Problem-Based Learning Approaches in Meteorology

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ABSTRACT

Problem-Based Learning, despite recent controversies about its effectiveness, is used extensively as a teaching method throughout higher education. In meteorology, there has been little attempt to incorporate Problem-Based Learning techniques into the curriculum. Motivated by a desire to enhance the reflective engagement of students within a current field course module, this project describes the implementation of two test Problem-Based Learning activities and testing and improvement using several different and complementary means of evaluation. By the end of a 2-year program of design, implementation, testing, and reflection and re-evaluation, two robust, engaging activities have been developed that provide an enhanced and diverse learning environment in the field course. The results suggest that Problem-Based Learning techniques would be a useful addition to the meteorology curriculum and suggestions for courses and activities that may benefit from this approach are included in the conclusions. © *2013 National Association of Geoscience Teachers*. [DOI: 10.5408/11-281.1]

Key words: problem-based learning, meteorology

INTRODUCING THE PROBLEM AND EXISTING COURSE DESIGN

This study assesses both the feasibility and usefulness of Problem-Based Learning (PBL) approaches in teaching meteorology. By means of a controlled and evaluated test implementation, it aims to discover if PBL could play a role in meteorology teaching at undergraduate and masters level in UK Universities. Two new PBL activities are introduced to an existing fieldwork based meteorology module. The activities are both designed in line with best practice guidelines for PBL, but are designed to be sufficiently different that conclusions about the overall suitability of PBL for meteorological teaching can be drawn. The success of the new activities is evaluated using a combination of student feedback, peer observation, analysis of resulting student outputs, and personal reflection.

The Problem: Passive Engagement of Students

Meteorology as a subject has a strong practical experimental component. Teaching students how to make effective measurements and how to use the data collected appropriately is a key part of the undergraduate curriculum, and also provides a strong transferable skill. Although a large element of practical work is included in the University of Reading's Meteorology and Climate BSc and MMet programs, in its current form much of this teaching follows a relatively traditional model of several self-contained experiments. Each of these experiments have well-defined expected outcomes, which are known by staff prior to assigning the experiments to students. While this approach has value, it fails to allow students to address key components of the most widely held view of experiential learning, the Kolb learning cycle (Kolb, 1984).

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A Possible Solution: Problem-Based Learning

PBL is an approach to teaching and learning that forms part of a broader spectrum of techniques known as Inquiry-Based Learning. Inquiry-Based Learning (IBL) can be broadly defined (Kahn and O'Rouke, 2004) to have the following characteristics:

- Engagement with a complex situation or scenario that is sufficiently open ended to allow a variety of responses or solutions;
- Students direct the lines of inquiry and the methods employed;
- The inquiry requires students to draw on existing knowledge and to identify their required learning needs;
- Tasks stimulate curiosity in the students, encouraging them to actively explore and seek out new evidence; and
- Responsibility falls to the student for analyzing and presenting that evidence in appropriate ways and in support of their own response to the problem.

PBL in particular involves students addressing a problem in a small group and defining the additional knowledge and investigation that they require to solve the problem. In many ways, PBL is as much about identifying the key unknowns in a problem and appropriate ways to tackle these problems as it is about solving the problem at hand. The PBL approach to learning does not require students to have mastered a body of knowledge before the completion of a project (as in a typical undergraduate or master's dissertation), but allows the understanding of the student and their ability to solve the problem to evolve together.

Broad Advantages and Disadvantages

Kahn and O'Rourke (2004) list a large number of potential advantages of PBL as a teaching style particularly

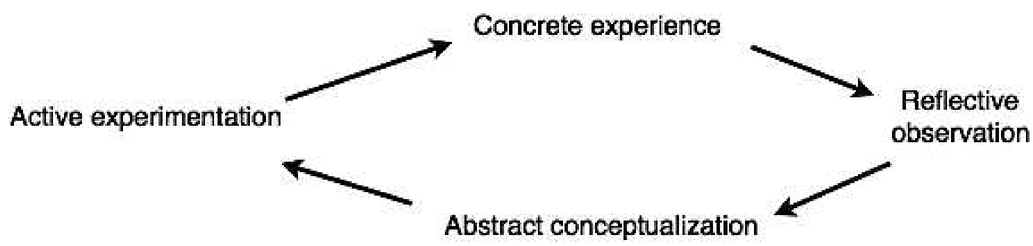

FIGURE 1: Kolb learning cycle (after Kolb, 1984).

associated with student motivation, engagement, and employability. They identify that "the modern 'knowledge economy' places a premium on the ability to create relevant knowledge that helps to solve specific problems" (p. 4).

PBL provides a way of encouraging students to participate in constructive experiential learning, as in the Kolb learning cycle (Fig. 1). This happens by encouraging students to engage in active experimentation to test their ideas and then use their experience of the outcomes of their experimentation to reflect on their grasp of the knowledge at hand. This reflective element is particularly important and can be enhanced in the PBL model by offering the chance for students to contrast their own performance and knowledge with that of their peers.

Despite these widely accepted benefits of PBL in the educational literature, there is current controversy over the effectiveness of minimally guided techniques in general. This controversy links to the paper of Kirschner, Sweller, and Clark (2006) who make the case that minimally directed techniques are incompatible with our knowledge of human cognitive architecture (in particular, the Atkinson and Shiffrin [1968] sensory memory–working memory–long-term memory model). Kirschner et al. (2006) argue that, since the capacity of working memory is limited, placing heavy demands on it by requiring problem-based searching should be avoided. Kirschner et al. also state that numerous studies have suggested that a more directed learning approach, particularly incorporating numerous "worked-examples" is a more efficient use of novice and intermediate learners' cognitive resources. Several responses to Kirschner et al. exist in the literature (Hmelo-Silver et al., 2007; Kuhn, 2007; Schmidt et al. 2007) along with a commentary on these responses by the original authors of Kirschner et al. (Sweller et al., 2007). Common to this discussion is the idea that PBL techniques without any guidance are inferior to those with some strong scaffolding provided by the course leader. They also agree that much more careful research with properly controlled experiments is required to fully assess the advantages and disadvantages of different educational techniques.

In practical terms, much of the discussion of the advantages and disadvantages of minimally guided techniques is focused on rather fundamentalist positions of fully guided or fully unguided teaching. In reality, any implementation of PBL in meteorology is likely to exist somewhere between these extremes with some guidance provided by course instructors. It should also be recognized, however, that PBL techniques may be more appropriate for intermediate and advanced learners, and thus, more appropriate for courses at the end of undergraduate programs and at the master's level. The reason for this is two-fold. First, to be delivered in a time-efficient manner, PBL requires students to have a relatively mature set of study skills, which they develop during the early undergraduate years. Second, PBL in meteorology requires students to have a firm background in the physics and chemistry of the atmosphere so they can ask and answer questions appropriate to problem at hand.

Despite the controversy about PBL techniques in the literature, it seems appropriate to investigate their usefulness in the meteorological context, provided that this is within a course with a range of different instructional techniques including directed learning. In this way, PBL techniques can be evaluated but at low potential detriment to students involved in the course if they prove to be of limited value.

Implementation in Higher Education and in Meteorology

Various reviews of the implementation of PBL approaches in higher education exist in the literature (e.g., Boud and Feletti, 1997; Savin-Baden, 2000). Even a cursory glance at these texts reveals three things about the implementation of PBL in higher education:

1. PBL has been used to refer to a broad range of educational activities from the design of an individual element of a problem class to the design of a full 3-year curriculum.
2. The implementation of PBL varies greatly between different subjects. Those with a strong element of practical problem solving (e.g., medicine and law) have been by far the most enthusiastic adopters of PBL.
3. Lack of understanding among academic staff on their role within a PBL exercise is a widespread barrier to implementation.

There has been little implementation of PBL techniques in meteorology or in related Earth and environmental science fields. Some literature on the implementation of PBL in Geography, Earth, and Environmental Sciences (GEES) subjects is available in a special edition of *Planet* (http://www.gees.ac.uk/planet/index.htm#). Of the articles in this issue, the most relevant is that which describes the implementation of PBL in a field course module by Perkins et al. A particularly interesting aspect of this article is the adoption of the "Seven-Jump" Maastricht model for PBL tutorials (Gijselaers, 1995; Table I). This model provides a framework for the PBL structure that is adopted in the two new activities introduced in Section 3 of this article (with some modification for activities that take place entirely on

TABLE I: Maastricht model of PBL tutorials (after Gijselaers, 1995).

Jump	Activity	Timing
1	Clarify terms and concepts not readily comprehensible.	Meeting 1
2	Define the problem.	
3	Analyze the problem and offer tentative explanations.	
4	Draw up an inventory of explanations.	
5	Formulate learning objectives.	
6	Collect further information through private study.	Between Meetings
7	Synthesize new information and test it against original problem. Reflect and consolidate learning.	Meeting 2

the Isle of Arran[2]) and characterizes PBL learning as a series of seven "jumps."

Perkins et al. (2007) report that PBL had a generally positive impact on the field activities and was equally at home in "hard-science" subjects. As noted above, however, clear tutor guidance was a key factor in its success. One major difference between our own field course and that of Perkins et al. is the length of preparatory time, which is long (16 hours) in the case of Perkins et al., and relatively short in our case (1 hour). Although the short preparatory time was necessary in our case because the course is shared between two universities with no chance to arrange preparatory classes, this should not be viewed as a disadvantage. In fact, the time-limited nature of the preparatory work is in many ways a more faithful simulation of real meteorological field work where planning of experiments is often done at short notice because of experimental and operational constraints.

Test Module: Atmospheric Science Field Course

The module chosen to test the implementation of PBL approaches in meteorology is an atmospheric science field course jointly taught with colleagues from the University of Leeds. The course is residential and takes place over 8 days, based at a field center on the Isle of Arran. Typically, there are around 35 students in the course, split equally between students from Reading and Leeds. The course is offered at both the third year undergraduate and at the master's level. The background of students on the course is diverse, with a wide range of mathematical skills in particular presenting a major challenge. Activities in the course are primarily field-based and include an all-day hike to the top of Goat Fell (approx. 850 m elev.), taking measurements along the way. The traditional approach to practical experimental learning adopted by meteorology incorporates only the active experimentation and concrete experience stages of the Kolb learning cycle. In this field course, students have the opportunity to participate in several different experiments at once, allowing them the opportunity to try to piece abstract concepts about the atmosphere together. However, a remaining problem with the course is that all the experiments have been designed by staff to have relatively simple outcomes, which are known at the outset by staff and sometimes students. Therefore, the reflective observation link in the Kolb learning cycle chain is often opaque or broken, making it difficult for the students to move to higher-level abstract conceptualization.

[2]The island of Arran is the largest island (167 square miles) in the Firth of Clyde, WSW of Glasgow.

Assessment of Current Course Design

To fully examine the current structure of the course and the way its current structure maps to the Kolb learning cycle, a course map was completed (Conole, 2010). Mapping the course in this way provides a concise summary of its current state and highlights the issues discussed in the previous section. Since the test module is made up of a series of discrete activities, it has also been possible to map these activities to the Kolb learning cycle. A video diary describing the initial mapping of the course and the problem at hand can be found at: http://cloudworks.ac.uk/cloud/view/3813. By mapping the course, additional issues associated with the course were highlighted or emphasized:

- The lack of opportunity for reflection in the course is clear; only one of the seven activities provides a way for students to examine their own work or put it in the context of others' work. As a consequence, many of the activities "short-circuit" the Kolb learning cycle.
- Along with this lack of reflective elements, no opportunity is provided to the students for formative feedback on their work. While the high staff–student ratio for the course does allow staff to have informal dialogues with students to improve their understanding, there is no way for students to gain feedback on their written work, which is, in some ways, a more concrete demonstration of understanding.

TEST CHANGES TO MODULE

Two New PBL Elements

With the key messages of the proceeding literature in mind, two similar but distinct PBL approaches were introduced into the atmospheric science field course module. The first of these PBL activities involved students in both the BSc and MMet programs and students from our partner, the University of Leeds. It focused on trying to address issues of missing stages in the Kolb learning cycle outlined above. The second activity involved only University of Reading students in the MMet program and was completed over a longer period of time, upon return to Reading. The aim of this activity was to provide a second M-level route to obtaining appropriate professional skills in environmental monitoring. Examples of course materials for each of the new activities are provided online at http://www.met.reading.ac.uk/~sws05ajc/teaching/pbl.html

PBL Activity I: Ozonesonde Launch

This activity involved the design of an experiment to launch an ozonesonde, a piece of equipment attached to a weather balloon that measures ozone concentrations throughout the atmosphere. Students were already part of mixed University of Reading and University of Leeds teams for other activities. The students were told that there were only enough resources to launch a single ozonesonde and that they should design an experiment to maximize the benefit of observations from a single launch.

The activity proceeded as follows:

1. The activity was introduced in a short lecture and through course documents. Some information about ozone in the atmosphere was given along with some technical details about the equipment available for use.
2. Students discussed how and when to launch the ozonesonde in their teams. They had access both to staff (as facilitators) and forecast information about future weather conditions to determine when an interesting time to launch would be (*initial abstract conceptualization phase)*.
3. Students were asked to write a short work plan for the launch. The work plan was requested to be in the form of a mock grant proposal to a fictional funding agency so that the process provided as close a simulation of real scientific practice as possible. The proposals were then presented to a steering committee of staff that assessed which of the proposals to take forward (*active experimentation phase)*.
4. The ozonesonde was launched according to the instructions of the successful bid and data provided to all of the groups to analyze *(second part active experimentation phase)*.
5. Following the launch students analyzed both the data produced by the experiment and the differences between the winning bid and their own. They were asked to comment on the differences between their bid and the winning bid and identify any deficiencies of either bid based on the results of the experiment. This part required the students to enter the reflective phase, based on the experimental design and to build this reflection back into their original abstract conceptualization.

PBL Activity II: Climate Monitoring Station Design

This activity took place following the return of students in the MMet program from Arran, and continued throughout the following autumn term. Students were given the problem of designing a new climate monitoring station for Arran based both on their experience of the field course location and meteorology and further original research from existing literature. The module convener and two members of the research staff facilitated the activity in three 1-hour discussion sessions. Students were asked to produce a 15-page design specification for the climate monitoring station detailing equipment used, fit to national and international monitoring priorities and operating procedure. The first task for the students was to decide on the priorities for the climate monitoring based on their own analysis of the literature and discussion in a group forum. The activity specifically targets the reflective observation and abstract conceptualization elements of the Kolb learning cycle, while using the observational experience gained on Arran as the active experimentation and concrete experience phases. The final assessment of the design specification emphasized these aspects.

METHOD OF IMPLEMENTATION AND ASSESSMENT

Design of the new PBL methods took place during academic year 2008–2009 and was introduced into the course in Autumn 2009. A second test implementation was then repeated with some modification in Autumn 2010.

Evaluation Methods

With any new teaching and learning activity, a crucial part of its successful introduction is a robust evaluation (Fry et al., 2008). Project evaluation was conducted using a range of techniques including student feedback, peer observation, analysis of resulting student outputs, and personal reflection. Student feedback was obtained through a carefully designed diagnostic questionnaire (Gibbs et al., 1988) that specifically explored the distinctions between the PBL approach and more traditional approaches used for the majority of the field course. A similar diagnostic questionnaire was applied to both activities and some questions were added to the questionnaire for Activity II to explore the differences between the two projects. Peer observation from other staff was easily implemented since both activities took place within a staff-intensive environment. Feedback was obtained through a separate diagnostic questionnaire and through unstructured interviews with colleagues. Again the emphasis was on which aspects of the PBL approach work well within a meteorological context. The interviews were used to check that answers to the questionnaires were truly diagnostic, providing an independent check of the methodology. The third stream of evaluation was through examination of student outputs for each activity and personal reflection from this perspective. It was clear that the reflective element of the activities was well incorporated since all students provided some reflection on their own and others work.

RESULTS FROM IMPLEMENTATION IN 2009

The two activities were first implemented as part of the course during academic year 2009–2010. The course took place between 4 and 11 September 2009 on the Isle of Arran. Thirty-two students took part in the course, 16 from Reading and 16 from Leeds. Of those students, three from Reading took the course at the master's level and also participated in the observing system design activity during the autumn term of 2009. The average mark for the course overall was 63% with a standard deviation of 5%. The ozonesonde activity had an average mark of 64% with a standard deviation of 10%. The observing system design activity had an average mark of 62% (no standard deviation is recorded since only three students participated). Raw results of the questionnaire are presented in Table II.

Reflection on Student Feedback

In general, both activities were well received by the students who assessed them with generally high scores in most categories. The questions can be divided up usefully into four broad categories on which to assess the success of the PBL implementation. The first set of questions assessed how well the activity was structured and communicated to students. Clearly the small group of students who took part in the observing system activity did not fully understand their task and this might have reduced their motivation in

TABLE II: Results of student survey of PBL activities following implementation in Year 1 (2009). Marks are awarded by participants on a scale of 1–10, with 1 being the highest mark. Statistics are based on 18 student surveys and 4 staff surveys for the ozonesonde activity, and 3 student surveys and 2 staff surveys for the observing system activity.

Criteria	Ozonesonde Students	Ozonesonde Staff	Observing System Students	Observing System Staff
How well did students understand the task?	3.2	3.5	6.0	3.5
How easily did groups quickly focus on the key questions required?	3.5	2.3	4.3	2.5
Was the activity a good simulation of a "real-world" case?	4.4	6.3	4.7	3.5
Did you anticipate the activity would improve your specific subject understanding?	3.7	5.0	4.7	3.5
How well did students engage with specific reflective activity?	2.9	2.7	2.0	1.5
Was all the required information provided to you in the project text?	3.9	5.3	7.7	1.5
How much were staff used to give subject specific information?	2.8	5.3	1.7	4.5
How much were staff used to give generic skills information?	4.9	6.8	1.7	4.5
Did comparison with other groups/students help students to reflect on their work?	3.0	6.3	N/A[1]	1.0
Did reflection help students improve their understanding?	5.3	4.7	N/A	6.0
Did students agree with the staff assessment?	2.8	N/A	N/A	N/A
Did the activity improve students' generic skills?	N/A	2.7	N/A	3.0
Did the activity improve students' subject specific skills?	3.7	3.3	N/A	2.0
Did you prefer the time constraint in the ozonesonde activity to the open-ended observing system activity?	N/A	N/A	3.0	N/A
Did you prefer working on your own in the observing system activity rather than in a team in the ozonesonde activity?	N/A	N/A	5.0	N/A
The observing system activity improved my subject-specific knowledge more than the ozonesonde activity.	N/A	N/A	4.0	N/A
The observing system activity was at a higher educational level than the ozonesonde activity.	N/A	N/A	2.0	N/A

[1]N/A = question was not asked to gain this information.

taking part. There was an interesting discrepancy between the perception of the ozonesonde activity as a good simulation of a real world task between the students (who generally thought it was) and the staff (who had a mixed reaction). This was a positive outcome since it suggested that the task was simpler than a complex real-world grant proposal, but this did not detract from its appeal to the students. In all activities, both staff and students judged that the students engaged well with the reflective part of the activity, which is a key part of the Kolb cycle and crucial to this new activity. Interestingly, the extent to which the students and staff believed that the reflection helped the students improve their understanding was more mixed.

The second set of questions considered how students gained the required information for the task. Answers showed the expected split between the two activities, with students taking part in the ozonesonde activity obtaining most of the required information in written form while students taking part in the observing system activity conducted their own research and engaged with staff. When assessing how staff were used, students were generally more pessimistic about their own input and claimed staff influenced both their subject-specific and generic skills more than the staff perceived. This is perhaps to be expected, but it was important for the success of the activity that the students believed that their input and decisions influenced the direction of both projects. The results identified that it should be emphasized to staff that they act as facilitators of the discussion since part of the PBL learning process is shaping and refining the problem at hand.

The third set of questions deals with the assessment of the activity upon completion by both groups. As mentioned above, both staff and students were somewhat mixed in their assessment of the utility of the reflective elements of the activities. Interestingly, students believed that the comparison with other groups was a very helpful part of the ozonesonde activity, whereas staff were more circumspect. In general, the projects scored well among all groups in their ability to improve both generic and specific skills.

Finally, the group of students who participated in both the ozonesonde and observing system activities were asked to compare them. Interestingly, for broader applications of PBL there was a clear preference for the time-limited ozonesonde activity and the focus that this brought to discussion. However, in general, the students believed the observing system activity to be at a higher educational level, which again fits well with the course design.

Participants were also asked to make specific and general comments on the activities. Few comments were received, but some of the most interesting were:

Student

"I didn't have much of an idea of what I was supposed to be doing or how to get a good mark in this."

"Good but should only be done sometimes."

"Encourages time keeping."

"Makes you think more for yourself, which encourages learning."

"I prefer more lecture-based teaching, not a fan of large research projects stuff. It is important it is more real-world, but 40% is still too heavy a weighting."

"Initial knowledge of the area needs to be taught first to better be able to do these activities, but it challenges you to think about stuff in a more realistic context which is good."

"It encourages you to think for yourself more. Although I didn't like it to begin with, it has taught me a lot."

Staff

"Encourages vibrant interaction between staff and students so that ideas are created and developed quickly. Allowed for quickly working through problems and assimilation of scientific knowledge."

"Good activity, although students found assessment of the speaking part a bit vague."

"You cover a lot less content but it may be more effective and the student learns a lot more from it by making mistakes and learning and developing things by himself. Combined with traditional approaches to teach the basics I think it is highly useful."

Unstructured Interviews With Colleagues

Informal consultation with colleagues revealed that both activities had been well received in the first instance and had enabled students to be more actively engaged in their learning and to explore different facets of both problems than they might otherwise have done. The major discussion point for the ozonesonde activity was the lack of training of staff both for the PBL process and in the specifics of the activity itself. There was particular concern about the role that the reflective activity should play. The major discussion point for the observing system activity was the lack of engagement between students and staff members outside contact hours. Both staff members felt that the students were disinclined to ask for help and expertise even though this was explicitly offered.

Consistency of Evaluation Using All Three Evaluation Methods

A coherent picture of the successes and failures of the activities in their first implementation arose from consideration of all three methods of evaluation. In general, staff and students found the activity to be worthwhile and both in the questionnaire evaluation and the informal interviews, both groups thought that the PBL approach promoted active engagement amongst the students. Evaluation of student work, informal staff interviews, and the questionnaire responses highlighted the problems in the introduction of the reflective elements, particularly in relation to the way in which staff participated in the activity. There were, however, some elements in which the different evaluation techniques give different pictures of the activities. Although the survey results suggested students didn't fully understand the purpose of the observing system activity, the student outputs (both in terms of a qualitative or quantitative evaluation) did not suggest that they performed any better or worse than in the ozonesonde activity or in the course in general.

Changes Made to Activities

Identified actions to improve the activity for 2010 were:

- Improving the documentation and introduction of the observing system task for 2010.
- Reconsidering the reflective part of the ozonesonde activity to ensure it boosts student understanding.
- Reiterating to staff that their role should be advisory only
- Adding informal contact periods (office hours) to the observing system activity to encourage informal contact between staff and students.

These actions were undertaken during academic year 2010 and modified activities were introduced into the course in September 2010.

RESULTS FROM IMPLEMENTATION IN 2010

The second implementation of the two activities occurred as part of the course during academic year 2010–2011. The course took place between 5 and 12 September 2010 on the Isle of Arran. Thirty-five students took part in the course, 12 from Reading and 17 from Leeds. Of those students, five from Reading took the course at the master's level and also participated in the observing system design activity during the following autumn term. The average mark for the course overall was 61% with a standard deviation of 4%. The ozonesonde activity had an average mark of 56% with a standard deviation of 4%. It should be noted that a different academic colleague at Leeds was responsible for marking the ozonesonde activity in each year of the course. While every effort is made to standardize marking, experience in previous years shows that the lower mark in the 2010 implementation is partly related to this change in marker. The observing system design activity had an average mark of 65% with a standard deviation of 7%. Raw results of the questionnaire are presented in Table III.

Reflection on Improvement to PBL Activities in Second Year of Implementation

Results from the evaluation of the PBL activity in the second year of implementation were extremely positive. In most cases where the evaluation of the 2009 module revealed that the activity had been successful, this positive result was maintained. In the areas where the 2009 evaluation identified improvements that could be made, the changes made to the PBL procedure generally improved both student and staff evaluations, specifically:

TABLE III: Results of student survey of PBL activities following implementation in Year 2 (2010). Marks are awarded by participants on a scale of 1–10, with 1 being the highest mark. Statistics are based on 21 student surveys and 3 staff surveys for the ozonesonde activity, and 5 student surveys and 2 staff surveys for the observing system activity.

Criteria	Ozonesonde Students	Ozonesonde Staff	Observing System Students	Observing System Staff
How well did students understand the task?	3.2	4.0	3.2	3.0
How easily did groups quickly focus on the key questions required?	4.2	3.0	2.6	3.0
Was the activity a good simulation of a "real-world" case?	4.2	4.7	2.4	2.5
Did you anticipate the activity would improve your specific subject understanding?	3.7	2.3	1.6	2.0
How well did students engage with specific reflective activity?	3.4	3.7	1.2	2.0
Was all the required information provided to you in the project text?	3.5	3.5	2.8	2.5
How much were staff used to give subject specific information?	2.2	6.7	1.4	5.5
How much were staff used to give generic skills information?	3.8	4.7	3.4	4.5
Did comparison with other groups/students help students to reflect on their work?	2.3	2.5	N/A[1]	2.5
Did reflection help students improve their understanding?	2.8	3.5	N/A	4.5
Did students agree with the staff assessment?	3.6	N/A	N/A	N/A
Did the activity improve students' generic skills?	N/A	3.0	N/A	3.5
Did the activity improve students' subject-specific skills?	2.6	3.3	N/A	3.5
Did you prefer the time constraint in the ozonesonde activity to the open-ended observing system activity?	N/A	N/A	6.8	N/A
Did you prefer working on your own in the observing system activity rather than in a team in the ozonesonde activity?	N/A	N/A	3.6	N/A
The observing system activity improved my subject specific knowledge more than the ozonesonde activity.	N/A	N/A	3.4	N/A
The observing system activity was at a higher educational level than the ozonesonde activity.	N/A	N/A	3.6	N/A

[1]N/A = question was not asked to gain this information.

- The improved documentation and introductory lectures incorporated into the observing system activity significantly improved scores in the first part of the survey. This was particularly true for students who showed that they understood the task better, were able to quickly focus on the task at hand, that they felt that the task was a reasonable simulation of a real-world activity, and that they engaged strongly with the reflective activity.
- The improved oral description and staff training for the reflective part of the ozonesonde activity significantly improved the scores of both staff and students in this part of the survey. Particularly interesting was the gain in the mark for subject specific skills for both staff and students.

Another interesting result of the second evaluation, perhaps related to the small sample size and variation between student groups, was the lack of preference for the time constrained, ozonesonde activity in the 2010 cohort. While there was a strong preference for this activity in the 2009 cohort, the 2010 cohort was enthusiastic about the observing system activity, but expressed no clear preference for this PBL style as opposed to the more limited, focused ozonesonde activity.

The 2010 control cohort who participated in both PBL activities also produced a number of interesting comments and suggestions on PBL in general:

> *"Applying what you learn to a 'real-life' situation focuses one's mind and gives the learning/research, etc., a full purpose."*

> *"I thought it was a very good way to go, in that we got the benefit of people with much more expertise. Also it was done in a relaxed way, which was good."*

They also had some interesting thoughts on how PBL might be applied more generally in their degree program:

> *"In meteorology, it would be good to have more of this form of teaching."*

> *"To do it justice, it should come at a time where other deadlines are not imminent."*

> *"Maybe with the final project a little more."*

Staff comments highlighted that this approach was only really successful with outgoing and able students (a comparison between the two cohorts participating in the observing system activity was quite revealing). The second cohort, which was generally of higher background ability, engaged fully with the exercise, were more content with its learning objectives, and had overall better performance.

CONCLUSIONS AND DISCUSSION

In conclusion, the test implementation of PBL approaches in meteorology have proven to be very successful and have provided useful new content for an existing course in an innovative style unfamiliar to students. In general, students enjoyed the freedom given to them by this approach and felt that it was a reasonably faithful simulation of a real-world activity, thereby improving their motivation for the task in question.

We plan to continue the experiment in future years and to seek to refine the methodology used to improve its implementation. One idea for the ozonesonde activity would be to switch the science experiment in question to one with more potential outcomes and experimental strategies to improve the diversity of student responses and observed features. Nonetheless, clearly the PBL methodology has an important part to play in the module, coupled with other teaching approaches.

More generally, it is clear there is a role for PBL teaching within meteorology as a complement to existing teaching styles. It would be difficult, however, to advocate moving to a whole curriculum PBL or IBL style for meteorology teaching in higher education, as is done in some disciplines and institutions (particularly in the medical sciences). Since meteorology represents somewhat of a departure for most students from their previous background knowledge and general approach to learning, a full PBL curriculum would not be able to provide the required breadth and depth of material that students require, particularly in their first two years of higher education.

The experience of implementing PBL in a meteorological context emphasizes that the key gain is in the real-world simulation aspect and its effect on student motivation. Successful implementation of a PBL activity within meteorology would require careful thinking about the kinds of activities that could be introduced if students had significant training and maturity to deal with this type of learning. and the production of carefully designed resources that provided adequate (but not too comprehensive) background material for the students. As was evident from staff responses, there is also a clear need to educate staff involved in the activity about the limits and purpose of their role in the activity, and the module convener should consider how best to do this in conjunction with designing the activity.

There are some clear benefits to limited PBL teaching that could be incorporated into other parts of the meteorology curriculum. For most meteorology programs, there are a few obvious candidates for small tests of PBL to see if the lessons learned in this project transfer to other study topics. In particular, topics with a strong public policy impact, such as climate change, could benefit from PBL activities that simulate the real-world questions asked of scientists by governments and large corporations. Additionally, in many institutions, final-year students complete a fairly traditional honors project with project topics and resources supplied by members of academic staff. Incorporating a PBL design and some element of peer review may better prepare students for the workplace in both academic and nonacademic environments by providing a simulation of the practice of real-world scientific research.

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