Problem-Based Learning in Teaching Theoretical Computer Science

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ABSTRACT: *Problem-based learning has proved to be an effective way to deliver university level courses in various disciplines. However, the foundational theoretical courses of computer science, such as the theory of formal languages or the theory of computability, are still mostly taught in the traditional behaviouristic settings. Beside other negative effects, traditional settings often leads to low student involvement and, as a consequence, to a high rate of withdrawal. In addition, in the traditional lecture-exercise-exam format, teachers' assessment of the progress and performance, and student comprehension of subject matter are quite difficult tasks. Very few computer science faculties have reported the use of innovative teaching strategies. Especially, the problem-based learning method is still underutilized.*

In this paper, we present our experiments and results in teaching a course of theoretical computer science taught in a problem-based learning (PBL) format and supplemented with learning diaries. The experiment was done on the multinational body of students, where the previous learning habits often greatly differed among the learners from different institutions and countries. We report on the methodological challenges of PBL, especially on practical implementation, and on the ways of scheduling, delivering, and assessing the learning process of highly diverse group. We argue that the combination of PBL and learning diaries yields a comprehensive and fair evaluation of learning. Our results show no interaction of PBL with gender or nationality. Our results and experience also indicate that even though the preparation and assessment phases were longer for PBL, the use of PBL in theoretical computer science teaching brings positive effects on important instructional goals, such as students' comprehension and involvement, and on the course dynamics and atmosphere.

1 INTRODUCTION

Theoretical courses of computer science, such as the theory of formal languages, automata, or the theory of computability, are regarded as the foundational parts in many computer science curricula. Often these types of courses form a preliminary body of knowledge needed for intermediate and advance level courses. Therefore, it is an ultimate goal of university-level educational institutions to deliver these courses in such a way that the subject matter is well understood by the students. Although this fact is well recognized among computer science educators, foundation courses are usually delivered in a traditional behaviouristic and teacher-centered way. This leads to many negative effects. In teacher-centered courses the involvement and motivation of learners is low, students do not actively develop their sense of educational ownership which leads to a low commitment to learning and low acquisition of knowledge, and, subsequently to drop-out. A high withdraw-rate from the theoretical computer science courses is a well known attribute at Finnish universities.

Currently, *constructivism* is the prevailing concept in modern learning theories (for a review see (Phillips, 1995)). From the constructivist view, learning is a personal, idiosyncratic process of active knowledge construction and the result of generative reflection on the student's current and past knowledge and experiences (Piaget, 1952). Learners are given responsibility for their learning, but are still encouraged and guided by the teacher. Students are directed to become owners of their learning experiences. Recently, constructivist approaches have been augmented with social perspectives of learning. It means that besides the fore-mentioned characteristics of constructivist approaches to personal learning, also group cognition and collaboration are considered as important factors influencing the overall learning process. Especially, so called *situated learning* (Brown et. al., 1989) stresses the importance of activity, context, social aspects, and the culture in which learning occurs. These two paradigms, constructivism and situated learning, form a *socio-constructivist framework* where the learning happens. It is noticeable how socio-constructivism forms a contrast to the traditional, behavioural approaches to learning, and a shift of emphasis from the behaviourist attitudes toward the constructivist view is observed.

Two central ideas support the constructivist learning process: the selection of good problems given to learners, and the collaboration between students and between students and teacher. Apparently, problem-based learning fulfils the needs implied by socio-constructivism (Rossetti, 1997; Woods, 1994). At the same time this method meets the existential challenges of development by supporting students in their process into intellectual and emotional maturity (Savin-Baden, 2000). Thus constructivism and especially problem-based learning offer a promising alternative to the teaching and learning of difficult theoretical courses in computer science. However, as far as we know, problem-based learning has not been applied to teaching of theory of computability or other theoretical courses in computer science. The reasons for this lack can be practical: the application of problem-based methods with real world problems and as natural in computing theory as in, for example, software engineering. Moreover, the behaviouristic teacher-based approach is well established in many faculties, so there might not be a motivation, room and content to change the status quo. Therefore, there is a need for studies reporting the use of PBL in theoretical computer science courses.

Along with the many challenges of teaching theoretical courses, the assessment of learning progress and comprehension of the subject matter are problematic. Traditionally, student assessment is done by the means of oral or written examination after the course. From the teacher’s point of view, post-assessment is not enough to obtain continuous feedback needed to develop insight into the learning process. A learning diary is one of the learning and assessment tools which brings about many positive effects (Lindblom-Ylänne, 2003). First of all, students are encouraged to process the matter thoroughly and independently, which increases their control over the learning. Learning diaries also provide the required feedback from the students to teachers, for instance it is easy to track the evidence of improvements. Teacher can also instantly obtain the critical information about how and what the students have reflected upon.

In our experiment, we have concentrated on how PBL and the traditional methods differ in terms of time needed to adapt, deliver, and evaluate the course and whether the PBL and learning diary method is suitable for a heterogeneous, multinational class, in terms of assessment in the course.

In the next sections we first introduce what problem-based learning is and describe the settings of our first problem-based course in the theory of computability. We outline the special challenges of adapting and teaching purely theoretical courses in a problem-based way (i.e., in constructivist paradigm) and present the results. Finally, we interpret the results and draw the conclusions.

2 PROBLEM-BASED LEARNING METHOD

The main strategy in *problem-based learning (PBL)* is to use problems, queries, or puzzles as the starting points for learning. In fact, problem-based learning is not just a single method or technique, but a variety of problem-based approaches, from lecture-based teaching to pure problem-based learning without any teaching or assessment by teachers (Boud, 1985; Barrows, 1986). Ellis et al. (1998) divide the problem-based learning methods into three categories. In the modest forms, which Ellis et al. call the *problem-based approach*, material is presented in normal lectures, but problems are used to motivate students and to demonstrate the background theory. In the hybrid models, or *guided problem-based learning,* the problems are solved in the groups, but the lectures are also used to present the fundamental concepts and conceptually most difficult topics. In *full problem-based learning,* the problems guide and drive the entire learning experience and no formal exposition of knowledge from the "expert" is given. Boud (1985) listed some of the general characteristics typical for problem-based courses:

- Acknowledgement of learners' experience.
- Emphasis on students taking responsibility of their own learning.
- Crossing of boundaries between disciplines.
- Focus on the processes of knowledge acquisition rather than the products of such processes.
- Change in the role of teacher from instructor to facilitator.
- Self- and peer assessment of learning.

- Focus on communication and interpersonal skills.

3 DESCRIPTION AND PARTICIPANTS OF THE COURSE

For a couple of years the intermediate level course "Theoretical Foundations of Computer Science" (TFCS) has traditionally been delivered in the lecture-exercise-exam format at the Department of Computer Science, University of Joensuu. Previously, the teachers prepared and gave the TFCS lectures, students attended the lectures and exercises sessions, and students completed one or two exams in order to pass the course. Due to difficult content, the course elicited several fear among the students and the withdraw-rate was usually very high.

Hoping to correct the situation, the TFCS course was adapted so it could be carried out using the problem-based learning (PBL) approach. The TFCS course was ran for ten weeks during the spring term of 2003 and covered the theory of computability from the finite automata, regular expressions and languages, to context-free grammars, pushdown automata, Turing machines, and solvability. The typical week consisted of fours hours of lecture sessions and two hours of demonstration sessions. The lecture was divided into two parts: in the first part the problem given previous week was discussed and processed in the groups and a new problem was presented; in the second part of the lecture session, the difficult subject matter was explained by the teacher. It is obvious that the role of teacher altered throughout the lecture sessions. During the first half of each session the teacher acted as a facilitator and tutor of the groups, whereas during the second half the teacher shifted to a more traditional approach. One week in the middle of the course was reserved for the "art exhibition", in which the students presented the artefacts created by formal languages, music or graphics based on grammars, such as Lindenmayer-systems for example.

In total, 79 students registered for the course, of which 75 has participated at least the first exercise session, taking either way of passing the course. Considering gender, there were 25 female and 39 male students participating actively in the course. There were 65 Finnish students and 12 foreign students (mostly from East European countries), of which actively participated 54 Finns and 10 foreign studets. All foreign students had previously passed some courses in mathematics and held at least Bachelor degree, while most of the Finnish students were freshmen or novices in computer science studies. Most of the students had no previous experience with the PBL method, while some of them were used to keep learning diaries. The language of instruction altered irregularly between Finnish and English according the need, the international students were offered with English language both in lecture sessions and in the exercise sessions. Three teachers were involved in the course: a course leader and two course assistants. Commonly, the course leader and sometimes one of the assistants participated in the lecture sessions to facilitate the group work. The communication between all the course parties was also supported by the means of mailing list, where the students were encouraged to contribute.

3.1. DYNAMICS OF LEARNING PROCESS

To allow for comparison, we allowed students to choose one of two alternative ways of passing the course. We offered either the problem-based way or the traditional, exercises-exam way. The vast majority of 61 students chose the problem-based way. For the initial experiment we have partially modified the seven-stage model (David et al., 1999) of teaching in PBL so it accommodates a five-stage model presented by Barrows (1986). An outline of the procedures used in the PBL TFCS course is given below:

0. *The problem is presented to students.*

1. *Unclear concepts are defined*: students actively look for the concepts and attempt to define them.

2. *The problem is identified and defined*: students in groups discuss the problem, identify important and relevant issues. The students try to create a preliminary hypothesis, thereby establishing their position toward the problem.

3. *Brain storming*: the group analyses the problem and different hypothesis are tested and compared.

4. *A general hypothesis is constructed*: the group attempts to create an integrated view of the problem.

5. *Defining the learning goals*: students recognize and write down their learning goal(s) for self-studying.

6. *Students engage in self-studying*: students independently process the subject matter and research literature. At this stage, the course tutors can provide support.

7. *Peer- and self-evaluation:* groups meet again and students share and compare their solutions; peer-teaching can take place. The learning goals are checked against the results.

The participants of the course worked in week cycles, submitting the problem report, the solutions for supporting exercises, and learning diaries once a week. It can be seen that there are distinctions between the activities of students in PBL courses and students in traditional courses. For instance, the group-work is facilitated from the very beginning in the PBL course, even in the lecture time. The students are not passive receivers of the information coming from the teachers, but rather create the knowledge actively through the social interaction and peer communication during the problem solving. The teacher's role is changed to the facilitator providing basic scaffolding mostly on the meta-cognitive level and only if needed.

A detailed description of the experiment setting, the details of problems used, and distributions of the grades comparing the PBL and traditional method are reported in (Hämäläinen, 2004).

3.2. ASSESMENT OF STUDENT LEARNING

There were two different sets of criteria for the two ways of passing the course. For the traditional, lecture-exercise-exam way, the overall grade was formed from 76% by the points of the exam taken after the course and from 24% by the exercise points. The grade of students taking the course in the PBL condition was formed as follows: problem reports counted for 51% of the grade, exercises counted for 24%, and learning diaries counted for 25%. The distributions of the three components of the PBL grade were selected in this way to motivate students to equally complete the exercise assignments and learning diaries and at the same time to guarantee that if only problem were reports submitted, the student would not fail. Concerning the assessment of learning diaries, the evaluation criteria were designed as follows: regularity counted for 16% of the grade, evaluation of learning process and learning goals counted for 20%, reflecting/processing on learnt matter counted for 20%, subjective learning experiences counted for 12%, overviews (e.g. concept maps) counted for 24%, other activities (e.g. extra tasks, own applications, aphorisms, comic-stripes, etc.) counted for 8%. The students were notified about the contributions of each of the reports, exercises, and diaries to the overall grade. Moreover, the distribution of criteria for the learning diary evaluation was designed with the cooperation with students. Problem reports, exercises, and learning diaries were regularly checked and students were provided with the feedback from the teachers.

4 RESULTS AND EXPERIENCES

In the current experiment we concentrated on two main domains. First, we estimated the times needed to adapt and deliver the TFCS course in a PBL way and compared to the times taken in the traditional approach. Second, we attempted to evaluate the assessment of the learning in terms of gender and educational background in the PBL method and learning diaries.

The results in terms of estimated time required to prepare and deliver the course and to evaluate students' learning are presented in the Table 1. Two factors influenced the results. First, the course was bilingual so additional time was required to prepare the materials. Second, the time needed for preparation and evaluation in the traditional setting is almost always a linear function of the number of students taking the course in the traditional way.

Table 1. Estimated time in hours needed to adapt, deliver, and evaluate the course.

	Lecture prep.	PBL prep.	Exams prep.	Exerc. prep.	Lecture session	Exerc. session	PBL check	Diary check.	Exam check	Other	Tot.
PBL	320	15	-	200	22	45	180	180	-	10	972
Trad	320	-	8	200	20	45	-	-	20	10	623

We identified two main components in usability of assessment process of a course in the PBL way. The first component addresses the issues of "guaranteed" learning in terms of tracking the achievement of the official learning goals in problem reports, learning diaries, and exercise tasks. The second part focuses on the issues of objectivity and “fairness” of the assessment towards the heterogeneous group of students. We especially focused on how the PBL method in TFCS course fitted to different learning types, gender, and previous learning experiences of the learners. We might link the learning types to the nationality into some extent, because according to our experiences the foreign students exhibit mostly traditional approach to learning. We have also observed that keeping and writing learning diaries in the TFCS course is appreciated by female rather than male students.

Table 2 shows the results in terms of student performance in the TFCS course. Table provides view on the distribution of the points of students who passed the course in PBL way among the gender (F=female, M=male) and nationality (H=home, F=foreign) for the exercise points, the points obtained from the problem reports, learning diary points, and total points.

There are several important results to be observed. Overall, there is no significant difference in the average of total points between females and males (although female scores were slightly higher) or between Finnish and foreign students. These facts support the claim, that the assessment was indifferent toward gender and nationality and therefore also objective while considering the learning types. There is, however, other evidence supporting our experience, that the learning diaries fit better for female students. The two sample two tailed unpaired t-Test assuming unequal variances was run, $t(39) = 2.06$, $p<0.05$, which suggests that there is a significant effect of gender on the learning diary points. No other significant difference between genders has been found.

Table 2. Point distributions between gender and nationality

		Gender		**Nationality**		**Overall**
		F	M	H	F	
Exercise points	N	22	33	47	8	55
	Mean	15.86	14.97	15.13	16.50	15.33
	SD	4.24	3.98	4.09	4.00	4.07
Problem points	N	22	33	47	8	55
	Mean	35.36	36.42	36.26	34.50	36.00
	SD	7.49	6.04	6.26	8.77	6.61
Diary points	N	22	33	47	8	55
	Mean	18.91	16.55	17.32	18.50	17.49
	SD	4.47	3.70	4.07	4.81	4.15
Total points	N	22	33	47	8	55
	Mean	71.27	67.91	69.20	69.63	69.26
	SD	13.93	11.23	11.92	15.71	12.37

Considering the nationality, there was no significant difference in total points, exercise points, problem reports points or learning diary points. Since only eight foreign students participated and passed in the PBL way, and we cannot draw any further conclusions based on the statistical tests in this direction because the sample size is small. However, from our experience and observations it follows that foreign students got slightly more points from the exercise sessions in which they practiced mostly the mechanical skills in TFCS.

5 DISCUSSION

Several crucial issues have to be considered before implementing a traditional course in a problem-based learning way. We have observed the differences in mechanics of the two approaches; in the traditional way the attention is paid on delivering and presenting the information; and in PBL way the focus is put on supporting the students.

A detailed look into the parts of learning diaries which were carefully checked reveals that in general female students reflected the learning process better and more deeply than male students and created more additional learning artefacts, such as applications of their own. Considering the nationality, we discovered that for foreign students the self-evaluation in learning diaries was an obstacle. Another difference was that Finnish students attempted to interpret the subject matter learned in their own words, while the foreign students in general repeated the passages from literature or other sources.

The results obtained from only problem-report scores and overall scores suggest that the method is appropriate for heterogeneous group of students. Although our students were from various institutions, with greatly varying levels of experience and knowledge, and taking slightly different approaches to learning under the PBL paradigm, their performance was balanced. By providing problems as a main means of constructing the knowledge, exercise tasks to practice mechanical skills, and learning diaries to allow for deep reflection, we equally addressed all the various requirements of modern constructivist instruction.

Considering the time required for adapting, delivering, and evaluating the course, it is clear that the assessment of problem reports and learning diaries took most of the time when the course was being delivered. However, in our way of adapting the PBL we did not rely on the self- and peer-evaluation as suggested e.g. by Barrows (1986). Barrows relies exclusively on peers and self-evaluation which would substantially decrease the time spent on the course. While comparing the assessment time per student in a PBL course with a traditional course with same number of students, the former turns out to be more effective and faster.

Concerning the educational goals, the PBL students showed greater motivation than we experience in the traditional courses. Since relatively few students participated in the traditional way, it is difficult to compare the level of their comprehension with students who opted to take the course in the PBL format. We currently are running an experiment under more controlled conditions which will allow us to compare not only the grade distribution but also the student comprehension between the conditions. Negotiation and social interaction in groups also leads to supporting the sense of ownership of learning. In PBL TFCS we experienced that students taking the course in PBL were also ready to demonstrate their knowledge in public.

Multicultural environment brought several challenges to application of PBL. First, at our department and also in the TFCS course, the foreign students form about twenty percent of the whole student population. For this reason we delivered the course in two languages, English and Finnish. Second and more important issue is the previous education experience. Most of our foreign students come from the rigid traditional institutions where the innovative teaching strategies are not widely applied. These students exhibited in the beginning of the course some problems in accepting the new approach to teaching. Some of the foreign students (17%, both passed) selected the traditional way of passing the course and some reported dissatisfaction with the course as such.

6 CONCLUSIONS

In this paper we have discussed the challenges and problems with the application of problem-based learning in teaching the theoretical computer science courses. We combined PBL with the use of the learning diaries, along with some of the traditional ways of teaching. We applied the method on a multinational group of students.

We argue that PBL can be effectively used for the teaching of theoretical computer science. From our results and experience, the assessment process is slightly for the teacher more time demanding as compared to the traditional way, however, longer assessment time is offset by positive outcomes of PBL. From the teacher’s point of view, this combination provides continual feedback and also the required insights into the learning process. The evaluation and assessment is balanced, objective, and relatively cheap. In conclusion, we maintain that PBL provides an adequate alternative to assessment of student learning.

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REFERENCES

BARROWS, H.S. 1986. A taxonomy of problem-based learning methods. Medical Education 20, pp.481-486.

BOUD, D. 1985. *Problem-based learning in education for professions*. Sydney, Higher Education Research and Development Society of Australasia.

BROWN, J. S., COLLINS, A., DUGUID, P. 1989. Situated Cognition and the Culture of Learning. Educational Researcher 18(1), pp. 32-42

DAVID, T., BURDETT, K., RANGACHARI, P. 1999. *Problem-based learning in medicine.* Worcester, Royal Society of Medicine Press Ltd.

ELLIS, A., CARSWELL, L., BERNAT, A., DEVEAUX, D., FRISON, P., MEISALO, V., MEYER, J., NULDEN, U., RUGELJ, J., TARHIO. J. 1998. Resources, tools, and techniques for problem based learning in computing. In *Working Group reports of the 3rd annual SIGCSE/SIGCUE ITiCSE conference on Integrating technology into computer science education*. pp. 41-56. Dublin, Ireland. ACM Press. Available from http://doi.acm.org/10.1145/316572.358296.

HÄMÄLÄINEN, W. 2004. Problem-based learning of theoretical computer science. Unpublished manuscript, University of Joensuu.

LINDBLOM-YLÄNNE, S., NEVGI, A. 2003. *Yliopisto- ja korkeakouluopettajan käsikirja.* In Finnish. Vantaa, Finland, WSOY.

PHILLIPS,D.C. 1995. The good, the bad, and the ugly: The many faces of constructivism. Educational Researcher 24(7), pp. 5-12.

PIAGET, J. 1952. *The origins of intelligence in children.* New York, University Press.

ROSSETTI, M. D. 1997. Activate this classroom at time now. In *Andradottir, S., Healy, K. J., Withers, D. H., Nelson, B. L., editors, Proceeding of the 1997 Winter Simulation Conference*.

SAVIN-BADEN, M. 2000. *Problem-based Learning in Higher Education: Untold Stories*. Buckingham. The Society for Research into Higher Education & Open University Press.

WOODS, D.R. 1994. *Problem-based learning: How to gain the most from PBL*. Waterdown, Ontario. D.R. Woods.