# Problem-based learning approaches in meteorology

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1 **Problem Based Learning approaches in Meteorology**

2 **Abstract**

3 Problem Based Learning, despite recent controversies about its effectiveness, is used

4 extensively as a teaching method throughout higher education. In Meteorology, there has

5 been little attempt to incorporate Problem Based Learning techniques into the curriculum.

6 Motivated by a desire to enhance the reflective engagement of students within a current

7 field course module, this project describes the implementation of two test Problem Based

8 Learning activities and testing and improvement using several different and

9 complementary means of evaluation. By the end of a two-year program of design,

10 implementation, testing and reflection/re-evaluation two robust, engaging activities have

11 been developed which provide an enhanced and diverse learning environment on the field

12 course. The results suggest that Problem Based Learning techniques would be a useful

13 addition to the Meteorology curriculum and suggestions for courses and activities which

14 may benefit from this approach are included in the conclusions.

15 1. **Introducing the problem and existing course design**

16 This study assesses both the feasibility and usefulness of Problem Based Learning (PBL)

17 approaches in Meteorology teaching. It aims to discover, by means of a controlled and

18 evaluated test implementation, if PBL could play a role in Meteorology teaching at

19 undergraduate and masters level in UK Universities. Two new PBL activities are

20 introduced to an existing fieldwork based Meteorology module. The activities are both

21 designed in line with best practice guidelines for PBL but are designed to be sufficiently

22 different that conclusions about the overall suitability of PBL for Meteorological teaching

23 can be drawn. The success of the new activities is evaluated using a combination of

24 student feedback, peer observation, analysis of resulting student outputs and personal

25 reflection.

26 1.1 The problem - passive engagement of students

27 Meteorology as a subject has a strong practical, experimental component. Teaching

28 students how to make effective measurements and how to use the data collected

29 appropriately is a key part of the undergraduate curriculum, which also provides a strong

30 transferable skill. Although a large element of practical work is included in the University of

31 Reading's Meteorology and Climate BSc and MMet programs, in its current form much of

32 this teaching follows a relatively traditional model of several self-contained experiments

33 with well defined expected outcomes known by staff prior to students conducting the

34 experiments. While this approach has value, it fails to allow students to address key

35 components of the most widely held view of experiential learning, the Kolb learning cycle

36 (Kolb, 1984).

37 [Figure 1 about here]

38 *1.2 A possible solution - Problem Based Learning*

39  PBL is an approach to teaching and learning that forms part of a broader spectrum of

40  techniques known as inquiry based learning. Inquiry based learning can be broadly

41  defined to have the following characteristics (Kahn and O'Rouke, 2004)

42  • Engagement with a complex situation or scenario that is sufficiently open ended to allow

43  a variety of responses or solutions

44  • Students direct the lines of inquiry and the methods employed

45  • The inquiry requires students to draw on existing knowledge and to identify their required

46  learning needs

47  • Tasks stimulate curiosity in the students, encouraging them to actively explore and seek

48  out new evidence

49  • Responsibility falls to the student for analyzing and presenting that evidence in

50  appropriate ways and in support of their own response to the problem.

51  PBL in particular involves students addressing a problem in a small group and defining the

52  further knowledge and investigation that they require to solve the problem. In many ways

53  PBL is as much about identifying the key unknowns in a problem and appropriate ways to

54  tackle these problems as it is about solving the problem at hand. The PBL approach to

55  learning does not require students to have mastered a body of knowledge before the

56  completion of a project (as in a typical undergraduate or masters dissertation) but allows

57  the understanding of the student and their ability to solve the problem to evolve together.

58  *1.2.1 Broad advantages and disadvantages*

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

60  teaching style particularly associated with student motivation and engagement and

61  employability. As they identify "...the modern "knowledge economy" places a premium on

62  the ability to create relevant knowledge that helps to solve specific problems..."

63  PBL provides a way of encouraging students to participate in constructive, experiential

64  learning, as in the Kolb learning cycle (Fig. 1). This happens by encouraging students to

65    engage in active experimentation to test their ideas and then use their experience of the

66    outcomes of their experimentation to reflect on their grasp of the knowledge at hand. This

67    reflective element is particularly important and can be enhanced in the PBL model by the

68    chance for students to contrast their own performance and knowledge with that of their

69    peers.

70    Despite these widely accepted benefits of PBL in the educational literature, there is current

71    controversy over the effectiveness of minimally guided techniques in general. This

72    controversy links to the paper of Kirschner, Sweller and Clark (2006, KSC06) who make

73    the case that minimally directed techniques are incompatible with our knowledge of human

74    cognitive architecture (in particular the Atkinson and Shiffrin (1968) sensory memory–

75    working memory–long-term memory model). KSC06 argue that since the capacity of

76    working memory is limited, placing heavy demands on it by requiring problem-based

77    searching should be avoided. KSC06 also state that numerous studies have suggested

78    that a more directed learning approach, particularly incorporating numerous 'worked-

79    examples' is a more efficient use of novice and intermediate learner's cognitive resources.

80    Several responses to KSC06 exist in the literature (Schmidt et al. (2007), Hmelo-Silver et

81    al. (2007), Kuhn (2007)) along with a commentary on these responses by the original

82    authors of KSC06 (Sweller et al. (2007)). Common to this discussion is the idea that PBL

83    techniques without any guidance are inferior to those with some strong scaffolding

84    provided by the course leader. They also agree that much more careful research with

85    properly controlled experiments is required to fully assess the advantages and

86    disadvantages of different educational techniques.

87    In practical terms, much of the discussion of the advantages and disadvantages of

88    minimally guided techniques is focused on rather fundamentalist positions of fully guided

89    or fully unguided teaching. In reality, any implementation of PBL in Meteorology is likely to

90    exist somewhere between these extremes with some guidance provided by course tutors.

91  It should also be recognized, however, that PBL techniques may be more appropriate for

92  intermediate and advanced learners and hence for courses at the end of undergraduate

93  programs and at masters level. The reason for this is two-fold. Firstly, to be delivered in a

94  time-efficient manner PBL requires students to have a relatively mature set of study skills

95  (which they develop during the early undergraduate years). Secondly, PBL in Meteorology

96  requires students to have a firm background in the physics and chemistry of the

97  atmosphere so that they can ask and answer questions appropriate to problem at hand.

98  Despite the controversy about PBL techniques in the literature it seems appropriate to

99  investigate their usefulness in the Meteorological context, provided that this is within a

100  course with a range of different instructional techniques including directed learning. In this

101  way PBL techniques can be evaluated but at low potential detriment to students involved

102  in the course if they prove to be of limited value.

103  *1.2.2 Implementation in higher education and in Meteorology*

104  Various reviews of the implementation of PBL approaches in higher education exist in the

105  literature (e.g. Boud and Feletti, 1997, Savin-Baden 2000). Even a cursory glance at these

106  texts reveals three things about the implementation of PBL in higher education:

107  • PBL has been used to refer to a broad range of educational activities from the design of

108  an individual element of a problem class to the design of a full three-year curriculum.

109  • The implementation of PBL varies greatly between different subjects. Those with a strong

110  element of practical problem solving (e.g. Medicine and Law) have been by far the most

111  enthusiastic adopters of PBL.

112  • A barrier to the implementation of PBL more widely is the lack of understanding amongst

113  academic staff on their role within a PBL exercise.

114  There has been little implementation of PBL techniques in Meteorology or in related Earth

115  and Environmental science fields. Some literature on the implementation of PBL in GEES

116  subjects is available in a special edition of Planet

117 ([http://www.gees.ac.uk/planet/index.htm#](http://www.gees.ac.uk/planet/index.htm#)). Of the articles in this issue, the most relevant is

118 that which describes the implementation of PBL on a field course module by Perkins et al.

119 A particularly interesting aspect of this article is the adoption of the 'Seven-Jump'

120 Maastricht model for PBL tutorials (Gijselaers, 1995). This provides a framework model for

121 tutorial structure for PBL activities that is adopted in the two new activities introduced in

122 section 3 (with some modification for activities which take place entirely on Arran). This

123 model characterizes PBL learning as a series of seven 'jumps':

124 [Table 1 about here]

125 Perkins et al. report that PBL had a generally positive impact on the field activities and was

126 equally at home in 'hard-science' subjects (although as above, clear tutor guidance was a

127 key factor in its success). One major difference between our own field course and that of

128 Perkins et al. is the length of preparatory time, which is long (16 hours) in the case of

129 Perkins et al. and relatively short in our case (1 hour). Although the short preparatory time

130 was necessary in our case because the course is shared between two Universities with no

131 chance to arrange preparatory classes, this should note be viewed as a disadvantage. In

132 fact the time-limited nature of the preparatory work is in many ways a more faithful

133 simulation of real meteorological field work where planning of experiments is often done at

134 short-notice because of experimental and operational constraints.

135 *1.3 Test module - Atmospheric Science field course*

136 The module chosen to test the implementation of PBL approaches in Meteorology is an

137 atmospheric science field course jointly taught with colleagues from the University of

138 Leeds. The course is residential and takes place over 8 days based at a field centre on the

139 Isle of Arran. Typically there are around 35 students on the course, split 50:50 between

140 students from Reading and Leeds. The course is offered at both third year undergraduate

141 and masters level. The background of students on the course is diverse; with a wide range

142 of mathematical skill in particular a major challenge. Activities on the course are primarily

143    field based and include an all day hike to the top of Goat Fell (~850m) taking

144    measurements on the way. The traditional approach to practical experimental learning

145    adopted in Meteorology incorporates only the active experimentation and concrete

146    experience stages of the Kolb learning cycle. On this field course, students have the

147    opportunity to participate in several different experiments at once, allowing them the

148    opportunity to try to piece abstract concepts about the atmosphere together. However, a

149    remaining problem on the course is that all the experiments have been designed by the

150    staff participating to have relatively simple outcomes, known at the outset by staff (and

151    sometimes students). Therefore, the reflective observation link in the Kolb learning cycle

152    chain is often opaque or broken, making it difficult for the students to move to higher-level

153    abstract conceptualization.

154    1.4 Assessment of current course design

155    To fully examine the current structure of the course and the way that its current structure

156    maps to the Kolb learning cycle a course map (Conole, 2010) was completed. Mapping the

157    course in this way provides a concise summary of its current state and highlights the

158    issues discussed in the previous section. Since the test module is made up of a series of

159    discrete activities, it has also been possible to map these activities to the Kolb learning

160    cycle. A video diary describing the initial mapping of the course and the problem at hand

161    can be found at: http://cloudworks.ac.uk/cloud/view/3813. By mapping the course

162    additional issues associated with the course were highlighted or emphasized:

163    • The lack of opportunity for reflection in the course is clear, only one of the seven

164    activities provides a way for students to examine their own work or put it in the context of

165    others work. As a consequence many of the activities 'short-circuit' the Kolb learning cycle.

166    • Along with this lack of reflective elements, no opportunity is provided to the students for

167    formative feedback on their work. While the high staff-student ratio on the course does

168    allow staff to informally have a dialogue with students to improve their understanding,

169 there is no way for students to gain feedback on their written work, which is in some ways

170 a more concrete demonstration of their understanding.

171 **2. Test changes to module**

172 *2.1 Two new PBL elements*

173 With the key messages of the proceeding literature in mind, two similar but different PBL

174 approaches were introduced into the atmospheric science field course module. The first of

175 these PBL activities involved students on both the BSc and MMet programs and students

176 from our partner the University of Leeds. It focused on trying to address issues of missing

177 stages in the Kolb learning cycle outlined above. The second activity involved only

178 University of Reading students on the MMet program and was completed over a longer

179 period upon return to Reading. The aim of this activity was to provide a second M-level

180 route to obtaining appropriate professional skills in environmental monitoring. Example

181 course materials for each of the new activities are provided on-line at:

182 http://www.met.reading.ac.uk/~sws05ajc/teaching/pbl.html

183 *2.2 PBL Activity I - Ozonesonde launch*

184 This activity involved the design of an experiment to launch an ozonesonde, a piece of

185 equipment attached to a weather balloon, which measures ozone concentrations

186 throughout the atmosphere. Students were already part of mixed University of

187 Reading/University of Leeds teams for other activities. The students were told that there

188 were only enough resources to launch a single ozonesonde and that they should design

189 an experiment to maximize the benefit of observations from a single launch.

190 The activity proceeded as follows:

191 • The activity was introduced in a short lecture and through course documents. Some

192 information about ozone in the atmosphere was given along with some technical details

193 about the equipment available for use.

194    • Students discussed how and when to launch the ozonesonde in their teams. They had

195    access both to staff (as facilitators) and forecast information about future weather

196    conditions to determine when an interesting time to launch would be (*initial abstract*

197    *conceptualization phase).*

198    • Students were asked to write a short work plan for the launch. The work plan was

199    requested to be in the form of a mock grant proposal to a fictional funding agency so that

200    the process provided as close a simulation of real scientific practice as possible. The

201    proposals were then presented to a steering committee of staff that assessed which of the

202    proposals to take forward (*active experimentation phase).*

203    • The ozonesonde was launched according to the instructions of the successful bid and

204    data provided to all of the groups to analyze. *(second part active experimentation phase).*

205    • Following the launch students analyzed **both** the data produced by the experiment and

206    also the differences between the winning bid and their own. They were asked to comment

207    on the differences between their bid and the winning bid and identify any deficiencies of

208    either bid based on the results of the experiment. This part required the students to enter

209    the reflective phase, based on the experimental design and to build this reflection back into

210    their original abstract conceptualization.

211    *2.3 PBL Activity II - Climate monitoring station design*

212    This activity took place following the return of students on the MMet program from Arran

213    and continued throughout the following autumn term. Students were given the problem of

214    designing a new climate monitoring station for Arran based both on their experience of the

215    field course location and meteorology and further original research from existing literature.

216    The module convener and two members of research staff facilitated the activity in three

217    one-hour discussion sessions. Students were asked to produce a 15-page design

218    specification for the climate monitoring station detailing equipment used, fit to national and

219    international monitoring priorities and operating procedure. The first task for the students

220   was to decide on the priorities for the climate monitoring based on their own analysis of the

221   literature and discussion in a group forum. The activity specifically targets the reflective

222   observation and abstract conceptualization elements of the Kolb learning cycle, whilst

223   using the observational experience gained on Arran as the active experimentation and

224   concrete experience phases. The final assessment of the design specification emphasized

225   these aspects.

226   **3. Method of implementation and assessment**

227   Design of the new PBL methods took place during academic year 2008/9 and was

228   introduced into the course in Autumn 2009. A second test implementation was then

229   repeated with some modification in Autumn 2010.

230   *3.1 Evaluation methods*

231   With any new teaching and learning activity a crucial part of its successful introduction is a

232   robust evaluation (Fry, Ketteridge and Marshall, 2008). Project evaluation was conducted

233   using a range of techniques including student feedback, peer observation, analysis of

234   resulting student outputs and personal reflection. Student feedback was obtained through

235   a carefully designed diagnostic questionnaire (Gibbs, Habeshaw and Habeshaw, 1988)

236   that specifically explored the distinctions between the PBL approach and more traditional

237   approaches used for the majority of the field course. A similar diagnostic questionnaire

238   was applied to both activities and some questions were added to the questionnaire for

239   activity II to explore the differences between the two activities. Peer observation from other

240   staff was easily implemented since both activities took place within a staff intensive

241   environment. Feedback was obtained through a separate diagnostic questionnaire and

242   through unstructured interviews with colleagues. Again the emphasis was on which

243   aspects of the PBL approach work well within a meteorological context. The interviews

244   were used to check that answers to the questionnaires were truly diagnostic, providing an

245   independent check of the methodology. The third stream of evaluation was through

246 examination of student outputs for each activity and personal reflection from this

247 perspective. It was clear that the reflective element of the activities was well incorporated

248 since all students provided some reflection on their own and others work.

249 **4. Results from implementation in 2009**

250 The two activities were first implemented as part of the course during academic year

251 2009/10. The course took place between 4th and 11th September on the Isle of Arran. 32

252 students took part in the course, 16 from Reading and 16 from Leeds. Of those students, 3

253 from Reading took the course at the masters level and also participated in the observing

254 system design activity during the autumn term 2009/10. The average mark for the course

255 overall was 63% with a standard deviation of 5%. The ozonesonde activity had an average

256 mark of 64% with a standard deviation of 10%. The observing system design activity had

257 an average mark of 62% (no standard deviation is recorded since only three students

258 participated). Raw results of the questionnaire are presented in Table 2.

259 [Table 2 about here]

260 *4.1 Reflection on student feedback*

261 In general both activities were well received by the students who assessed generally high

262 grades in most categories. The questions can be usefully divided up into four broad

263 categories on which to assess the success of the PBL implementation. The first set of

264 questions assessed how well the activity was structured and communicated to students.

265 Clearly the small group of students who took part in the observing system activity did not

266 fully understand their task and this might have reduced their motivation in taking part.

267 There was an interesting discrepancy between the perception of the ozonesonde activity

268 as a good simulation of a real world task between the students (who generally thought it

269 was) and the staff (who had a mixed reaction). This was a positive outcome since it

270 suggested that the task was simpler than a complex real-world grant proposal but that this

271 did not detract from its appeal to the students. In all activities both staff and students

272 judged the students to engage well with the reflective part of the activity that is a key part

273 of the Kolb cycle and crucial to this new activity. Interestingly, the extent to which the

274 students and staff believed that the reflection helped the students improve their

275 understanding was more mixed.

276 The second set of questions considered how students gained the required information for

277 the task. Answers showed the expected split between the two activities, students taking

278 part in the ozonesonde activity obtained most of the required information in written form

279 while students taking part in the observing system activity conducted their own research

280 and engaged with staff. When assessing how staff were used, students were generally

281 more pessimistic about their own input and claimed staff influenced both their subject

282 specific and generic skills more than the staff perceive. This is perhaps to be expected, but

283 it was important for the success of the activity that the students believed that their input

284 and decisions influenced the direction of both projects. The results identified that it should

285 be emphasized to staff that they act as facilitators of the discussion since part of the PBL

286 learning process is shaping and refining the problem at hand.

287 The third set of questions deals with the assessment of the activity upon completion by

288 both groups. As mentioned above, both staff and students were somewhat mixed in their

289 assessment of the utility of the reflective elements of the activities. Interestingly, students

290 believed that the comparison with other groups was a very helpful part of the ozonesonde

291 activity, whereas staff were more circumspect. In general the projects scored well amongst

292 all groups in their ability to improve both generic and specific skills.

293 Finally, the group of students who participated in both the ozonesonde and observing

294 system activities were asked to compare them. Interestingly for broader applications of

295 PBL there was a clear preference for the time-limited ozonesonde activity and the focus

296 that this brought to discussion. However in general the students believed the observing

297  system activity to be at a higher educational level, which again fits well with the course

298  design.

299  Participants were also asked to make specific and general comments on the activities.

300  Few comments were received, but some of the most interesting were:

301  Student

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

303  mark in this."

304  "Good but should only be done sometimes."

305  "Encourages time keeping."

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

307  "I prefer more lecture based teaching, not a fan of large research projects stuff. It is

308  important it is more real-world, but 40% is still too heavy a weighting."

309  "Initial knowledge of the area needs to be taught first to better be able to do these

310  activities, but it challenges you to think about stuff in a more realistic context which is

311  good."

312  "It encourages you to think for yourself more. Although I didn't like it to begin with it has

313  taught me a lot."

314  Staff

315  "Encourages vibrant interaction between staff/student so that ideas are created and

316  developed quickly. Allowed for quickly working through problems and assimilation of

317  scientific knowledge."

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

319  "You cover a lot less content but it may be more effective and the student learns a lot more

320  from it by making mistakes and learning/developing things by himself. Combined with

321  traditional approaches to teach the basics I think it is highly useful."

322  *4.2 Unstructured interviews with colleagues*

323  Informal consultation with colleagues revealed that both activities had been well received

324  in the first instance and had enabled students to be more actively engaged in their learning

325  and to explore different facets of both problems than they might otherwise have done. The

326  major discussion point for the ozonesonde activity was the lack of training of staff both for

327  the PBL process and in the specifics of the activity itself. There was particular concern

328  about the role that the reflective activity should play. The major discussion point for the

329  observing system activity was the lack of engagement between students and staff

330  members outside contact hours. Both staff members felt that the students were disinclined

331  to ask for help and expertise even though this was explicitly offered.

332  *4.3 Consistency of evaluation using all three evaluation methods*

333  A coherent picture of the successes and failures of the activities in their first

334  implementation arose from consideration of all three methods of evaluation. In general,

335  staff and students found the activity to be worthwhile and both in the questionnaire

336  evaluation and the informal interviews thought that the PBL approach promoted active

337  engagement amongst the students. Evaluation of student work, informal staff interviews

338  and the questionnaire responses highlighted the problems in the introduction of the

339  reflective elements, particularly in relation to the way in which staff participated in the

340  activity. There were however, some elements in which the different evaluation techniques

341  give different pictures of the activities. Although the survey results suggested students

342  didn't fully understand the purpose of the observing system activity the student outputs

343  (both in terms of a qualitative or quantitative evaluation) did not suggest that they

344  performed any better or worse than in the ozonesonde activity or in the course in general.

345  *4.4 Changes made to activities*

346  Identified actions to improve the activity for 2010 were:

347  • Improving the documentation and introduction of the observing system task for 2010.

348 • Re-considering the reflective part of the ozonesonde activity to ensure it boosts student

349 understanding.

350 • Re-iterating to staff that their role should be advisory only

351 • Adding informal contact periods ('office hours') to the observing system activity to

352 encourage informal contact between staff and students.

353 These actions were undertaken during academic year 2010 and modified activities were

354 introduced into the course in September 2010.

355 **5. Results from implementation in 2010**

356 The second implementation of the two activities occurred as part of the course during

357 academic year 2010/11. The course took place between 5th and 12th September on the

358 Isle of Arran. 35 students took part in the course, 12 from Reading and 17 from Leeds. Of

359 those students, 5 from Reading took the course at the masters level and also participated

360 in the observing system design activity during the following autumn term. The average

361 mark for the course overall was 61% with a standard deviation of 4%. The ozonesonde

362 activity had an average mark of 56% with a standard deviation of 4%. It should be noted

363 that a different academic colleague at Leeds was responsible for marking the ozonesonde

364 activity in each year of the course. While every effort is made to standardize marking,

365 experience in previous years shows that the lower mark in the 2010 implementation is

366 partly related to this change in marker. The observing system design activity had an

367 average mark of 65% with a standard deviation of 7%.

368 *5.1 Reflection on improvement to PBL activities in second year of implementation*

369 [Table 3 about here]

370 Results from the evaluation of the PBL activity in the second year of implementation were

371 extremely positive. In most cases where the evaluation of the 2009 module revealed that

372 the activity had been successful this positive result was maintained. In the areas where the

373     2009 evaluation identified improvements could be made the changes made to the PBL

374     procedure generally improved both student and staff evaluations, specifically:

375     • The improved documentation and introductory lectures incorporated into the observing

376     system activity significantly improved scores in the first part of the survey, particularly for

377     students showing that they understood the task better, were able to quickly focus on the

378     task at hand, that they felt that the task was a reasonable simulation of a real-world activity

379     and that they engaged strongly with the reflective activity.

380     • The improved oral description and staff training for the reflective part of the ozonesonde

381     activity significantly improved the scores of both staff and students in this part of the

382     survey. Particularly interesting was the gain in the mark for subject specific skills for both

383     staff and students.

384     Another interesting result of the second evaluation, perhaps related to the small sample

385     size and variation between student groups was the lack of preference for the time

386     constrained, ozonesonde activity in the 2010 cohort. While there was a strong preference

387     for this activity in the 2009 cohort, the 2010 cohort was enthusiastic about the observing

388     system activity, but expressed no clear preference for this PBL style as opposed to the

389     more limited, focused ozonesonde activity.

390     The 2010 control cohort who participated in both PBL activities also produced a number of

391     interesting comments and suggestions on PBL in general:

392     "...applying what you learn to a 'real-life' situation focuses one's mind and gives the

393     learning/research , etc., a full purpose..."

394     "I thought it was a very good way to go, in that we got the benefit of people which much

395     more expertise. Also it was done in a relaxed way which was good."

396     They also had some interesting thoughts on how PBL might be applied more generally in

397     their degree program:

398     "In Meteorology, it would be good to have more of this form of teaching..."

399 "...to do it justice, it should come at a time where other deadlines are not imminent."

400 "Maybe with the final project a little more."

401 Staff comments highlighted that this approach was only really successful with outgoing

402 and able students (a comparison between the two cohorts participating in the observing

403 system activity was quite revealing). The second cohort, which was generally of higher

404 background ability engaged fully with the exercise and were more content with its learning

405 objectives and had overall better performance.

406 **6. Conclusions and discussion**

407 In conclusion, the test implementation of PBL approaches in Meteorology have proved to

408 be very successful and have provided useful new content for an existing course in an

409 innovative style unfamiliar to students. In general, students enjoyed the freedom given to

410 them by this approach and felt that it was a reasonably faithful simulation of a real-world

411 activity thereby improving their motivation for the task in question.

412 We plan to continue the experiment in future years and to seek to refine the methodology

413 used to improve its implementation. One idea for the ozonesonde activity would be to

414 switch the science experiment in question to one with more potential outcomes and

415 experimental strategies to improve the diversity of student responses and observed

416 features. Nonetheless, clearly the PBL methodology has an important part to play in the

417 module, coupled with other teaching approaches.

418 More generally, it is clear there is a role for PBL teaching within Meteorology as a

419 complement to existing teaching styles. It would be difficult, however, to advocate moving

420 to a whole curriculum PBL or EBL style for Meteorology teaching in higher education as is

421 done in some disciplines and institutions (particularly in the medical sciences). Since

422 Meteorology represents somewhat of a departure for most students from their previous

423 background knowledge and general approach to learning, a full PBL curriculum would not

424    be able to provide the required breadth and depth of material that students require,

425    particularly in their first two years of higher education.

426    The experience of implementing PBL in a Meteorological context emphasizes that the key

427    gain is in the real-world simulation aspect and its affect on student motivation. Successful

428    implementation of a PBL activity within Meteorology would require careful thinking about

429    the kind of activity that could be introduced, if students had significant training and maturity

430    to deal with this kind of learning and the production of carefully design resources that

431    provided adequate but not too comprehensive background material for the students. As

432    was evident from staff responses, there is also a clear need to educate staff involved in the

433    activity about the limits and purpose of their role in the activity and the module convener

434    should consider how best to do this in conjunction with designing the activity.

435    There are some clear benefits to a limited amount of PBL teaching that could be

436    incorporated into other parts of the Meteorology curriculum. For most Meteorology

437    programs, there are a few obvious candidates for small tests of PBL to see if the lessons

438    learnt in this project transfer to other study topics. In particular, topics with a strong public

439    policy impact such as climate change could benefit from PBL activities that simulate the

440    real-world questions asked of scientists by governments and large corporations.

441    Additionally, in many institutions final year students complete a fairly traditional honors

442    project with project topics and resources supplied by members of academic staff.

443    Incorporating a PBL design and some element of peer-review may better prepare students

444    for the workplace in both academic and non-academic environments by providing a

445    simulation of the practice of real-world scientific research.

446    **Acknowledgements**

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**Figure Captions**

**Figure 1:** Kolb learning cycle after Kolb (1984)

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510

| Jump | | |
| --- | --- | --- |
| **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 |

511     **Table 1:** Maastricht model of PBL tutorials (after Gijselaers, 1995).

512

CRITERIA

| CRITERIA | OZONE STUDENTS | OZONE STAFF | OBS. SYS. STUDENTS | OBS. SYS 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 information required 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 | 1.0 |
| 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 |

| CRITERIA | OZONE STUDENTS | OZONE STAFF | OBS. SYS. STUDENTS | OBS. SYS STAFF |
|---|---|---|---|---|
| Did you prefer the time constraint in the $O_3$ activity to the open-ended Obs. Sys. activity? | N/A | N/A | 3.0 | N/A |
| Did you prefer working on your own in the Obs. Sys. activity rather than in a team in the $O_3$ activity? | N/A | N/A | 5.0 | N/A |
| The Obs. Sys. Activity improved my subject specific knowledge more than the $O_3$ activity? | N/A | N/A | 4.0 | N/A |
| The Obs. Sys. Activity was at a higher educational level than the $O_3$ activity? | N/A | N/A | 2.0 | N/A |

514 **Table 2:** Results of student survey of PBL activities following implementation in year 1

515 (2009). Marks are awarded by participants on a scale of 1-10 with 1 being the highest

516 mark. N/A means a question was not asked to gain this information. Statistics are based

517 on 18 student surveys and 4 staff surveys for the ozonesonde activity and 3 student

518 surveys and 2 staff surveys for the observing system activity.

519

| CRITERIA | OZONE STUDENTS | OZONE STAFF | OBS. SYS. STUDENTS | OBS. SYS 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 information required 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 | 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 |

| CRITERIA | OZONE STUDENTS | OZONE STAFF | OBS. SYS. STUDENTS | OBS. SYS STAFF |
|---|---|---|---|---|
| Did you prefer the time constraint in the $O_3$ activity to the open-ended Obs. Sys. activity? | N/A | N/A | 6.8 | N/A |
| Did you prefer working on your own in the Obs. Sys. activity rather than in a team in the $O_3$ activity? | N/A | N/A | 3.6 | N/A |
| The Obs. Sys. Activity improved my subject specific knowledge more than the $O_3$ activity? | N/A | N/A | 3.4 | N/A |
| The Obs. Sys. Activity was at a higher educational level than the $O_3$ activity? | N/A | N/A | 3.6 | N/A |

521 **Table 3:** Results of student survey of PBL activities following implementation in year 1

522 (2010). Marks are awarded by participants on a scale of 1-10 with 1 being the highest

523 mark. N/A means a question was not asked to gain this information. Statistics are based

524 on 21 student surveys and 3 staff surveys for the ozonesonde activity and 5 student

525 surveys and 2 staff surveys for the observing system activity.

526

Concrete experience

Reflective observation

Abstract conceptualization

Active experimentation