4. THE EVOLUTION FROM PROBLEM SOLVING TO PROBLEM-BASED LEARNING (PBL): A CASE STUDY IN EARTH SCIENCES AT UNIVERSITY COLLEGE CORK

Bettie Higgs
UCC

INTRODUCTION

This chapter describes how my use of problem solving has evolved towards Problem-based Learning over the past five years, and how continued development is informed by research (Barrett, 2005; Carroll et al, 2004; Cerbin, 2000), and by evaluation of student learning in my courses. Barrett (2005: 56-57) clarifies the distinction between problem solving and Problem-based Learning:

> One of the most important points about problems in Problem-based Learning is that it is not a question that first the students receive inputs of knowledge e.g. lectures, practicals, handouts, etc., and then "apply" this knowledge to a problem they are presented with later in the learning process. This type of a situation is not Problem-based Learning it is problem solving (Savin-Baden 2000). It is like making a cake when you have already been given the recipe and all the ingredients. One of the defining characteristics of the use in Problem-based Learning is that students are deliberately presented with the problem at the start of the learning process. This is like getting the challenge of preparing a celebratory meal for a special occasion where no recipes or ingredients are given.

CONTEXT

Three discrete units in the final year earth sciences undergraduate module were amalgamated into one module called Applied Geophysics, Computer Applications and Geodynamics. One of the challenges I faced was to integrate these three units into something coherent. Another challenge was to make the subject matter relevant, understandable and interesting to the students. The theme of the module became 'the investigation of the sub-surface using the laws of physics'. I attempted to include practice that was authentic, so that the students used equipment and methodologies that are used in the workplace.

At first I focused on the content of the course and hoped it was at an appropriate level, and the students would 'get it.' I assumed the relevance of the topics I covered was obvious to the students. At that time poor attendance generally across the 4th year modules was discussed at staff meetings. Although this module did not suffer too badly, I was concerned that any students not attending were missing out.

I decided to introduce small problems to be solved during the last 15 minutes of each lecture slot. These were to be handed in at the end of the session. Students could work in groups, and they could ask me questions to guide them to the answers. One percent of the module mark was awarded for participation in each of these exercises. These were my first ventures into the reconstruction of the traditional lecture mode of teaching.

As well as improving attendance, I realised there were other benefits to this innovation. Problem-solving encouraged the students to review the material that had been introduced during

Handbook of Enquiry & Problem Based Learning. Barrett, T., Mac Labhrainn, I., Fallon, H. (Eds). Galway: CELT, 2005.
http://www.nuigalway.ie/celt/pblbook/

the lecture. A brief look at the work handed in gave me immediate feedback, and an effective measure of the student understanding of the course material. In addition, I was surprised to discover that answers were usually messy in layout, in mathematical rigour and in logical thinking. This highlighted gaps in the development and maintenance of quantitative problem solving skills in the overall degree programme.

Work was handed back at the start of the next session. I was able to begin the session with some appropriate feedback and guidance to the students, based on their work. The students appeared to identify with the comments, and frequently asked more focused questions than I had been used to with previous groups. I was encouraged to develop this problem-solving further. Reading the literature on teaching and learning (for example, Gibbs et al, 1998) increased my awareness that student learning can be improved when the relevance of the topic is made explicit and the assignment is authentic. Often in the geological workplace there is a problem to be solved. This led me to think about how the main course assignments could be introduced to the students in a more authentic problem-solving way. I will concentrate in the following discussion on two of these course assignments, namely: investing the subsurface using seismic surveying and interpreting the subsurface using electrical surveying.

INVESTIGATING THE SUBSURFACE USING SEISMIC SURVEYING

The module contains a project which is essentially a problem to solve, although I did not initially see it that way. In seismic surveying, shock waves are sent down through the Earth, reflect and refract at the interfaces between rock layers, and are recorded when they arrive back at the surface. When the recorded data is interpreted it can give a uniquely clear picture of the subsurface. I had inherited an authentic data set, consisting of seismic sections and velocity logs acquired by an oil company carrying out exploration in the North Sea. My predecessor had allocated two contact hours per week, for 20 weeks, for students to work on the data sets and present an interpretation. There were 20 repetitive tasks to be carried out, and it was obvious that the students found this a little tedious. When I took over this activity I halved the time commitment while trying not to reduce the element of skills training. The students would employ the same procedural and cognitive skills to solve the problem.

The way I did it at first

I gave a number of detailed lectures related to the problem that I planned to give to the students. I anticipated what the students needed to know. I showed the students a video which demonstrated how seismic data was collected offshore, and emphasised the nature of the data. The students were then presented with the scenario in which there was a problem to solve.

I asked the students to work in pairs, and gave each pair a full data set. I then gave the students a list of instructions telling them what they had to do to solve the problem. The last instruction asked the students to locate a borehole in the North Sea for optimum hydrocarbon production, and this was given as an incentive to encourage them to take an interest in the practical work. While the students carried out the instructions, a feeling of tedium set in around the middle of the exercise. Students lost momentum. They drifted in and out of class, and partners did not attend, leaving the other partner to do the work. There was a predictable surge to get the work done in the last week of term. This caused the students increased stress levels, and the submitted work would sometimes be rushed and often came in late.

The way I do it now

I took a new look at this assignment. It seemed to me that concentrated engagement in class would allow the contact hours to be reduced, and avoid tedium setting in. I framed the whole project as a real problem to be solved, briefly shown in Box 1.

Box 1
An oil company has spent €15,000 per day over the summer collecting offshore seismic data in the North Sea, associated with a known hydrocarbons reservoir. Due to the huge costs involved, the company needs to optimise the extraction of hydrocarbons from this reservoir. They do not have a seismic interpreter, and indecision is costing them €1000 per day.

You are to interpret the data collected and recommend the best location for a production well(s). The cost of drilling a production well is in excess of €1,500,000.

The students are given a base map and shown the area of interest. I give some brief instructions to the students to help them proceed, as follows:

To solve this problem you will need to:

1. Acquire appropriate data
2. Interpret reflectors for the:
    - top of the Chalk
    - base of the Chalk
    - base of the Triassic
    - top of the Middle Permian (Rotliegend)

You will need TWTT (two-way travel time) from velocity/stratigraphy logs of exploration boreholes.

3. Prepare seismic contour maps in TWTT for each of the four reflectors interpreted. Ensure that faults are indicated on these maps. Do not smooth contours around the faults.
4. Write a report, including the following:
    - Production of seismic charts
    - Methodology of seismic interpretation, and procedures involved in the production of the TWTT contour maps
    - A suggested site for a production well

(Note: each student should produce their own report)

This assignment will count for 15% of the module assessment.

This new format has been tried, and there has been a marked improvement in class attitude. I give a smaller number of lectures prior to the introduction of the problem. The students still work in pairs, but pairs can discuss their work with other pairs. I introduce the problem, and ask the students what data sets they need to solve the problem. They reason through the problem, but usually identify only step one of the solution, before requesting data sets and further information. If I have the requested data sets I hand them over. Some of the data sets have poor legibility, just like the real world. The students must decide when a visit to the library or a web-search might be necessary. We discuss a timetable for the work. They get on with problem solving and they ask questions as they go along. I am available in the room to guide and interact and discuss. If I see students heading off in an unproductive direction I have to decide whether or not to interject. My role is scaffolding, guiding, facilitating. The work is now done in five weeks instead of 10.

Assessment of student work is still a challenge. The pairs must negotiate the workload and commitment to working together. Although certain steps along the way gain a common mark, individual final reports are submitted and this allows a component of independent assessment.

The way I will do it in future

Reading around the theories of PBL has provided a formal framework for me to assess what is going on in my classroom, and to consider developments for the future as I move from problem-solving to Problem-based Learning. Barrett (2005) believes that the course should begin with the problem. All subsequent lectures and discussion should relate to the problem. Posing a problem can prime students to be ready to receive information (Perkins, 2001).

Next semester, I will try this approach and instead of beginning with lectures I consider relevant to the practical exercise, I will begin with the problem. Students must define what the problem is, and ensure the group has a common goal. I will ask the students to request information and explanations they need to help them with the problem they are solving. In this way the lectures and discussions may seem more relevant. The students may gain more from a lecture which is fulfilling a need they have identified themselves, or answering a question that they have posed. I will monitor the success or otherwise of this approach.

Videos of people actually grappling with similar problems in industry will be available as a resource to reinforce relevance, and to show people working in teams and discussing finance and strategy. Within the problem posed, each pair of students will have a budget. This will include purchase/commissioning of the data set. The students may encounter costly setbacks. They will have to deliver their recommendations within budget. Students will attach meaning to something, but it may not be the desired meaning. My role will continue to be guiding and facilitating students, knowing when to step in so that they obtain what they need. The students will be asked to present their recommended borehole locations to their peers. The nature of this problem means that there is no unique interpretation of the data set, and students will have to reason, justify, argue and defend their interpretation. This performance of understanding will take place before they submit a report, and will allow them to review what they have learned from working on the project, and receive peer and tutor feedback (Huxham, 2005). This is authentic science.

INTERPRETING THE SUBSURFACE USING ELECTRICAL SURVEYING

The way I did this in the past

This field exercise was carried out at a location convenient to the campus, and involved measuring the electrical properties of materials in the subsurface using geophysical equipment. Much of the time was spent showing the students how to use the equipment. Final reports and follow-up work showed that some students were failing to see beyond the mechanics of the equipment, and could not even remember which properties they were measuring. Past students have told me that it is later, in the work-place, that they realise the relevance of this exercise!

The way I do this now

I listened to the experiences of past students and decided to frame this exercise as a problem to be solved. Last semester a real live problem presented itself. The students were given the problem half way through the course, subsequent to lectures that were aimed at supporting and guiding their approach to this type of problem. The problem that arose is outlined briefly in Box 2.

Box 2
A farmer has had his land rezoned for housing. He needs to insert a large diameter pipeline at approximately 5 metres depth, crossing the area, and draining to the north, before he can begin to build. He would like an appropriate geophysical survey carried out to advise him of the best route for the pipeline, so that he can avoid hitting costly bedrock at depth.

The class divided themselves into two groups of six, and negotiated their own transport to the site (approx 25km). I supplied them with what I considered appropriate equipment. Each group carried out two survey lines. The lines had an agreed overlap so that direct comparison of results could be made between groups. Back in the laboratory each group processed their own data. Processing was relayed via a data projector, and members of the second group could watch if they wished. I was available for procedural guidance, and to interject with questions to help students broaden and justify their interpretations of the data. Final printouts were made for each member of the group, and copies were given to the other group. In this way the processed data was pooled between the two groups to aid their final interpretations. Each group discussed what should go into a final report, but each member wrote their own individual version for assessment purposes.

A price was negotiated with the landowner, to cover the cost of transport to the site, and for each student to be paid €10 for the completed work. Though this was not a princely sum there was great delight at being paid for a first geophysical job. This gave a good buzz when received at the end of the module, and reinforced the relevance and authenticity of the work they had carried out.

A brief summary report went to the landowner with several recommendations. A recommendation that a trial pit be dug at a specified location was carried out by the landowner. Although this occurred subsequent to the completion of the assignment, it provided excellent formative feedback for the students on the validity of their interpretations.

The way I will do this in the future

I will continue to pose a real problem, with the assistance of local landowners. However the students will be given the problem earlier in the module and will have to decide within their own group which method of surveying is the most appropriate. They will plan the project, including data collection, data analysis and logistics, and will be required to put forward their plan for scrutiny before carrying it out. They will need to identify what support they need, and can request information, formal lectures, and discussion sessions to assist them in addressing the problem. Usually two types of guidance are sought, procedural, related to the use of equipment, and research methods related to finding resources.

I will encourage group work rather than just working in pairs. For this purpose I have designed a more conversational and interactive approach to the data analysis (Higgs, 2004), in response to Laurillard (2004) who critically evaluates the use of information and communication technology (ICT) to facilitate student learning. This will allow me, the teacher, to step back, so that students can work with the problem together. A portion of the marks will now be assigned to the group work, to reflect how well they approached and carried out the work on the problem.

I will monitor how these changes affect equality of opportunity. While encouraging the team work skills commonly sought after in graduates, some level of individual performance should be accommodated. This is authentic. The real world is like this, with individual as well as group endeavours gaining recognition. Individual members of the group will be encouraged to play to their strengths supported by team members playing to other strengths. The success of the learning lies partly in the effective pooling of the tasks and of the learning. When all goes well, the groups will interact, creating an effective community of learners.

IMPLICATIONS AND DISCUSSION OF THE PROBLEM-BASED LEARNING (PBL) APPROACH

Over the past five years I have moved from 'problem solving' towards 'problem based learning' in courses that I have designed. This has been an evolution rather than a revolution. Small amounts of risk-taking and handing over control to the students have paid off in their learning.

The learning outcomes are also evolving. Instead of 'the student will demonstrate understanding of …' an outcome may take the form 'the student will be able to use a variety of strategies to investigate or predict …'. The performance of understanding is specified (presentation, report or exam) rather than the course content that will be learned. This is part of the handing over of control from teacher to student.

I see the merits of PBL, but as one part in a palette of tools and techniques in my teaching. If the traditional lecture can be enhanced to inspire learning, and to entertain, it will never die. Students will still rate highly a good lecture, and say they 'like to get good notes'. It is the review, re-working, questioning and *extension* of these notes that can be encouraged by a well-designed PBL approach. A balanced mix of authoritative discourse and dialogic discourse within any programme must be achieved, and may vary according to the discipline. Often in the earth sciences academics feel that certain material must be 'covered', and so PBL has not yet been fully exploited. In Manchester University an earth science degree programme was to be redesigned to be entirely Problem-based Learning. At the time some staff had never heard of PBL. This was to be an all or nothing approach. Concerns expressed by staff, and subsequent discussion, are leading to a more moderate approach to PBL, allowing a space to learn the techniques, and practice the risk-taking which is necessary in truly student-centred PBL.

DESIGN CHALLENGES FOR THE FUTURE

I would like problems to encourage students to think outside of the module, linking to other modules they have studied, and integrating with other subject areas such as environmental science, quaternary geology, and engineering geology. This integrative learning approach is something I want to foster with other science departments in the future. Key questions to bear in mind were asked by Cerbin (2000) when he used PBL to study the nature of learning: 'How does knowledge transfer to a new context?' and 'How do student's prior beliefs about a subject affect understanding of new ideas?'

Perkins (2001) states that information will only be valuable when students are ready for it. Students can be primed with the challenge of a well designed problem. Ideally, working on a problem should provide students with further ideas, hypotheses and ways of thinking about issues. Perkins divides problems into reasonable (lending themselves to step-by-step thinking and incremental solution) and unreasonable (requiring breakthrough thinking). Breakthrough thinking is characterised by a 'long search' followed by a 'cognitive snap' and rapid progress towards a solution. Perkins says that there is an art to approaching unreasonable problems, and students can be trained for this task. Allowing a student to approach a problem in their own way can help encourage breakthrough thinking. Although both types of problem have value, in the context of my module I would like to ensure that problems contain some small scale experiences of breakthrough thinking. Problems can become 'more unreasonable' as students progress from 1st year to 4th year. This depends on the structure of problems, making design an interesting challenge, and ensuring the continued evolution of my courses in years to come.

REFERENCES:

Barrett, T. (2005) "What is Problem-based Learning?" in G. O'Neill, S. Moore, B. McMullin. (eds.) *Emerging Issues in the Practice of University Learning and Teaching*. Dublin: All Ireland Society for Higher Education (AISHE).

Cerbin, W. (2000) "Investigating Student Learning in a Problem-Based Psychology Course," in Pat Hutchings (ed.) *Opening Lines: Approaches to the Scholarship of Teaching and Learning*. Menlo Park, California: The Carnegie Foundation for Advancement of Teaching.

Gibbs, G., Morgan, A., and Northedge, A. (1998) *How Students Learn.* The Open University Centre for Higher Education Practice.

Higgs, B. (2004) "Designing ICT to Encourage Group Learning," Unpublished report. University College Cork, Department of Geology.

Huxham, M. (2005) "Learning in Lectures: Do 'Interactive Windows' Help?" *Active Learning in Higher Education*, 6, 1: 17-31.

Carroll, T., Hurley, D., and McHale, D. (2004) "Designing and Implementing a Module on Problem-Solving in Mathematics," in A. Hyland (ed.) *University College Cork as a Learning Organisation*. Cork: University College Cork.

Laurillard, D. (2004) "The Conversational Framework," in R. Holliman and E. Scanlon (eds.) *Mediating Science Learning through Information and Computing Technology.* London: Routledge Falmer.

Perkins, D. (2001) *The Eureka Effect: The Art and Logic of Breakthrough Thinking.* New York: Norton.

Savin-Baden, M. (2000) *Problem-based Learning in Higher Education: Untold Stories.* Buckingham: SRHE/Open University Press