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Using student experience of problem-based learning in virtual space to drive Engineering educational pedagogy

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***Abstract:** This paper reports outcomes of an investigation into the different ways students' go about problem-based learning (PBL) in virtual space. Five qualitatively different conceptions of PBL in virtual space were discovered, and each reveals variation in how students attend to learning by PBL in virtual space. Results indicate that PBL in virtual space when appropriately designed with respect to students' online learning experience can: 1) be responsible for making students aware of deeper ways of experiencing PBL in virtual space, and 2), engender graduate attributes and capabilities of problem solving, ability to transfer basic knowledge to real-life scenarios, ability to adapt to changes and apply knowledge in unusual situations, ability to think critically and creatively, and a commitment to continuous life-long learning and self-improvement.*

Introduction

This paper reports outcomes of an investigation into variations in students' experience of problem-based learning (PBL) in virtual space, and demonstrates how this knowledge can be used to influence pedagogy.

Why do this study?

Over a decade ago an Organisation for Economic Co-operation and Development (OECD) report (1996, p. 84) recognized that knowledge-based economies were an important emerging force in the economic and political world at that time. Since then, knowledge economies have become a dominant issue for administrators (Bullen, Fahey, & Kenway, 2006) in countries that rely on knowledge, information, and technology for investment dollars. In many of these countries economic policy is intrinsically linked to higher education because this is seen as a vehicle for promoting employment and economic development (Burbules, 2000). Educators, particularly in higher education, need to align their activities with requirements of the knowledge age.

Early career professionals in today's global market can expect to make several job changes (Polanco, Calderón, & Delgado, 2004) and may even move into job fields that are unrelated to their formal qualifications (Siemens, 2005).

As a consequence, higher education is now required to prepare graduates who: can operate in a wide range of knowledge areas (Polanco et al., 2004); are life-long learners and have well developed personal learning skills (Polanco et al., 2004); are critical thinkers; and are able to contribute significantly to their professions and society. This is especially relevant for engineering professionals since future society will rely on today's engineering graduates to develop and integrate further technological advances. Unfortunately, in recent years, the ability of engineering graduates has been

questioned with most of the criticisms relating to lack of basic mathematical and science reasoning, and low retention of knowledge (Polanco et al., 2004).

As well as these discipline specific skills and competence, it is also important for engineering graduates to acquire a range of generic, or transferable, skills that will allow them to operate effectively in the future professional environment. Unfortunately it has also been recognised that engineering education does not completely address these critical generic skills (National Academy of Engineering, 2004). Deficiencies have been identified in the ability to work in multi-disciplinary teams, the ability to work in a global virtual environment, digital communication skills (Thoben & Schwesig, 2002), ability to transfer basic knowledge to real-life engineering scenarios, ability to adapt to changes and solve problems in unusual situations, ability to think critically and creatively, and a commitment to continuous life-long learning and self-improvement (Ribeiro & Mizukami, 2005). Engineering courses have sometimes failed to provide graduates with the skills and competence that the profession considers necessary to be successful in today's virtual global professional environment (Wellington, Thomas, Powell, & Clarke, 2002).

Educational approaches are required that will address these deficiencies. To address these emerging competence needs, many engineering education providers are turning to problem-based learning (PBL). PBL is an instructional approach that is based on engaging the learner in activities that simulate the demands of real life professional practice. Many engineering education providers are also using the latest communication technology and turning to online or distance education (for example Rovai, 2002, p. 1) in an attempt to develop new markets.

Unfortunately there is only a limited amount of systematic research into what constitutes an effective online learning environment (Reushle, 2005), and few empirical studies of computer-supported collaborative learning in online environments (Wallace, 2003). There is also a dearth of research into what constitutes an effective learning experience for adult learners who undertake PBL instruction in virtual space. The majority of previous studies in engineering PBL have been situated in on-campus environments (some examples are Alocilja, 2007; Boothby & Marra, 2003; Franz, Ferreira, & Thambiratam, 1997; Gabb, Vale, & Krishnan, 2006; Hassan et al., 2004; Polanco et al., 2004; Ribeiro & Mizukami, 2005). A study is needed that will add to the existing body of knowledge on learning and teaching engineering by PBL conducted in the online environment in virtual space.

Aim of this paper

The aim of this paper is to extend existing PBL studies and to report findings of an investigation into how students go about PBL in virtual space in an engineering course in order to best prepare educators and students for the emerging needs in engineering and other professional education in the knowledge society.

What was done

A qualitative study was undertaken in the context of the University of Southern Queensland (USQ) Faculty of Engineering and Surveying (FoES) PBL course, ENG1101. Although this course is delivered in both internal (on-campus) and external (off-campus) modes, it is the external mode that is of relevance to this paper since students studying in this mode do not meet face-to-face and conduct their studies entirely in virtual space. This course reflects current literature in online education and PBL, and represents an opportunity to investigate how students go about PBL in virtual space in an engineering education context.

Method

Phenomenography

The well accepted and documented interpretative qualitative research approach of phenomenography is often used by educational researchers, and was chosen for this investigation. The basic premise is that analysing students' responses to the questions will reveal a '*limited number of qualitatively different ways*' (Marton, 1984, p. 31; Marton & Booth, 1997) of experiencing PBL in virtual space, and that this will be possible even if the differences are grounded in reflective thought and not

necessarily in immediate physical experience (Marton & Booth, 1997; Marton & Pang, 1999; Pang, 2002).

The phenomenographical approach concentrated on developing a representation of the variation in students' interpretations of how they went about PBL in virtual space in the context of the ENG1101 course. In accordance with the '*non-dualistic*' view (Marton & Pang, 1999; Pang, 2002), both the students themselves and their understanding of PBL in virtual space were considered simultaneously during the data analysis. Though the analysis was concerned with discovering the collective, rather than any individual, experience, initially the analysis concentrated on individuals and later moved to considering the collective experience. Data was viewed with different aspects in focus and ultimately preliminary themes began to emerge. Groups of emerging themes with common meaning were then considered as the beginnings draft categories of description. Each category of description represents one way of experiencing PBL in virtual space. The categories differ in the aspects of the experience that were noticed and focused on simultaneously by the students. The process was iterative and involved going back and forth between these emerging categories and the data to check meaning and context. From this process a draft meaning statement was also developed for each category of description.

The analysis process also concerned determining if a logical organised structure existed that would represent the relationship between these emerging categories of description. The process of looking for emerging themes that were relevant to PBL in virtual space, grouping by considering common meaning and differences, reanalysing the data, and looking for structure, involved an iterative process that was very dynamic at first but later stabilised as the process continued. The categories of description, and the structure linking them, became the primary 'outcome space' (Marton, 1981, 1984) from the data analysis.

Individual student responses to the questions were then ranked into the highest possible level of conception from the data collected. This provided total numbers of responses falling into each conception. A comparison between each conception was then made by totalling responses from before the course and those made after the course.

Data

The source of data for this study was text-based responses to four questions before the course and a further four questions after the course, presented on the course learning management system (LMS). Responses were captured and stored as digital text files to reduce cost and the possibility of transcription errors. All students enrolled in ENG1101 were required to answer the questions as part of their individual reflective portfolios that are a requirement of the course, and as such they formed part of the summative assessment. However, students were advised that agreement to have their responses used in the research study was voluntary, did not form part of the formal assessment in the course, and would not impact on their marks or grades in the course.

None of the authors were responsible for facilitating or assessing any work, including responses to questions, from the PBL teams involved in this study. The authors thereby remained neutral and had no influence on student responses.

Context and Participant Profile

Context

The course, ENG1101, is the first of a strand of four consecutive PBL courses and is compulsory for all students in FoES. Students enrolled in ENG1101 may be studying any of the nine majors offered in FoES (agricultural, civil, computing/software, environmental, electrical/electronic, mechanical, mechatronic, surveying, and GIS). At the USQ students may elect to study in the on-campus (internal) or off-campus (distance or external) modes. Approximately 75% of the Faculty's 2,500 students study by distance education, which is carried out entirely online, without face-to-face meetings, and is therefore conducted in virtual space. External students study from various geographic locations around the world, which enriches the learning experience due to the cultural diversity, but also creates its own set of logistical problems (Gibbings & Brodie, 2006, 2008). These problems are further

complicated in ENG1101 by the fact that students in the same PBL teams may be studying at Associate Degree (two year degree), Bachelor of Technology (three year degree), or Bachelor (four year degree) levels.

Participant Profile

Total enrolment in ENG1101 in semester one, 2007 was 308. Of these, 191 were enrolled in the external mode, though responses were analysed only from the 138 external students who answered both the before and after questions and indicated that their responses could be used for the proposed research study. The responses selected for analysis were from both males and females (87% males and 13% females), each of the nine study majors was represented, and responses were received from students of various age groups. Ages ranged from 17 to 58 years with an average age of 28 years.

Results

Outcome Space

Findings are presented as five categories of description that represent the qualitatively different ways of experiencing PBL in virtual space expressed by the students. The outcome space from this study is represented in graphical form in Figure 1. The categories of description reveal that PBL in virtual space may be seen as: 1: 'A necessary evil for program progression'; 2: 'Developing skills to understand, evaluate, and solve technical Engineering and Surveying problems'; 3: 'Developing skills to work effectively in teams in virtual space'; 4: 'A unique approach to learning how to learn'; or 5: 'Enhancing personal growth'. The range of categories represents increasing awareness of certain aspects of PBL in virtual space. Some students may discern only one aspect, others may sequentially become aware of more than one aspect, while others may be simultaneously aware of more than one aspect. This demonstrates that some ways of experiencing are more complex, or richer than others.

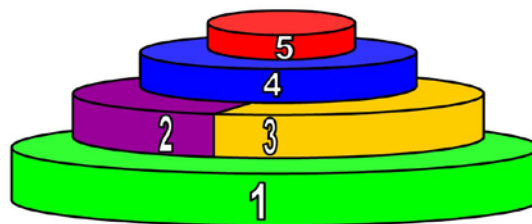


Figure 1 – Graphical representation of expanding awareness associated with categories

Figure 1 symbolises the metaphor of a series of terraces. The higher levels represent higher level awareness, and conceptions at these levels would normally be expected to include those of lower levels. To continue the metaphor, if someone were to ascend the terraces, they would have to transcend the lower levels to get to the top terrace. Levels two and three are considered at the same level, since one can walk around on this terrace level. Level four may include aspects of awareness from category two only, or from category three only, or from both categories two and three. The outcome space therefore also presents the relationship between the different ways of seeing PBL in virtual space.

The variations in meaning of PBL in virtual space are presented in the following referential aspects of each category. The meaning of each category is supplemented with quotations from the student responses.

Category 1: 'A necessary evil for program progression', PBL in virtual space is experienced as completing assessment items to a suitable standard in order to successfully complete the course and progress in academic programs. When going about PBL in this way, students' main motivation is passing the assessments. Students are simultaneously attending to individual and team assessment items, and the operational logistics of preparing and submitting team assessment work.

... all I wanted to aim for was a pass so that I would not have to undertake this course again

Category 2: ‘Developing skills to understand, evaluate, and solve technical Engineering and Surveying problems’, PBL in virtual space is experienced as gaining knowledge and practical skills of a technical nature that may be useful in students’ future professional endeavours. When going about PBL in this way, students are interested in acquiring new, as well as enhancing existing, skills and competence. Students are simultaneously attending to solving technical problems; acquiring new and enhancing existing technical knowledge, skills and competence; and the practical application of these skills in the work environment.

... necessary required skills for me to understand, evaluate and solve the technical problems presented

Category 3: ‘Developing skills to work effectively in teams in virtual space’, PBL in virtual space is experienced as developing skills and knowledge of how to work effectively in virtual teams. When going about PBL in this way, students focus on skills necessary to effectively operate in teams in virtual space. Students are simultaneously attending to team work in general, the practical application of these skills to effectively operating in teams in virtual space, and there is an awareness of the real-life application of these skills.

The predominant areas I have gained knowledge in are leadership, team dynamics and emotional intelligence.

Category 4: ‘A unique approach to learning how to learn’, PBL in virtual space is experienced as learning about, and gaining understanding of, the process of how to learn. When going about PBL in this way, students’ central focus is on processes concerned with their own learning. Students are simultaneously attending to what they are learning as well as external acts and internal (personal) processes relevant to how they are achieving that learning.

I learnt about how i learn

I basically learnt how I learn aswell as how my team mates learn!!

Category 5: ‘Enhancing personal growth’, PBL in virtual space is experienced as providing an opportunity for personal satisfaction, self improvement, and to grow as a person. When going about PBL in this way, students’ focus is on taking the opportunity to reach their full potential and to be the best they can be, which is considered a move towards an instinctual human need for ‘self-actualisation’ (Maslow, 1943). Students are simultaneously attending to: professional careers; their own personal lives; future society and ethical responsibilities to this society.

I have already discovered the benefits of reflection and find it invaluable in my day-to-day living, and I feel that many students will grow as a person through an introduction to the technique

Several aspects demonstrate an expanding awareness across the categories. The completion of the academic program in Category 1 may be considered as seeking some sort of external endorsement, whereas all subsequent categories have more of an internal focus for the students. The virtual space aspect of students’ experience also varies across the five categories:

- In category one there is an understanding that team work in virtual space is necessary to solve the PBL scenarios in order to successfully submit assessments. This is restricted to mechanics of team work and does not extend to how the team operates, nor issues associated with team dynamics.
- In category two this awareness expands to realising the need for better communication with the team in virtual space, since this is a skill that will be useful in future work. Although students are aware of the technical and other skills they have acquired, the ability to communicate effectively in virtual space is considered one of the major achievements from the course.
- In category three the physical separation of the team causes students to consider learning to use the communications and other technologies as an object of study itself and an aid better team work.
- In category four, students understand that the learning in virtual space is quite a different experience from on-campus study, and as external students they also recognise that the PBL course is different from other external courses. PBL in virtual space provides the context that is seen as important for their future professional careers.
- In category five, students have been issued a difficult challenge to study PBL in virtual space and when they successfully achieve this they experience a great sense of accomplishment.

Other aspects that demonstrate expanding awareness across the categories are:

- How students view the use of their time to undertake the course: students in lower categories believe the course takes too much of their time, whereas in higher categories there is an increasing appreciation that the time is a worthwhile investment in their own futures.
- How students use their team with respect to communication, mentoring, critiquing, and evaluation: students in lower categories work as individuals and only use the team to the extent they must to pass assessments, whereas in higher categories the team becomes a critical part of learning with the use of communication, collaboration, mentoring and knowledge building all taking on increasing significance in higher categories.
- how students see and relate to their team in the context of a learning community and how they operate and interact with the team: students in lower categories see themselves as individuals and don't assimilate as being part of the team, whereas in higher categories they take an increasing ownership of the team and genuinely see themselves as part of a cooperative, collaborative team.
- How students use self reflection and feedback: students in lower categories tend not to use reflection and feedback, but these increase through the categories to become important aids to personal learning in categories four and five.

Response Frequency Analysis

The presentation of the response frequency analysis is largely visual since it is concerned with discovering broad obvious trends. The results help to interpret the outcome space with respect to its application in education and team based curriculum.

The inference is drawn that any difference in results from before and after the course was grounded in the learning experience in ENG1101, although it is acknowledged that other life experiences during the same period may also be influential. It is also acknowledged that students after the course may be better able to express themselves and describe their experiences compared to before the course however, this difference in language and jargon usage is accounted for by attention to meaning and context during the data analysis process.

Figure 2 presents a graphical summary of the response frequency and compares the before (pre-course) and after (post-course) groups. Category '2+3' in the figure represents those responses that indicate a simultaneous awareness of core meaning from both categories two and three. These are considered in this way since, as represented in the metaphor of terraces in Figure 1, categories two and three are considered at the same hierarchical level. Students may experience aspects of awareness from category two only, or from category three only, or simultaneously from both categories two and three.

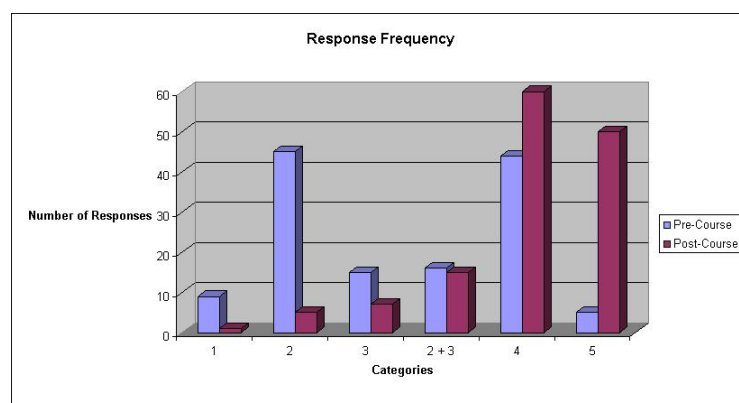


Figure 2 – Pre and post course response frequency

An obvious trend can be seen. Responses from before the course indicate a strong awareness that students expect to learn some technical skills, and also that they expect to be exposed to a learning experience that should provide opportunities for them to discover information about how they learn. This is suggested by the large number of responses in Category two (Developing skills to understand, evaluate, and solve technical Engineering and Surveying problems) and Category four (A unique approach to learning how to learn). In contrast, responses from the after group indicate a significant

shift in awareness towards Categories four (A unique approach to learning how to learn) and five (Enhancing personal growth). This may be viewed as evidence that the design, delivery, and general approach of ENG1101 has ushered students into some deeper ways of experiencing PBL in virtual space.

Discussion and Conclusion

Student Learning

If appropriately designed and delivered, PBL in virtual space can be an effective way to engender necessary discipline and soft or transferable skills in engineering graduates. In this respect, a number of deficiencies in Engineering education identified in the introduction to this paper have been addressed including:

- ability to work in multi-disciplinary teams in a global virtual environment,
- acquisition of digital communication skills,
- the ability to transfer problem solving skills to real-life engineering scenarios, and
- development of a commitment to continuous life-long learning and self-improvement.

From these findings it is logical that the students should be made aware of these different ways of experiencing the PBL in virtual space by designing appropriate activities early in the course. These activities need to be properly integrated into the course and should probably form part of the assessments items such as individual reflective portfolios.

Virtual Learning Aspects

Learning in virtual space provides the context for this research study. Lindsay, Naidu and Good (2007) noted that learning in virtual space is a pedagogically different learning experience. This was highlighted in the referential aspects for each conception, but it is believed that the pedagogy still needs to adhere to proven strategies, and it may be simply the delivery of the course and facilitation that is different. There is not just a physical separation, but a psychological separation as well and this has been shown to affect student learning since it changes the context in which they construct their knowledge (Lindsay et al., 2007). Students see the virtual learning aspect differently in each of the identified conceptions. This ranges from carrying out basic operational aspects of the course that are necessary to pass assessment items in conception one, through seeing effective communication and team work in a virtual learning environment as a transferable skill to be learnt in conceptions two and three, to more complex understanding of the educational and learning opportunities offered in this learning context in category four, and finally to conception five where students experience a deep personal satisfaction from successfully studying in virtual space. Conceptions four and five in particular recognise that virtual learning is different from more traditional face-to-face learning.

Close and Recommendations

This paper reported the findings from a study to identify the qualitatively different ways in which students experience PBL when studying in virtual space so as to inform pedagogy. In light of the preceding findings and discussion, it is recommended that the following elements be considered when designing a PBL course for delivery in virtual space:

- Authentic real-life PBL scenarios are essential as they provide relevance to future professional careers, and engender problem solving skills that arm students with the ability to adapt to changes and solve problems in unusual circumstances.
- Ensure a non-threatening supportive communication environment to encourage the development of team skills and mentoring, to facilitate cooperative and collaborative virtual team work, and to provide a forum for students to explore different perspectives by social interaction in the context of their learning.
- Provide activities, such as analysing and critiquing professional codes of conduct, which will encourage students to appreciate that life-long learning and self-directed learning are necessary ingredients for success in their future professional lives.
- Make students are aware of the different ways of going about PBL in virtual space.

Results from this research contribute to improved design and delivery of the course and most importantly make a significant contribution to existing theory with respect to the emerging problems associated with offering PBL in virtual space. Only once the critical ways that students experience the act of learning by PBL in virtual space have been established, can curriculum design be enhanced to support this learning and to introduce students to more sophisticated ways of learning.

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