the case: example 5 requires a deep investigation of spacecraft dynamics.

1. Preservation of green belt land
2. Road pricing
3. Promotion of Tourism
4. Open Source Publishing
5. Alternative strategies to send humans to Mars
We have found that facilitating PBL effectively to be the hardest thing to get right. Facilitation works best when the facilitator is the author of the problem because they can bring their tacit knowledge to bear. This however is not always (in fact, not usually) possible. In our case classes are too large for a single facilitator and problems written by academic staff are facilitated by teaching faculty or graduate assistants. The following slides discuss some of the issues.
One of the aims of PBL is to build a sense of community. We can break that down into 3 relationships: intra-group relations, inter-group relations and staff-student relations. As part of the first we need to consider the balance between group work and individual work.
Only individuals have learning outcomes. This conflicts with the division of labour that group work seems to promote. If a problem breaks down into neat chunks there is a danger that it will get divided up and shared in a manner that does not allow all students to achieve all the learning objectives. If a problem is highly integrated there is a danger that only a subset of the group contribute. This is one reason why PBL developers promote problems that are complex and open-ended. One role of the facilitator is to guide groups to plan their work so that everyone covers the basic learning objectives. This should be necessary for them to play a full role in the discussion of the problem. The investigation phase is carried out individually. There are then two main roles for group interaction, as we’ll see on the next slide.
First some preliminaries. In some implementations of PBL, groups write themselves a set of rules and members take certain roles (which generally rotate from meeting to meeting). Rules will encompass whatever the group thinks it needs to function effectively. In some of our implementations attendance rules, for example, are reinforced by penalties on marks for assessed group work. Groups may also assign roles for meetings, such as chairperson and minute taker. We do not generally impose roles, but someone in the group has to be responsible for making a note of who has agreed to do what; and then whether they have done it or not.

The main function of the group is peer tutoring, and this has the two aspects to which we referred on the previous slide. First, by discussing research relevant to the problem students reinforce their basic knowledge. They have to speak comprehensibly and listen critically. Second, they construct the group response to the problem, which entails using their knowledge critically.
The facilitator is key to promoting both of these aspects. This cannot be done if the facilitator provides a lecture that effectively damps out any group conversation, or if the facilitator allows groups to wander some distance from the point or to be satisfied with a shallow, or wrong analysis. Facilitation is therefore a delicate balance between dominating with too much information and being unhelpful with too little. We have found that, despite some of the received wisdom, generally it is best if the facilitator is an expert in the subject and the problem and is able to make these judgments.

It is sometimes thought that PBL curricular do away with lectures. This is not necessarily the case. It is often crucial to provide an expert lecture on a topic once students understand why it is relevant.

The final interaction is via assessment. This interaction should be authentic in the context of the problem. We'll discuss this further in the next section.
But before we leave assessment note that the interaction between groups can a useful component in various ways. The obvious one is to ask groups to assess each others’ work. We have seen this work well where groups evaluated each others’ script for a laboratory experiment. We have also seen it working where groups post their solutions on say a whiteboard for the class to respond to.

Another approach is where the results from other groups are required to complete a problem, for example where the groups supply missing data.
Finally, although it is the aspect that probably requires settling first, is the method of group formation. This varies between implementations and even within implementations as everyone has their favourite (and their least favourite which they will be certain never works). We have found friendship groups (where students form their own) to be less effective where group meetings occur mainly in facilitated scheduled slots, but quite effective where groups are expected to arrange the majority of their own unsupervised meetings. Others will disagree. We do not like groups with too large an ability range within the group which we find benefits no-one so we engineer groups to this extent. Some of our groups tend to be long lasting, some vary from module to module, largely depending on the density of PBL within the programme.
We saw that constructive alignment is a key feature of curriculum planning. One of its most important ingredients is assessment. Students are largely assessment-driven. If the assessment does not require students to solve the problem then it will undermine the PBL approach. We would go further: if the assessment asks students to behave as students and not as professionals, then the professional gloss of the PBL problem is largely redundant. A typical example of unaligned assessments is the student presentation. If the problem context does not require a presentation then adding one on for assessment purposes undermines the attempt to inculcate professional values.
Here are a couple of examples where presentations are integral to the problem. In the telescope project students build their own simple refracting telescopes with a CCD detector and use it to observe a simulated eclipsing binary at the other end of the laboratory. Since their telescopes are unique, so too are their observations and, in particular, their calibration of the detector. No one can tell them if it’s right. However, the observing time for each group is much less than a binary period, so to get a complete light curve, and hence to deduce the properties of the binary system, groups must exchange data. They do this at a conference where they submit their partial results. Their data will be of use only if they have calibrated their detectors correctly. Thus, students are motivated to carry out the task correctly, and check that they have done so, not just for the purpose of gaining marks but of interacting in an authentic way with their peers.

The leaking water pipes in the desert is a similar set-up. Groups have to exchange data on the dielectric constant of wet and dry sand in various wavebands to see if this could provide the basis for the remote detection of leaks.

We call this approach “authentic assessment”.
The two assessments on the previous slide were by oral reports. Here are a couple of other authentic assessments by written report. The report on the patent application is somewhat simplified from the real thing (as is the patent application the students get) but is nevertheless a simulation of a real-world output that can be assessed. The insurance scam problem requires a report to for insurance company on a set of experiments that will allow another lab. to determine the authenticity of a artefact.
Many PBL implementations structure group work by assigning group roles for meetings: someone to chair the meeting, someone to keep the minutes and so on. In some situations this works well. For example at Leicester we have a Management course in which students run a company. Their board meetings are most effectively managed if there is an acknowledged chair and secretary and everyone else has a designated role in the company. The Finnish system has a reported in each group meeting whose job it is to evaluate the performance of the group individually and as a whole after each meeting. Generally though many tutors find assigned group roles tedious, with a tendency to generate over-assessment. The problem we think arises from the artificial nature of group roles. Students know that, with the exception of a chair and secretary, their teachers don’t do this. We usually just get our facilitators to assess “engagement” at group meetings on a very simple scale (basically, very effective, sufficient and not a lot). But we also ask groups to keep a written project plan, shown here as a project tracking form, in which they track who is doing what and what has been done.
The problems of group assessment are not specific to PBL so we shall be brief. Generally a report or presentation will be a group responsibility and the group will bet a single mark. If the problem requires the contributions to be divided (for example contributions from different stakeholders to a single report) then it is clear how to divide the marks. The problem of course arises when the contributions to a group report are not equal. The marks can then be weighted by some form of peer review or peer assessment. We also use a weighting for attendance at group meetings.

It is perhaps useful to remember that PBL uses group work to aid learning. It does not follow that assessment has to be by group. It would seem odd if there were no feedback to the students on their solution of the problem, but there does not have to be an assessed report or presentation if this is not aiding their learning in a way that justifies the resources. PBL is an alternative pedagogy by which (among other things) students learn the same discipline content as by any other approach. If all that is at stake is this subject knowledge and its applications to solving problems then there seems to us to be nothing wrong with a conventional examination.
Finally, a lot of the problems in PBL arise because of assessment. Assessment is expensive on staff resources; over-assessment is easy and wasteful. In fact, assessment in PBL is no different from assessment in general: if you decide what it is for you are likely to make a better job of it. Let’s look at some possible reasons for assessment. Competence is most readily related to the acquisition of skills. We do not think that PBL is a good approach to skills training. If you want students to give presentations then a straightforward training in presentation skills is probably the best approach, with practice, feedback and a competency threshold. Once students have shown themselves to be competent at presentations, there is no need to go on testing them on presentation skills. This can reduce the assessment workload.

Likewise the purpose of assessment in a training context is to give feedback. It is confusing if this is muddled up with gathering marks that are supposed to be distributed (normally or otherwise). In competency based assessment and training everyone should be getting close to 100%, at least eventually. Then there are three different grading exercises one might want to carry out. We distinguish between progression (pass all but the worst) and selection (fail all but the best). Using selection tests for progression can lead to simply marking random noise at the progression boundary.

Our experience is that awareness of these distinctions can simplify the assessment load for both staff and students. For example, if process assessment is for competence, there is no need to carry on with it once this is achieved.
Our final section will look at some case studies of PBL problems to illustrate the variety of forms that PBL can take.
The key features of the cases are indicated using the symbols on this slide. There is no commentary on this set of slides.
Case Study 1

Professor Alwyn is director of learning and teaching at a new University with centralised control over pedagogy. The University wishes to differentiate itself from its competitors but without moving too far beyond the comfort zone of traditional directions of student learning. Professor Alwyn has therefore decided on a highly structured approach to PBL. Students are given a ‘problem a day’. Facilitators meet their groups together once at the start of the day to present the problem, and twice later on to check on progress. The day ends with groups presenting their solutions.
Example: The shape of water

Hook: Alliance pictures are making a documentary *Giganticus, A Tiny Adventure* in which a shrunken submarine travels though a human body. At this point the animators want to know the shape of a water molecule.

Trigger:

Alliance International Pictures

I have more questions for you! I know that the formula of water is $\text{H}_2\text{O}$ but I have realized that the atoms could be arranged in many ways. Unfortunately, I don’t know the scientifically correct one. And since this film is going to include loads of chemistry, I would really appreciate it if you can send me instructions on how to sketch molecules that contain more than two atoms with the science behind it.
- There are two issues to worry about. First, which atoms are connected to which? Second, how are the atoms arranged in space? The sketches of the animator indicate the problem for water.
- The aim of today’s session is to find out about the shapes of molecules. This involves the use of a theory known as VSEPR – Valence Shell Electron Pair Repulsion. This topic is well handled in the textbooks – see the textbook reference sheet for up-to-date references. .........
- Suitable for:
  - central control of learning environment
  - control of learning outcomes
  - full time facilitators
  - group space
  - parallel presentations
Dr Towbar has volunteered to take the first year mechanics course for the past 10 years. He likes the clear-cut problems and their mathematically precise solutions. The fact that students find the material dry and unengaging he puts down to their lack of preparation for university physics and a lack of respect for scientific tradition. He is convinced they need to know this material and there is only one way of teaching it. He is decidedly unhappy that the new head of teaching has introduced teaching teams for the introductory courses; unhappier that his colleges Professor Sideliner and Dr Rubytin want to introduce PBL and cannot see the dangers of departing from traditional methods. The only concern of his HoD is that nothing should impact on research time. But how, Dr Towbar wants to know, will students learn mechanics if they are allowed to develop their own ideas?

Here’s how his colleagues convinced him...
Chypsis Toys Ltd
Our marketing department see a niche for a roller-coaster toy of some sort: nothing too complicated – just a straight track for example. In order to convince potential investors we need some good laboratory data and calculations as to what can be done.

What are the sources of friction? What heights do you think we can use for successive humps? How many humps should we have? I'll need a formal report from you with your results.
There are at least 4 methods

1. Measure acceleration

2. Use constant acceleration with distance \( v^2 = 2g_{\text{eff}}s \)

3. Use constant acceleration with time

\[
m\ddot{x} = mg \sin \theta - \mu mg \cos \theta \quad \text{so} \quad g_{\text{eff}} = g \sin \theta (1 - \mu \cot \theta)
\]

4. Use work done

Which will you choose?
• Suitable for
  – Core learning objectives
  – Simple experiments
Professor Kay in is an enlightened head of chemistry. His great outreach team has succeeded in keeping up student numbers in a difficult environment with a number of innovative programmes. But many of the new students are ill-prepared for university chemistry delivered in the traditional way, and by the end of the first semester may of them are disillusioned. Professor Kay wants to see the ingenuity and innovation currently applied to outreach carried through to the year one courses. As a start he has secured funding to develop a PBL module to run alongside the lecture programme.
Given recent climatic irregularities DfERA have decided that it is the right time to pilot a new system which will monitor variations in tide height at a fixed location over long periods of time. The system operates by monitoring the amount of light which reaches the sensor (at the sea bed) as it is known that the greater the depth of the tide the lower the intensity of light which reaches the sea bed.

We would like you to help us iron out a few of the technical issues with this system. As mentioned above the intensity of the light which reaches the sensor will decrease as the tide depth increases, we would like you to help us calibrate the instrument.
• The deliverable for this problem takes the form of a written report to the government agency which will include some basic calculations of the intensity of light reaching the sensor using the Beer-Lambert law.

• While investigating the problem the students should see the difficulty in estimating an extinction coefficient for sea water. In order to simplify the problem we give them this data as part of the resources but for the second part of their report (in reply to the follow-up letter) they should comment on some of the factors that affect the extinction coefficient and why this would complicate matters.
• Suitable for
  – using alongside traditional methods
  – adding variety and skills while supporting core learning
Professor Dreamer is appalled that in his tutorials, which he carefully prepares to be interesting and thought-provoking, final year students find it difficult to apply basic physics to new situations. The students are an able group, some of whom could go on to research, but he worries that their lack of creativity and inquisitiveness will hold them back. How can he get them thinking, formulating their own questions, and exploring and expanding their own understanding?
H-R diagram for a young stellar association

V. Fictitious

We present the H-R diagram for observations of a young cluster of stars. It is of interest that the best fit line is somewhat steeper than the usual H-R diagram. It may be relevant that these stars show no sign of convective envelopes even down to well below a solar mass.
Example student paper
S2_2_SolarPower(Anfield, Earle) Paper
IST Vol6, d m 2005

Viability of Solar Gravity Power
M J Anfield & M A G Earle

A U Thor (J Spec Tops., 1) postulates that gravitational energy is a viable source of power for the Sun. His simple model, in which he takes the core of the Sun to contain a growing black hole radiating at its Eddington limit, proves sufficient to power the Sun.

Consider a black hole at the centre of the Sun to be radiating at its Eddington limit. At the Eddington limit the pressure of the emitted photons exerts a force equal and opposite to that of gravity upon the accreting matter. From this we derive an equation relating the luminosity $L$ of the hole to its mass $M_{bh}$

$$M_{bh} = \frac{\sigma_T - L}{4\pi G m_p}$$

where $\sigma_T$ is the Thompson scattering cross-section. We calculate the mass of the black hole required to provide the solar luminosity to be $6.5 \times 10^{25}$ kg. This is small in comparison to the mass of the Sun. If the matter of the black hole were at a density of $10^{15}$ kg m$^{-3}$ it would have a diameter of only about 5 km. These findings support the 'Thor postulate' that gravitational energy from the collapse of a cloud of gas releases sufficient energy to power the Sun.
Example referees report

A2R.A1_3.Giants
B Smith, G Jones, E Evans

Significance of the work
Adams et al write in response to a letter by M Davies published in JST1.1, {A1_3.Giants}. They have demonstrated that it may not be possible for an accurate measure to be made of the distance to the cluster LS101 using comparison of red giant luminosity because it would not be possible to resolve the individual stars.

Method Used
The authors use results from their paper A1_2.Supernovae [JST1.2] and find the number of red giants within the cluster of 100 000 stars to be 17 620. They then assume a cluster radius of 3 pc, for which absolutely no justification is given. This allows them to find that the angular separation of the red dwarfs is 0.694". This is the limit of Earth based observation suggesting that Davies's results may be flawed.

Conclusions
The method used by the authors is correct and accepting their assumption of the radius of a galactic cluster, produces an accurate result.
A resolution of 0.694" is at the limit of observation and considering the possible error in the assumptions, this result may not be accurate. However, the result does fit well with what Davies says in his letter. A second method would be of use to confirm the result.
We believe that this paper is significant as it will prevent the inaccurate results given in Davies's letter being used. we therefore recommend the paper be accepted for publication.
Suitable for
- multiple inputs, multiple outputs
- student centred learning
- loosely defined objectives
- minimal supervision
Dr Jackson needs to design a week-long activity for a new first-year group with diverse A-levels. He wants to introduce the PBL process in a science environment, build good study habits, and introduce critical thinking skills. He chooses astronomy as a subject area, as none of the students have studied it before.
Dear Dr. Jackson,

I've read both Bauval & Gilbert and Trimble's account of the relationships between the four 'airshafts' in the Great Pyramid and certain bright stars. The Trimble paper strikes me as closely reasoned - I'd trust it if it weren't for the fact that B&G use it as a basis for increasingly weird theories. So what should I do? Assume that both are unfounded? Or neither? Can you and your students help me out? I'd really like this as background to a paper I'm writing so need to know where the solid ground is.

I thing I'd really like to know is whether these alignments could be coincidental. How likely is it that a N-S shaft would point at a bright star?

Thanks for your help,

Daniel Jones
• This is a contentious area in the field of Egyptology. Many web resources will be very biased. Can the students recognize inappropriate web use?

• Students have two laboratory sessions using planetarium software. They should design and carry out an experiment to ascertain whether the shafts might align with bright stars by chance.

• Support sessions will be scheduled to introduce basic astronomy concepts including co-ordinate systems, time, and magnitudes.
• Suitable for
  - a discrete time period
  - no parallel activities
  - introduction to group work
  - “summer school” outreach
Dr Brown from Physics and Dr Green from Geography had what they thought was the brilliant idea of collaborating on an interdisciplinary module on climate change. The subject matter was topical, core, and, by joining forces, would halve the workload. So they each put together half a lecture course and looked forward to a successful collaboration. It was not to be. The student evaluations were disappointing; the examination results even worse. Drs Brown and Green decided to meet on neutral territory in the coffee bar to iron out the problems. They quickly got to the core of the matter. The physics students could do the physics but couldn’t master the geography; the geography students had no idea how to apply the physics. A joint lecture course was not an appropriate vehicle for an interdisciplinary module for students with different backgrounds. Dr Green thought it time he revealed his hand:

"Have you ever come across PBL ....."
Dear Sir/Madam,

The RSPCA considers it important that people are made aware of the potentially fatal consequences of leaving pets in a car. We would like to commission from you a flyer to distribute as part of a campaign to persuade people that it is just not acceptable to leave an animal in a car, even for a short while. The flyer should be eye-catching and memorable, but must describe the situation, in such a way that a general member of the public will understand it. Something that we consider important, for instance, is the amount of time it would take for conditions in the car to become life-threatening. We would also like you to separately present us with the scientific data to support any claims you make on the flyer, so we can make it available on our website for any interested parties.

Yours sincerely,

Sandra Mostow
Dear Team,

I read the article in *Tomorrow* the other day, the one about these new plants that are going to solve all our global warming problems by sucking the carbon out of the air. I reckon it’s time to run another “What is Global Warming?” piece.

I’d like you to put together an article on the science - not all the GM business, I don’t want to poke that hornet’s nest again for a bit, we’ve only just shifted the last of the mail after that article about the pig with the two heads…

No, what I’d like you to do is produce a feature on the natural state of play - what’s the environment like at the moment, what are these plants going to do, why are they different to ‘normal’ plants etc. Then what global warming is - Not too long, and keep it nice and simple, yeah? But for God’s sake, get the science right – I don’t want another “Daily Bugle dumbs things down” fiasco again…

Cheers,

Jon Bleth, Editor, Daily Bugle
Facilitators notes:
Guide the students to research:
What is heat? What is temperature? Transfer of heat.

Refs. 
Breithaupt, Chapter 6 (6.1, 6.2, 6.4)
Keller, Chapter 16 (16.2, 16.6)
Tipler, Chapter 18 (18.1) Chapter 19 (19.1) Chapter 21 (21.4)

Guide the students to these references and ensure they come up with a research plan for the day.
• Suitable for
  - small classes
  - large option component
  - experienced group members
  - complex topics
Case Study 7

Drs Sane and Rymans have been approached by the TDA to provide online learning materials for part time PGCE students making a career change to teaching physics. They have to cover a lot of material in a short time but above all they have to show how to make it interesting and not just list of what meds to be known. In a face-to-face teaching environment PBL would be an obvious choice but for various reasons it would be difficult to implement on line. Dr Sane suggested a “problem a day” solution: relativity short problems that would be given a strong steer. Dr Rymans thought this would lack coherence and instead proposed an overall problem for each chapter but with the students guided through the PBL process along a particular pathway. The assessments showed that at least some of the students got the point and used PBL to inform their approach to teaching.
### Motion in 1D

<table>
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<th>Hook</th>
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<tr>
<td>Dimensional analysis</td>
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<td>Dynamics</td>
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<td>Conservation laws</td>
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**Problem:** The lead shot used in shotgun cartridges consists of small spherical pellets 2-3mm in diameter made by pouring molten lead through a frame suspended in a high tower, a method used since its invention by William Watts in 1782. In order to produce spherical shot the lead must solidify before the pellet has reached terminal velocity. How high should the tower be?

**Trigger**
| **Motion in the plane** | **Problem** A design for a spaceship that would also function as an orbital space station might look like the dumbell form of Spaceship USS Discovery 1 from the film 2001: A Space Odyssey. The picture shows an artist’s impression with the spaceship moving round the Earth oriented like a plane flying through the air. Is there anything wrong with this? |

- Circular Orbits
- Equilibrium and Stability
- Dynamics of rotational motion
- Simple Harmonic Motion
Facilitator notes

- Lecture material (Powerpoint and audio) leading the student though the problem
- Questions for forum discussion:

1. The following is an extract from a report in the Guardian newspaper
   “To get around a bend, athletes have to tilt their body to fight the centrifugal force that pulls them in a straight line.”
   Is this a wrong explanation? A useful one?
2. How you would explain why a more massive satellite doesn’t orbit more slowly?
3. What are the practical considerations in deploying a tether to boost a spaceship orbit?
4. Make a list of as many examples of (approximate) SHM as you can.
- Suitable for
  - limited facilitation
  - limited group opportunities
  - varied prior learning
  - somewhat asynchronous learning
Dr Keane had just returned from a summer school on PBL full of enthusiasm to improve his laboratory session as he had always intended. He’d worked out a great scenario abandoning his groups on a desert island with parts from a crashed aircraft and challenging them to make a rescue beacon, which he thought would be a great hook. To input a design element into the labs, Dr Keane decided to make the experiment as open-ended as possible; but he was sure he had covered all the learning objectives. This was the root of his problem. See if you can spot what went wrong from the problem statement.
You are the crew of cargo plane which has been 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. These include a rescue beacon but no power source. Air traffic control knows you are missing but does not know where you are.

You begin to explore the island. There is plenty of fruit to eat and the climate seems balmy with a pleasant sea breeze. How can you attract attention? If only you could find a way to power those rescue beacons ...
Case Study 8: Getting it right

Dr Keane decided to review the situation. On reflection it was quite clear. The students had taken all too literally the opportunities for multiple strategies in the environment they had been given. One doesn’t do physics experiments on a desert island, at least not with careful notes and estimates of errors. What you do is Blue Peter science and see if it works, and this is what he had got.

But it could be fixed. The same learning objectives could be embedded in a different scenario....
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. The airport emergency team arrived at the scene quickly, but Bob was unharmed and able to exit the aircraft unassisted. Pilots are advised to 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.

HQ want us to look at the following circuit:

A capacitor will smooth the output if the wind is gusting.
This is a real problem. The data in the newspaper report gives some indication of the wind speeds involved. The laboratory models will not have speeds this large so it is necessary to understand at least some the theory in order to scale them up. It is not sufficient to simply get the device working in the lab.
• Suitable for
  - design of lab experiments
  - relating theory to practical
  - incorporating simple computation
  - mixing different areas of physics
Case study 9: Advanced Physics

- Professor Snow is a research cosmologist who is familiar with PBL problems in elementary physics and thinks they are quite a good idea for the simple stuff since any half-decent student will be able to pick this up from the books however it is taught, but he doesn’t see how students can learn relativity without his lectures. And in any case there aren’t any unsolved problems in relativity that students could possibly tackle. One day over tea he expounded on this to one of his colleagues who was enthusing about his PBL session. A few days later here’s the problem his colleague came up with:
Problem:
Area 51 Briefing Document
The following partly redacted document has been obtained from MI6 files

TOP SECRET RESTRICTED CIRCULATION
Additional information on Area 51 (Roswell UFO)
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX examination of partially charred material within the crash zone appears to indicate an expected journey time of three months XXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXX designation of the home world as zeta (2)-Reticuli XXXXXXXXXXXXXXXXXXXX
XXX advanced wormhole technology XXXXXXXXXXXXXXX

Initial investigations concluded that this was part of a hoax to discredit the US military. The physical limitations on near light speed travel even allowing for the effects of special relativity on proper time were thought to rule out any nearby star for the alien host planet. However, recent advances in technology (especially GPS systems) have verified the importance of gravitational effects on time dilation. Exploratory studies in general relativity have failed to rule out the possibility of wormhole structures in spacetime that might be constructed by an advanced civilisation having access to negative energy 'matter' despite the paradoxes that appear to arise by allowing travel into the past.

Produce a technical report on this issue.
Facilitator Notes

- A technical report is expected to give details of the basis for relativity (special and general) – the text suggests applications to the GPS technology as a good example as well as (or instead of) the standard tests
- Symbolic manipulation programmes can be used to solve Einstein’s equations and equations of motion
- Black hole solutions should be investigated to be ruled out as wormholes
### Analysis

- Suitable for
  - Students with sufficient maths background
  - Introducing relativity and taking it to an advanced technical level

Students would be expected to come to this module with a background in vector analysis and probably some knowledge of Cartesian tensors. Note that the question is open-ended because we don’t know whether wormholes could exist!
Finally a few references.
This is our own work, but it is none-the-less probably as good a starting point as any if your principle aim is to get on and implement PBL.
Here and on the next slide are some of the most quoted references to different aspects of PBL

  
  Gives a general survey of various approaches and the underpinning theoretical context. The authors recognise the malleability of the PBL approach in the face of discipline and other contextual demands.

  
  A practical guide based largely on experience in the University of Delaware

  
  Includes some interesting case studies of how things can go wrong (and be put right).

- Savin-Baden M (2003) *Facilitating Problem-Based Learning*
  
  Another of the authors many books on PBL. Again it is based on a wide perspective of PBL implementations
Further Reading

  A seminal work on the development of PBL
- Woods D R (1994) *Problem-based Learning: How to Gain the Most from PBL*
  A student manual for a "pure" form of PBL that centres around self-directed (peer) learning
- Azer S (2004) Navigating Problem-Based Learning
  A manual for medical students containing some useful insights from the student perspective
Finally, if you would like some help in taking PBL further .... Give piCETL a call.
About πCETL Consultancy

• πCETL offers various forms of consultancy on the implementation of PBL
  
  - Seminars --
  - Workshops ½ day – 3 days for problem development, staff training and evaluation
  - Specifically tailored to your needs
  - Either in Leicester or in your home institution or via video conference

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Module Developers

Listed here are some of those who have contributed directly or indirectly to the development of the teaching materials in Physics and Interdisciplinary Science in this presentation.

- Faculty Staff
  - Chemistry: Jonny Woodward,
  - Geography: Jörg Kaduk
  - Physics: Tim Yeoman, Nigel Bannister, Mervyn Roy, Mike Goad, Richard Jameson, Ted Thomas

- Teaching Fellows
  - Chemistry: Dylan Williams; Physics: Cheryl Hurkett

- Graduate students
  - Paul Abel, Kay Clarke, Alun Salt

- Undergraduates
  - Michael Briggs, Dan Brookes, Andrew Carter, Michael Cambell, Lee Cullen,