Problem Based Learning in the Software Engineering Classroom

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Abstract

Software engineering lecturers are faced with the teaching of concepts which sometimes are not easy for inexperienced students to understand. Therefore, it can be useful to consider and use non-traditional teaching methods which can improve students' learning. In this paper, we discuss problem-based learning and how its use can improve students' understanding of concepts. We present factors which should exist in 'pure' problem-based learning. We then describe how one of the authors used problem-based learning in a class who were required to understand information flows through software engineering diagramming techniques, with the ultimate view to being able to analyse and design computerized information systems. This problem-based learning class was observed and analysed by the second author. The analysis presented focuses on the problem-based learning factors, how they were implemented in class, and the strengths and weaknesses of the use of problem-based learning in this way. In conclusion, the authors discuss how the teaching could be improved through modifying the teaching method for a future class in which problem-based learning will be used. This modification is expected to enhance the students' learning and their experience.

1. Introduction

Problem based learning, or PBL as it is generally known today, evolved from innovative health services curricula introduced in North America over 50 year ago and is the most significant innovation in education for professionals for many years. Some will even dispute that it is the most significant development since the shift of professional training into education [1]. For the education of software engineers it has been recognized that approaches such as problem based learning can help students' development, especially their creative abilities [2], [3]. The fundamental idea behind PBL is that the starting point for learning should be the problem that the learner wishes to solve [4]. PBL is a way of constructing and teaching courses using problems as the motivation and focus for students' activity. Team formation and role distribution are essential to the use of PBL. The Medical faculty at McMaster University in Canada introduced the tutorial process, not only as an explicit instructional method [5] but also as central to their philosophy for structuring an entire curriculum, promoting student-centered multidisciplinary education as a basis for lifelong learning in professional practices. For software engineering, the "challenge is to develop that group of activities that can foster insight – a level of abstract understanding that can apply from situation to situation – rather than emphasizing detailed procedural understanding" [6].

Some key features of the McMaster model are evident in an earlier curriculum reform by medical faculty at Case Western Reserve University in the late 1950's. The McMaster philosophy led to the widespread use of PBL in many professional fields by 1980 [7].

2.1 Components of PBL

In the literature, PBL has been defined and described in a variety of ways. It is used to refer to numerous contextualized approaches to instruction that fastens much of learning and teaching in real problems [8]. This focus on concrete problems as initiating the learning process is vital in most definitions. For example, Barrows and Tamblyn [9] defined the concept of PBL as "the learning that results from the process of working toward the understanding or resolution of a problem". PBL can adopt various forms, depending on the nature of the domain and the specific goals of the programs it belongs to [10], [11]. Savin-Baden [12] argues that there are no closely defined traits of PBL, only people working in a range of contexts using various PBL-approaches. However, despite the many variations of PBL that aim to align it with specific educational or disciplinary contexts, for comparative research a core model or fundamental definition is needed to serve as a basis of comparison with other education methods. Barrows (1996) developed a core model based on the original method from McMaster University, which describes six core characteristics of PBL.

1. Learning is student-centered.

One of the key elements of PBL is that it is student-centered, as they design their learning to meet individual career aspirations and goals. Under tutor guidance, PBL prepares them to become effective and efficient constant learners. Rather than the tutor making judgments about what the student should learn, responsibility is placed on the students' shoulders for their own learning. The tutor designs the problem simulations and guides and directs students in developing their learning.

A criticism of student-centered learning is that students, as novices, cannot be expected to know what learning they need. The literature on novice-expert learning does not entirely argue this fact; rather, it stresses that our students come to us, not as the proverbial clean slates, but as individuals whose prior learning can greatly influence their current learning

2. Learning occurs in small student groups

PBL incorporates mutual learning approaches and uses groups to support motivation for learning. The question must be asked: If small group, self-directed, self-assessed PBL is so great for learning, why isn't everyone doing it? Perhaps it is the fear of the unknown and the lack of resources. The use of PBL requires that teachers change and change is not easy. The PBL learning environment is active, cooperative, provides prompt feedback, and allows opportunities to account for personal learning preferences.

3. A tutor is present as a facilitator or guide

In PBL the tutor's role is to facilitate and to try to bring out the best in the group by helping the students explore the problem, develop their critical thinking and reflect on the experiences they are having. They also support reflection as this improves problem solving and improves the learning [13], [14]. The tutor is not the group's expert resource that will provide the answers nor should the tutor use this as a chance to lecture

4. Authentic problems are presented at the beginning of the learning sequence, before any preparation or study has occurred.

Problem-based learning (PBL) should use real world situations. Problems should be well structured, multifaceted and be presented as they would occur in reality. In the context of PBL, a multifaceted problem is one that is complex which does not have straightforward solutions, and reflects situations that students may find themselves in. Learners use the problem to establish what is known as well as detailing what needs to be known. As students work through these real-life multi-faceted problems, their learning about the topic should increase. They will determine their learning issues, which can then be matched with the learning outcomes.

5. The problems encountered are used as tools to achieve the required knowledge and the problem-solving skills necessary to eventually solve the problems.

As stated earlier, students are expected to work in teams as a basis for PBL. The skills necessary for successful teaming include: consensual decision-making, dialogue, discussion team maintenance, conflict management, and team leadership skills. Graduates who have these skills will have better life-long opportunities. PBL problems should be devised and presented to ensure that students encounter situations where such skills are developed.

6. New information is acquired through self-directed learning

Students are required to identify their own learning needs as well as developing the strategies and skills to meet those needs. The tutor facilitates this learning, but students are also expected to reduce their dependency on the tutor, searching for other sources of information, and consequently, increasing their critical thinking skills. Making the learning processes explicit and teaching and assessing them as part of the course will do this: learning skills will develop over time.

3. The Case Study

Participants on the BSc in Information Systems undergraduate degree course at the University of Limerick (UL), generally commence study at 18 years of age. They have no prior information systems education or work experience. Students attend a 12-week module, Information Flows in Business, in the first semester of second year. Learning outcomes for the module include being aware of information within business firms and being able to design and model information flows in businesses. This requires that they should be able to design typical and improved information flows within a business. These include order processing, inventory, marketing and sales, payroll and personnel. This is a difficult topic for those who do not have prior business experience.

During academic year 2007-2008, the class attending this module consisted of 8 undergraduate students, 5 of whom were studying the B.Sc. in Information Systems. One 3rd year student from the B.Sc. in Applied Mathematics and Computing and two business students who were on Erasmus study from Universities in Sweden and Germany also participated. These three students brought different work experience, age profile and culture to the group and these students also had to be engaged with the topic.

One of the authors, Ita, was the module lecturer. Having previously taught more experienced business and computer systems students modelling techniques, mainly data flow diagrams, entity relationship diagrams, and logical record structure [15], she recognised that this module would be difficult for this class of younger students. Her experience has made her aware that "the education of software engineers is faced with many challenges" - including that curriculum guidance will tell us what to deliver, they do not tell us how to deliver [16]. Furthermore, she felt that the varied background of students should be leveraged. Therefore, Ita took the step of implementing problem-based learning into the class. Three relevant problems were devised and each problem was implemented in 4 1-hour sessions. These were supplemented with lectures, which were typically held after the problem was completed. These lectures presented and discussed the concepts developed during PBL sessions.

Yvonne, also an author of this paper, has been conducting research into PBL. She worked with Ita during class time to support its implementation. While students were working on the first problem, Yvonne attended the sessions and discussed with Ita how the sessions should be conducted. During the second problem, Yvonne attended the sessions and observed what was happening. Ita worked with the students alone when they implemented the third problem.

3.1 Problems presented

The problems were posed at a high level, and students had to take these problems to develop detailed diagrams showing information flows and entities about with the business should be concerned when computerizing such a system. The problems were:

- You are required by a local bicycle repair shop to design a Computerized Information System for their use. The bicycle shop will sell and repair bicycles.
- You are required to diagram the information flows and entity relationships as part of the development of a database system in a hospital.
- You have been asked to draw up a list of the information systems needed within a sports centre. You should also present diagrams, which show the expected information flows through the centre.

Students were divided into two groups of 4, depending on the point at which they were at in the problem. They used A1 (594X841mm, 23.4X33.1in) sheets of paper around the walls, and all students were given markers to allow them to write on the sheets. They could discuss additions to, and removals from, what was already written up. In fact, they were very much encouraged to make changes, and neatness of the final result was not required.

Sometimes it was useful for students to move to a different group while working on the problem. For example, one student, David, had spent time working in a warehouse, so he understood what happened when goods were ordered, stored and sold to a customer. In this case, he became the 'user' of the system and other students were able to question him to discuss information flows when that was relevant. It was also important to have students who took leadership roles not take over the conversation, so again, it was useful to be able to move people around to ensure that all students were participating in the discussion.

3.1 Working through the problem - Hospital

The problem that the students were given about the hospital was to produce a diagram of the information flows and entity relationships as part of the development of a database system. This was the second problem, so students had previously worked through a scenario in which they had discussed the bicycle shop transactions and how information flowed around the system. They had drawn basic data flow diagrams. They had attended formal lectures on topics such as the use of models in decision-making, how models are used in the analysis and design of computerized information systems and a brief introduction to some models.

At first, the students groups discussed what happened in a hospital (events) and who was involved in the hospital scenario (entities). They also had to decide what 'entities' undertook which 'event'. While Ita knew that they were identifying events and entities, these terms were not spoken about as students listed those involved. After some discussion, the students presented the lists, which included:

Entities	Events
Patient	Arrived at hospital Had details taken Admitted to hospital Assigned to ward
Doctor	Examined patient Made diagnosis
Nurse	Dispensed medicines
Pharmacist	Read prescriptions Dispensed prescriptions
Staff Manager	Determined work rotas Decided upon bed assignments

Students then decided what 'attributes' each entity had. As previously, they did not know that they were determining 'attributes' – they discussed what data would need to be held about each entity. Figure 1 shows a copy of patient attributes identified through discussion. Students were then required to determine the relationships between entities. This was done

through them having discussion on the entities and events previously identified and asking questions such as 'Who does the patient talk to?', 'What happens to the prescription?'. In this manner, they were able to identify the linkages between entities. At this stage in the process, Ita, the lecturer, gave a 1-hour lecture on the topic of entity-relationship diagrams. She presented the concepts of entity, relationship and attribute. She also introduced the concept of putting all of this information into a diagram. She presented the concept of cardinality, giving examples of how cardinality is recognized. At the next class, students had to draw the entity-relationship diagram based on the information they had already established about the system. Figure 2 shows an extract from this diagram.

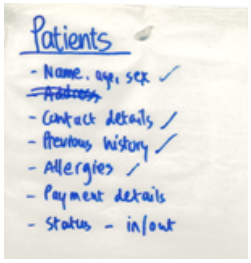

Figure 1: Patient 'attributes' as identified by the students

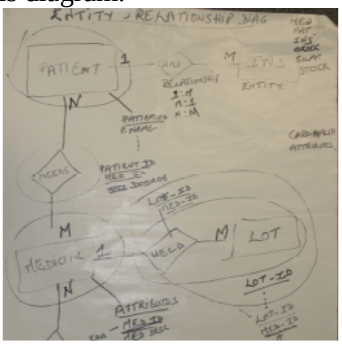

Figure 2: Extract from entity-relationship diagram

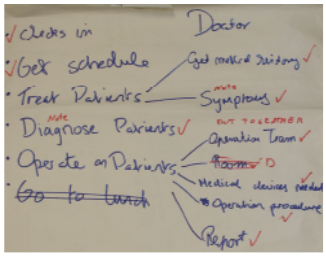

Figure 3: Student notes taken during the PBL discussions

Once the entity-relationship diagram was completed, Ita again gave a lecture on how this could be used as a basis for a logical record structure resulting in a good database design. The next stage was for the students to carry out a similar exercise to construct a data-flow diagram showing the information flows around the system. Figure 3 shows student notes, which were written during this process. As with the entity-relationship diagram development, the interactive PBL sessions were interspersed with lectures about the topic.

4. Research Methodology

As stated, Yvonne attended class during two different problem sessions. The focus of the research project was how the students were handling the problem in class and how the lecturer was facilitating. Having taken notes, Yvonne compared the problem, the facilitation and the participation of the class with standard PBL methodology. Following this comparison she discussed aspects of the PBL implementation with Ita, enquiring into such aspects as group learning outside class, the prior experience of the students and the structure of the teams. She held a formal interview with the tutor, which focused on the tutor's experiences with PBL. The notes taken and the results from the formal interview were analysed using the main characteristics of the Barrows [10] core model and is presented in the next section under the six headings.

5. Observations on the Case Study

When we evaluate the core model in terms of the process or methodology adapted in the Computer Science class, a number of issues arise:

1. Learning is student-centered

In fact, the focus was totally on the need to develop and help the student learning in small groups cope with real life situations. Students were able to discuss and develop ideas among themselves, with guidance from their tutor when it was required. Prior experience and learning from other classes, particularly in the case of the two Erasmus students became central to these discussions. However, when we evaluate student centered in terms of the core model of Barrows [10] student centered focus was slightly different. In our case, the

students did not entirely develop their own learning issues based on the problems presented by the tutor. In addition, the tutor was much more heavily involved in directing the teams on their learning than in a pure PBL situation.

2. Learning occurs in small student groups.

In terms of the learning in small groups, this was not evident in the true sense; while the class was small there was no suggestion the class met separately to discuss the problems being presented. In this case, while the group was relatively homogeneous, three people from the class were not in the core group from the B.Sc. in Information Systems. This resulted in little or no interaction outside the classroom. Meeting outside of formal classroom time was not a requirement from the tutor's perspective, as problems were completed during contact hours.

3. A tutor is present as a facilitator or guide.

The tutor in this case was not a facilator as would be the norm in a PBL environment. Although she tried to stand back and allow the students' prior learning to flow, Ita was involved in directing the class and giving guidance. However she stimulated the group by asking leading questions, energizing the group and helping them to move forward. The people undertaking this module were relatively young, both in age and in their time at University. Therefore, for Ita not to give guidance would have been unfair to the students who were experiencing PBL for the first time. This is very consistent with the literature where in a number of cases PBL was only introduced in the 3rd or 4th year of the course. However, it should also be remembered that this was the first PBL class in which Ita was involved, and she experienced the difficulty of ensuring that she allowed the students to learn, rather than her giving them too much guidance. It was also a challenge for her not to give the answers to questions, which would be much more normal for her teaching background. Rather, she had, on occasion to remind herself that she was there more as a facilitator than as a lecturer.

4. Authentic problems are presented at the beginning of the learning sequence, before any preparation or study has occurred.

The problems that were presented would have allowed the students to develop the skills sets to not only solve future problems but also to take these skills to the work place. They were built on the developing the learning issues of the student and the learning outcomes set by the tutor. The scenarios presented were those for which students required little specialist knowledge. If we take the bicycle shop scenario, students could easily understand how a bicycle was sold or recorded for repair. However, at times, the solution discussed by the students did require some specialist knowledge. For example, in the case of the hospital, they themselves decided that there would be a pharmacy there, and this raised the issue of disposing of out-of-date medicines – a scenario which Ita had not considered when developing the problem. The positive side of such discussion was that students were exploring areas, which they themselves had unearthed. In summary, the learning issues developed by the students must match the learning outcomes set by the tutor.

5. The problems encountered are used as tools to achieve the required knowledge and the problem-solving skills necessary to eventually solve the problems.

The literature on problem solving is identified by a wide variety of theoretical frameworks. Even with the range of differences in details and terminology, all of models agree that an organized domain-specific information base — and meta-cognitive functions that operate on that knowledge — are essential parts of successful problem solving. There is also a fairly broad consensus that differences in motivation and thinking account for problem-solving styles. [17]

6. New information is acquired through self-directed learning, objectives and assignments.

There was little evidence that self-directed learning was taking place. However, it was evident that students were learning from other students and reflected on this learning. For example, some of the students shared learning from their work experience with the class. Students were learning a concept, which can be very difficult to grasp in the lecturing setting.

The use of PBL provided them with the facility in which they could construct diagrams including concepts. Therefore, during lectures, they were able understand these concepts.

6. Moving from hybrid-PBL to pure-PBL

We made a conscious decision not to roll out the PBL concept in its pure form. Given their experience level, we consider that we made the correct decision.

In this case, PBL was implemented for a small group of students, so was relatively successful. The lecturer, Ita, moved between groups to ensure that students could continue their work. In the cases where students were stuck on a point, Ita could ask questions to make them probe further – a question as simple as 'Who does that' or 'What happens next?' can get the discussion flowing again. When students were not participating in the discussion, a technique is to ask that student's opinion, or to get that student to write on the wall chart.

In the coming academic year, Ita will be using PBL yet again – but this time will be more conscious of the PBL requirements. In this case, the class will have 20 registered M.Sc. in Software Engineering students, and the topic will be mainly focusing on Software Quality. Students will have come to the course with an undergraduate B.Sc. degree in a related discipline. It is unlikely that any of them will have experienced PBL in previous education. Students will be assessed through poster presentation and reports. Through this, students will also receive peer feedback, and they will also get formal evaluation throughout the module from the lecturer. We are also evaluating more creative methods of assessment, which are unlikely to be used in this current module, but will be considered in future years.

From her experience with PBL in last year's module, and following this research, Ita will be implementing changes which will bring her teaching closer to 'pure' PBL – in reality she is implementing a hybrid-PBL.

Yvonne will undertake training with Ita and other faculty members within the University of Limerick who propose implementing PBL. This is expected to improve the understanding of the PBL methodology, the role of the student in determining their learning issues, the facilitation process, the importance of the student's role in the team, the assessment methodology and problem development. For example, in pure PBL, problem development requires building a community of people who can provide relevant problems, which can be worked on during structured class sessions and outside of class time

8. Future development of PBL

The implementation of PBL should be considered as an approach to learning rather than just a technique to support learning .An effective PBL curriculum is not just one that is a collection of well thought out and well designed subjects. It is critical to have a clear map of the entire domain of learning in addition to the curriculum structure. Students should be able to progress through course material and be able to establish that they are learning what the course intended them to achieve. In PBL, we are not only trying to develop knowledge which is important in every learning process, but we are trying to develop the professional skills that will help the student during the learning process and their professional life.

Of concern within European Universities is the Bologna agreement. The Bologna document details the importance of a number of skills required in University education:

- Responsibilities assumed in the group,
- Criticism.
- Organization and manipulation of non-structured information.
- Critical thought, initiative and search for information
- Oral communication and written skills.

These are the very skills that are being developed using the PBL model. In our case, while we have used a hybrid model we were still able to work towards the skill set detailed in the Bologna document. However, we have selected one module within an entire course, the

remainder of which has used more traditional methods of teaching. To be of real benefit to the student, we should consider the entire curriculum design. Successful implementation of PBL will not come easily. This may cause further difficulties as personal, academic and financial levels. Faculty will require extensive training. University management will be required to modify regulations and possibly allow a reduction in course content. Fundamental beliefs will be challenged. Building a comprehensive PBL community requires determination and commitment from all levels – student, faculty and management – to make it work.

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