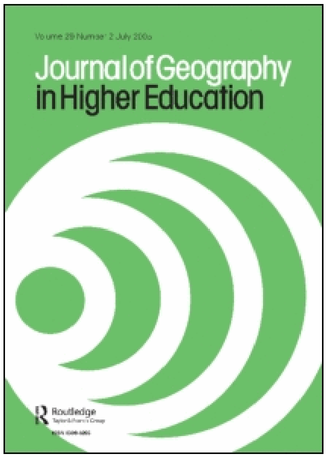

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Application of Problem Based Learning through Research Investigation

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Application of Problem Based Learning through Research Investigation

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ABSTRACT *Problem-based learning (PBL) is a teaching technique that uses problem-solving as the basis for student learning. The technique is student-centred with teachers taking the role of a facilitator. Its general aims are to construct a knowledge base, develop problem-solving skills, teach effective collaboration and provide the skills necessary to be a successful lifelong learner. This study evaluates the application of PBL in an undergraduate Earth Systems Interactions unit and an exercise based around the Urban Heat Island. The initial execution of PBL was mixed with many students fully engaged in the material, but others found the approach insufficiently structured. Some students were not able to adapt to the unusual challenges of PBL, partly because it was their first exposure. When asked about what they had learnt from their PBL experience, the students emphasized the technical rather than the problem-solving skills. In subsequent years, a more directed project-based learning approach was introduced, which improved students' overall satisfaction and performances.*

KEY WORDS: Problem-based learning, earth systems interactions, research project, evaluation

Introduction

Problem based learning (PBL) is a student-centred educational method that uses problem-solving as the starting point for learning (Bligh, 1995). PBL is designed to develop problem-solving strategies, disciplinary knowledge bases and skills simultaneously by placing students in the active role of problem-solvers (Doig, 1993). This is achieved by confronting students with problems typical of the real world.

In PBL, the problem is presented first and serves as the organizing centre and context for learning (Bligh, 1995). The approach begins with teachers designing a problem based on desired curriculum outcomes, learner characteristics and compelling, problematic situations from the real world (Fournier, 2002). Ideally, the problem involves an issue that changes with the addition of new information; is not solved easily or formulaically; and does not always have a 'right' answer (Doig, 1993). In PBL, the problem-solving process is central and involves the following steps: (1) Observation or information gathering; (2) Questions, ideas and hypothesis formulation; (3) Learning issues/inquiry strategy; (4) Action plan; and (5) Reflection. In practice, PBL is often constructed as a group activity that imparts team skills, not always successfully (Dolmans *et al.*, 2001).

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Several advantages and disadvantages of the PBL approach are outlined in Table 1. In PBL, teachers develop a sketch or template of teaching and learning events in anticipation of students' learning needs. Ideally teachers allow the learners to identify their resource needs, and arrange for their availability. Students effectively identify their own learning objectives (Maudsley, 1999b) and, importantly, should engage in cycles of reflection on their own problem-solving (Hmelo & Ferrari, 1997), which leads them to higher-order thinking. The overall effectiveness of the method in developing higher-order thinking as well as a sound knowledge base is still uncertain (Barrows & Tamblyn, 1980; Savin-Baden, 2000).

There are several general objectives in PBL (Hmelo & Ferrari, 1997):

1. Construct an extensive and flexible knowledge base.
2. Develop effective problem-solving skills.
3. Become effective collaborators.
4. Become intrinsically motivated to learn.

Achieving these objectives depends on the mode of execution. Implementation of PBL requires simultaneous changes in curriculum, instruction and assessment practices, to styles which are often foreign to students and teachers alike (Barron *et al.*, 1998; Evans & Taylor, 1996; Kaufman & Holmes, 1996). This may impede the introduction of PBL.

The PBL approach is widespread in medical (e.g. Albanese & Mitchell, 1993; Vernon & Blake, 1993; Bligh, 1995; Colliver, 1999, 2000; Doig & Werner, 2000; Norman & Schmidt, 2000; Jolly, 2006) and engineering schools but is less used in other disciplines (Winn, 1995; Maudsley, 1999a). In the geography discipline, there is a paucity of studies

Table 1. Advantages and disadvantages of PBL

Advantages	Disadvantages
Nurturing and enjoyable[1]	Score lower on basic knowledge exams[1]
Engages in backward rather than forward reasoning[2]	Students view themselves as less prepared[1]
Promotes reflection on students' own learning[2]	Large cost associated with larger class sizes[1]
Students memorize less[2]	Weakness of criteria used to assess PBL outcomes[1]
Students preferred active learning[2]	High resource utilization[1]
More stimulated, challenged and satisfied[2]	Students find it difficult to gauge what and how much to study[2]
Students cram less for exams[3]	Interpersonal aspects can cause anxiety[2]
Students have more autonomy and innovation[3]	Difficult for teachers to gauge how much direction is required[4]
Students learn self-directed learning skills[3]	
Students show better integration of basic concepts[3]	
Develop higher-order thinking skills[4]	

Sources: [1] Albanese & Mitchell (1993); [2] Bligh (1995); [3] Norman & Schmidt (1992); [4] Hmelo & Ferrari (1997) relating to PBL despite the fact that geographical work is well suited to a PBL approach (cf. Bradbeer, 1996; Pawson *et al.*, 2006). Previous geography PBL studies have focused on field research and research methods training (Bradbeer, 1996; Spronken-Smith, 2005).

This paper focuses on the implementation and evaluation of PBL in a newly created undergraduate unit called Earth Systems Interactions (ESI) in 2002. As a science-based unit, it employed primarily online journals as information resources and was therefore less resource intensive than is sometimes the case. This paper addresses the introduction of this PBL exercise, experiences from its first year of operation and its subsequent refinement in the following two years.

Problem Based Learning Approach in the Earth Systems Interactions (ESI) Unit

Overview of the Unit

The unit *Earth Systems Interactions (ESI)* deals with the interactions and feedbacks amongst the Earth's different subsystems—the atmosphere, ocean, mantle and crust, cryosphere, and biological systems. In addition, it examines how these have changed on a global scale. The unit examines the dynamics of the earth by identifying the major driving processes and responses of the biosphere to energy, water and biogeochemical cycles in the earth system. The characteristic spatial and temporal scales over which they occur are also examined. These processes and cycles are viewed from two different timescales. First, thousands to millions of years where the inexorable processes of solid-earth change dominate all others. Second, decades to centuries where natural changes have major effects on humanity and the effects of human activity on global processes are most pronounced.

Earth systems science has recently received a great deal of interest in the scientific community and more specifically in geography (Pitman, 2005). This is largely due to advancements in global climate modelling, field measurements and remote-sensing techniques. These important aspects are explicitly addressed in the unit. Moreover, the increasing stress placed on integrative and holistic approaches by environmental managers is examined.

ESI is a third-year geography unit, an elective in the undergraduate geography curriculum and a core for those undertaking a major in atmospheric sciences. An average of 25 students each year are enrolled from arts, science, environmental science degree programmes and across the atmospheric science programme. The unit is designed to engage students actively in synthesis and the integration of concepts and to apply their knowledge of process to questions of environmental change on global scales. It is well suited to a PBL approach because the earth system science tends to be more open-ended and allows a wide-ranging exploration of issues. The unit provides knowledge on global processes across a range of disciplines providing a truly interdisciplinary unit. Students are engaged in learning through weekly lectures (two one-hour lectures per week for 9 weeks) and a series of student-led seminars that include peer review (two 3-hour sessions per week for 3 weeks). Moreover, the unit is centred on a research-based (PBL) activity that runs over the first 8 weeks (2 hours per session but also includes a half-day field exercise). The assessment includes a PBL research report (35 per cent) written individually through a scientific synthesis report in journal style, a research seminar (30 per cent) and an end-of-unit exam (35 per cent) on broader lecture materials presented throughout the semester.

The PBL activities in ESI as described in this paper link well with the unit objectives and the overall theme of integration and synthesis across disciplines to solve problems related to the Earth System. In addition, the PBL approach encourages self-directed learning and promotes lifelong learning skills that are part of the university's vision.

Implementation of PBL

A framework for problem-solving, developed in the medical disciplines (Barrows & Tamblyn, 1980; Azer, 2001) has been adapted for the ESI unit in Geography and Environmental Science (Figure 1). One of the aims of introducing PBL was to provide research skills (Spronken-Smith, 2005) and improve the teaching/research nexus (Elton, 2001). The framework for doing the research was developed (Figure 1) and provided to the students 'up front'. In addition, the nature of geographical studies (and related disciplines such as biology) often necessitates the inclusion of a fieldwork and analysis component in the framework and this was an important component of PBL in this case. Bradbeer (1996, p. 17) sees the "advantage and attraction for PBL within [geography] fieldwork is that it enables focus on place, on landscape and on geography as a discipline of synthesis to be sustained". In addition, there is an opportunity for student reflection on their direct experience that can lead to deeper understanding and thinking, which may influence the initial evaluation of the problem (Figure 1). It is argued that, for students to engage in a problem, successfully navigate the problem-solving process and achieve the general objectives of PBL, the course designer must address the following principles (Barron *et al.*, 1998):

1. Define learning appropriate goals that lead to deep understanding.
2. Provide scaffolding such as 'embedded teaching', 'teaching tools' and sets of 'contrasting cases'.
3. Ensure multiple opportunities for formative assessment and revision.
4. Develop social structures that promote participation.

Using these design principles and the framework (Figure 1), a work plan was developed following Doig (1993) and Hmelo & Ferrari (1997) (Table 2), which could easily be adapted for other geography units. Certainly, this work plan could be applied through directed learning. However, PBL places the learner at the centre, which contrasts with traditional teacher-centred models, such as lectures. As such, PBL approaches require a different type of educator (Maudsley, 1999b)—or at least a change in teaching practice. There has to be a move away from authoritarianism and dispensing facts (Maudsley, 1999b); instead the teacher becomes a facilitator of knowledge construction (Hmelo & Ferrari, 1997). Therefore, as a teacher in PBL it is important to use expertise subtly and sparingly while having an informal and empathetic style (Maudsley, 1999b), a difficult task for some educators (Murray & Savin-Baden, 2000).

In the ESI unit the worksheet was executed by:

1. Developing a real-world problem—a problem in the area of global change and earth system science was selected. In this case it was the Urban Heat Island (UHI). In the year 2003, half of the world's inhabitants were living in urban areas (Population Reference Bureau, 2003). As urbanization continues alterations to the natural

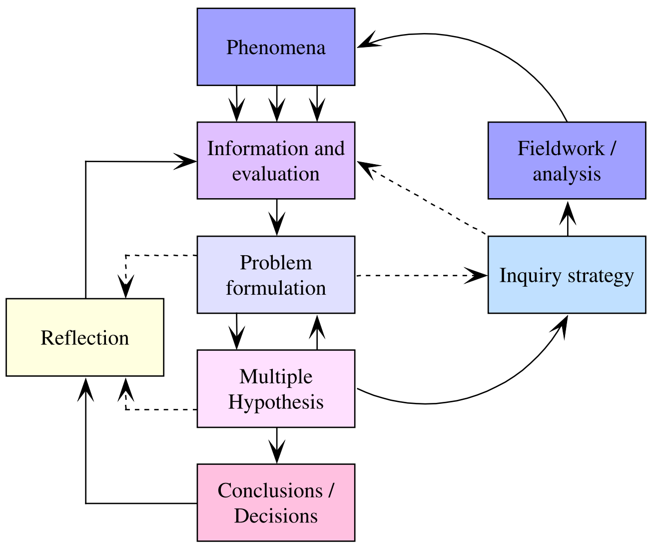

Figure 1. PBL framework used in the Earth System Science unit for this case

environment due to the physical structure of the city, and its artificial energy and pollution emissions, interact to form distinct urban climates (Bridgeman *et al.*, 1995). These urban climates can often be undesirable causing increases in air pollution and aiding the formation of Urban Heat Islands (UHI) (Coutts *et al.*, 2007). Urban warming can have substantial implications for air quality and human health (Stone & Rodgers, 2001). Factors generating UHI are believed to include: emissions of atmospheric pollutants, anthropogenic heating, reduced horizontal airflow due to increased friction, absorption and retention of energy from solar radiation, reduced long-wave loss due to limited sky view factor and reduced evapotranspiration from vegetation removal, which is a natural cooling mechanism (Stone & Rodgers, 2001; Arnfield, 2003), a phenomenon whereby urban areas are warmer than the surrounding rural areas. The UHI was chosen in particular because it allowed students to actively engage in the research process through the use of multiple methods. This problem was predefined for the unit but, if time and resources permitted, problem formulation could be part of the PBL process.

2. Providing information in the form of two lectures to provide background information. Students were then expected to do further reading as they thought appropriate.
3. Students then worked in small groups to formulate the problem and develop a hypothesis regarding urban heating.
4. Students then developed a range of research inquiry methods (this was constrained by available resources, instrumentation and time).
5. A range of resources were identified by the students. Staff then developed components to help students along each line of inquiry, with the following modules being developed:
   a. Historical data analysis looking for heating trend over time (Peterson & Owen, 2005).

Table 2. Worksheet for the application of PBL in the ESI unit

Starting the group			
1. Introductions 2. Setting the scene and introduction to PBL roles (including facilitator)			
Starting the urban heat island (UHI) problem			
1. Setting learning objectives 2. Presenting the UHI problem 3. Bringing home the problem – so what?			
Information	Hypothesis	Inquiry strategy	Field work/analysis
Students have a growing synthesis of information on the UHI obtained through personal inquiry and lecture material that is relevant to hypothesis generation	Students conjecture regarding the problem. This may involve causation, effect possible resolutions, etc.	Students list what they need to know or understand in order to complete the problem. Resource identification	Students engage in things that need to be accomplished in order to complete the problem
4. Reflection–reasoning through the problem. Continue re-representing, analysing and synthesizing ideas. May lead to further iterations of the process.			
Information	Hypothesis	Inquiry strategy	Field work / analysis
Analyse, synthesize and resynthesize	Expand/focus	Identify/justify	Formulate plan
Problem follow-up			
1. Discuss resources used and their critique 2. Reassess the problem. Apply what has been learned, revise hypothesis list			
Information	Hypothesis	Inquiry strategy	Field work/analysis
Apply new knowledge and resynthesize	Revise	Identify new issues, if necessary	Redesign decisions
Presenting the problem			
1. Synthesis of ideas and results into a journal-style report			
Post-problem reflection			
2. Knowledge abstraction and summary (what has been learned) 1. Self-evaluation followed by comments from the group and the facilitator regarding: • reasoning through the problem • self-directed learning • participating in the group			

Source: Adapted from Doig (1993); Hmelo & Ferrari (1997).

b. Fieldwork involving transects across the city to collect temperature data (Torok *et al.*, 2001).
c. Satellite remote sensing to investigate spatial temperature trends (Voogt & Oke, 2003).
d. By the end of the PBL tasks students were expected to have addressed the issues above, and to communicate their results in a journal-style research report.

6. Logistically, the class of ~25 students was broken into two streams and a session was held every week over the first 8 weeks of the semester. The venue changed from week to week depending on the resources required. One weekend day was required by each student to collect field data. The overall success of the PBL and an educational method was mixed and is detailed below followed by a description of the logistical implementation of PBL within the ESI unit.

Reflection on the Success of PBL in the ESI Unit

In weighing up the pros and cons of the PBL approach, it is particularly important to assess student learning. One of the problems is to define criteria to assess outcomes of PBL (Albanese & Mitchell, 1993). It is difficult also to assess the impact of PBL in a single unit, when really an entire programme is required to influence higher-order thinking; some have argued that it is not possible to implement a PBL approach in a single course unit alone (Maudsley, 1999a). Despite claims that the PBL process is based on fundamental educational principles, there is little evidence to suggest better learning outcomes for students (Barron *et al.*, 1998; Colliver, 1999, 2000). Ideally, what is needed for evaluation is pre- and post-course self-evaluation of student understanding, a measure of the depth of understanding and a questionnaire designed to determine student satisfaction (Dods, 1997). This requires substantial effort and may not be achievable in all circumstances. Alternatively, simultaneous evaluation across two groups educated in PBL and traditional methods, respectively, with an emphasis on treatment effects, can also offer insight (Colliver, 2000). Such a systematic evaluation of PBL was beyond the scope of this study. It was also difficult to assess pre- and post-implementation of the PBL in this case because the unit was designed in 2002 with the PBL approach already included. In order to investigate the success of the PBL module within the ESI unit, students undertook a survey at the end of the unit in each year 2002–2004. The survey included broad-ranging questions regarding organization and structure, learning and understanding, interest and motivation, lecture interaction and physical aspects of presentation, along with specific questions on the PBL component, which are reproduced in Table 3. In addition, students were strongly encouraged to produce written comments. Spaces were provided for written comments in three areas: (1) things you liked about the unit; (2) things that you did not like; (3) other feedback. The survey was informal and administered in class the by the unit staff. These scores and written comments form the basis of the following assessment.

In general, students found the approach more nurturing and enjoyable, and were more stimulated, challenged and satisfied as evidenced by 64 per cent of respondents in 2004 saying they 'strongly agree' that the approach and synthesis was worthwhile. These students are likely to be more engaged in learning as also found by Bligh (1995) and Albanese & Mitchell (1993). For example one student wrote "this unit made me more

Table 3. Responses from student surveys in 2002 and 2004[a]

	2002	2004	Statistics for Student's *t*-test for independent samples
Scored questions			
"The sessions were well integrated with the rest of the unit"	3.71	3.44	($t = 1.03$, df $= 25$, $p = 0.31$)
"The synthesis of material into a report was a good idea"**	3.94	4.46	($t = -2.11$,df $= 25$, $p = 0.04$)
"The field work was a worthwhile component"**	3.03	3.96	($t = -2.13$,df $= 25$, $p = 0.04$)
Written response categories			Statistics for chi-squared analysis
Field trip or research sessions disorganized**	44%	25%	($\chi^2 = 3.14$, df $= 1$, fisher exact (one-tailed) $p = 0.05$)
Allowed synthesis and/or exploration of topic in detail*	31%	50%	($\chi^2 = 2.49$, df $= 1$, Fisher's exact (one-tailed) $p = 0.07$)
Improved skills and made students more active	25%	25%	($\chi^2 = 0$, df $= 1$, Fisher's exact (one-tailed) $p = 1$)

Notes: [a] The average response from relevant scored questions (range from 1 = strongly disagree to 5 = strongly agree). For the scored questions Student's *t*-test for independent samples was used on the raw survey data to test for difference between the two samples. Also summarized are the responses to the request for written comments regarding what students liked and did not like about the unit. These have been grouped into three general classes of responses. Statistics for chi-squared analysis of the written response frequencies are given to test for differences from the expected frequency. The survey was from a sample of 16 students in 2002 and 11 in 2004. Questions are highlighted with a * if significant at the $p < 0.1$ confidence level and ** at the $p < 0.05$ level.

active as a student. It stimulated and made me curious, an excellent unit" (2004 survey). In addition, it has been suggested that the PBL approach can encourage higher-order thinking and integration of knowledge (Norman & Schmidt, 1992). It can encourage learners to be more autonomous and innovative and to be more reflective about what and how they have learnt (Bligh, 1995). Although these aspects were not assessed directly the students' comments did reflect this, for example: "PBL research sessions were interesting. Learned more, learned different skills, forced to think about work." The PBL process should promote self-directed learning that leads to lifelong learning skills (Norman & Schmidt, 1992).

On the downside, students have been shown to perform lower on basic knowledge-based exams and view themselves as less well prepared for the real world (Dods, 1997). Students also find it difficult to gauge how much and what to learn (Bligh, 1995). In this study the students generally found themselves acquiring good research skills, as illustrated by the high fraction (25 per cent) of written comments that mentioned gaining such skills (see Table 3). Finally, interpersonal aspects of the approach, such as team working, have been documented to cause some anxiety (Bligh, 1995); however, student comments did not reflect this in this case.

Assessment of the Execution of PBL in the Unit

In 2002 when the unit was first introduced, the execution of the PBL project ran several steps ahead of the pedagogical development. This occurred because the students were guided through the unit and they helped to set their own learning pathway. This meant that materials had to be developed 'on the fly' and as a result the students' 'doing' of the project took precedence over the 'understanding' and problem-solving process, a problem also encountered by Baron *et al.* (1998). There was also reluctance from both the students and the teacher to make a full switch to student-centred learning. This probably reflects unfamiliarity with this type of approach on the part of both students and teacher. As a result the approach was almost like a guided project and somewhere midway along the continuum between teacher- and student-centred learning. In this instance the project could be viewed as more 'project-based' learning, which utilizes real-world work assignments on time-limited projects to achieve mandatory performance objectives and to facilitate individual or collective learning (DeFillippi, 2001). Students in the unit may have felt constrained by the development of discrete modules that were held every second week. These modules were centred on historical data analysis, field data collection using automobile transects, and thermal analysis of satellite imagery. The range of modules were developed by the students but guided based on available resources and time constraints. The downside of this approach was that some students felt as if the modules were like individual practical sessions that were just tied together at the end by writing a report.

In 2002 there was little formative assessment throughout the PBL activity. Students often felt that they did not know how they were going, even though the overall objectives of the PBL approach were clear. The idea was that students themselves would consider what and how much to learn. Written feedback from students indicated that a few enjoyed the intellectual freedom, but that most wanted even more guidance as shown by the high number of written responses regarding disorganized fieldtrip or research sessions (see Table 3).

The other issue is how to assess whether students have met the objectives of PBL. It is difficult to directly test students' abilities to achieve these types of objectives. A survey of students was initiated in one of the sessions to investigate what the students thought they had learnt (Table 4). Students were asked to list three things they learnt in the class and this was designed to see if they had met the set learning objectives (Table 4). It is interesting that the majority of students stated that they had learnt computer skills (use of Excel or Mapinfo, especially use of equations and graphs and technical things) rather than the problem-solving process itself. Again this reflects the 'doing' of the project rather than the 'thinking' of the project. This perception may be improved through better facilitation, stronger statement of the PBL objectives at the outset and enhanced critical reflection.

In this unit, students were assessed in a written report on the research conducted during the PBL project. Using this method of assessment, students' ability in problem formulation and hypothesis building, integration of methods, data analysis, synthesis of concepts and conclusions could be gauged. The assessment is then a test of their ability to write a coherent report but does not directly assess how well students have learned to solve problems. The class reports were of high standard (for the most part) and the ultimate grade reflected their engagement with the PBL process (Table 5). The results from their projects will be featured in a forthcoming article.

Lastly, there was a mixed reaction from students to the PBL approach. Overall students thought the PBL activity was worthwhile and the scored response to the question of whether "the synthesis of material into a report was a good idea" scored highly (see Table 3). Some thought that the project was worthwhile and a good way of integrating and covering a topic in detail. This is reflected in written comments (see Table 3) and may be because of the higher level of integration and synthesis than would be expected from laboratory or field reports alone. Others, however, thought that the project was disorganized and needed more structure (see Table 3).

Given the students' perception that the PBL project and associated field work was disorganized the unit was given even more structure in 2003 and 2004 but still allowed for

Table 4. Response of students after one of the research sessions when asked "What were three things you have learnt from this session?" for the session on analysis of data from automobile transects of the Urban Heat Island ($n = 12$): responses were grouped into the five categories below

Learning objective	Response (%)
Develop a hypothesis for the development of the urban heat island and apply an inquiry strategy to address it	7
Understand the processes of cooling during field data collection and apply a cooling factor to adjust the field data	7
Determine the magnitude of the urban heat island using previously collected field data	12
Examine the spatial nature of the urban heat island	22
Utilise Excel and MapInfo to process relevant heat island data	52

Table 5. Average class marks (%) for each assessment item since introduction of the unit in 2002

	Peer seminar	PBL report mark	Exam total	Unit total
2002	76	73	65	70
2003	75	87	70	75
2004	78	82	73	75

flexibility in what and how students undertook the sessions. In some sense this represented a further move away from fully student-centred learning. In addition, in 2003–2004, formative feedback was given to students after each session during small-group discussions. The result was a significant ($\chi^2 = 3.14$, df = 1, Fisher's exact (one-tailed), $p = 0.05$, see Table 3) decrease in the written survey responses from 44 per cent to 25 per cent, which indicated the "Field trip or research sessions were disorganized" (see Table 3). The number of responses related to "Allowing synthesis and/or exploration of topic in detail" increased significantly from 31 per cent to 50 per cent ($\chi^2 = 2.49$, df = 1, Fisher's exact (one-tailed), $p = 0.07$, see Table 3). Pleasingly, the average grade also increased from 73 in 2002 to 87 and 82 in 2003 and 2004, respectively (see Table 5).

Conclusions

Initially, student attitudes were divided between engagement with PBL and merely thinking it disorganized. This, perhaps, represents two different styles of student learning and differing capacities for self-directed independent learning, which would be in broad alignment with phenomenographic studies on student learning in geography (Bradbeer *et al.*, 2004). Improvement, after the first year (2002) probably reflects the elimination of teething problems but also changes in the way the PBL activity was structured. PBL theory suggests that the unit should have benefited from a further shift away from authoritarianism and dispensing facts and toward student-centred learning (Maudsley, 1999b). However, in this case, in 2003–2004, the PBL activity was given more structure, increased guidance from the teacher, and shifted to a more project-based approach. So, there may be an optimal weighting of student- and teacher-centred learning. In order to accommodate the various student skills in adapting to PBL in a single unit, this optimal weighting seemed to be somewhere about halfway along the student-/teacher-centred learning continuum. In fact, shifting to an entirely student-centred learning approach is difficult as it requires a shift from the methodological comfort zone of both teachers and students. In this light, it is difficult to know how much an educator should direct students (Maudsley, 1999b). It is apparent that there needs to be a balance of lecture and PBL-based learning (Doig & Werner, 2000), which in turn necessitates a balance between coverage and depth (Dods, 1997). It is important to develop personal skills, to be a better facilitator. Likewise students also need to adjust to the PBL approach and this puts additional pressure on the teacher to execute a PBL project effectively. This study suggests that some students were not able to adapt to the new PBL approach easily, which resulted in concerns about 'disorganization'. A more systematic approach to the implementation of PBL throughout the curriculum would allow students to adjust and benefit fully from a more student-centred learning approach by being able to (1) construct an extensive and flexible knowledge base; (2) develop effective problem-solving skills; (3) become effective collaborators; and (4) become intrinsically motivated to learn.

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