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# DESIGN AND IMPLEMENTATION OF PROBLEM-BASED LEARNING IN A GRADUATE ENGINEERING COURSE

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## ABSTRACT

*In this paper it is described how a graduate engineering course is modified so that it can be taught using problem-based learning (PBL). In the first part of this work, PBL is discussed in general, and in the second part it is described how PBL has been used in the past by others, and what should be taken into account when a PBL course is designed. In the third part there is a description of the old course, an explanation for why it was chosen as an example, and a description of the renewed course. The renewed course was held for the first time in the fall of 2010, and the feedback is based on discussions with the students. On the basis of those discussions, it can be concluded that students like the general idea of PBL, and encourage the faculty to use it in the future and in other suitable courses.*

## NOMENCLATURE

LUT Lappeenranta University of Technology
PBL problem-based learning

## INTRODUCTION

The education at Lappeenranta University of Technology (LUT) is still mostly traditional in the sense that a lot of the education still relies on basic lectures and exercises. The efficiency of such educational methods have been questioned. In its strategy, LUT calls for continuous improvement in the quality and productivity of the education it gives. As a response to this challenge, the Laboratory of Fluid Dynamics has in recent years invested in enhancing its education [1], and in order to further improve the education and learning outcomes in the Laboratory of Fluid Dynamics, problem-based learning (PBL) has been introduced to a course in gas dynamics.

In PBL, the students work in small groups and study what they need to know in order to solve a problem they have partially defined themselves [2]. In PBL, the learning is connected to a real-life problem-solving environment so that the environment reflects real working situations as much as possible. This gives the students a chance to think how the things they learn at classes are connected to real life and work-related problems.

Williams et al. [3] describe PBL as having the following phases: (1) presentation of a problem, (2) identifying the problem, (3) creating a hypothesis, (4) gathering additional information, (5) creating a joint educational task (6) independent study, (7) creating a synthesis and applying the new information, and (8) reflecting on the learning process. All the phases, except the independent studies, are done in groups with the help of a tutor. PBL is currently widely used in higher education in medicine, but also in engineering and science, psychology, and pharmacy as well as in educational studies.

Dunlap [4] has studied how studying in a PBL environment affects the self-efficacy of information technology students. Almost all students improved their ability to study independently.

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The improvement in the independent study skills was partly due to the fact that the students noticed that they were able to work by themselves, and act as professionals. Also peer review and reflections during the group sessions improved the students' self-esteem, thus improving their self-efficacy.

In order to investigate how PBL affects the knowledge and skills of students, and to find out possible barriers which might hinder the effects of PBL, a meta-analysis was performed on 43 articles by Dochy et al. [5]. They found that PBL had a coarse positive effect on students' skills and their ability to take advantage of their knowledge. None of the articles reported negative impacts. A slight negative tendency was reported in students' knowledge. Dochy et al. mention that this negative tendency was due to two of the articles reporting large negative influences. Other articles reported neither positive nor negative results. The same authors performed another meta-analysis on the effects of PBL from the viewpoint of assessment [6]. PBL had the best positive impacts on the learning outcomes, when the assessment reflected on how the principles that connect issues together were understood. Students who studied in the PBL environment understood the fundamentals better and were better at applying the principles they studied.

Reeves and Laffey designed an undergraduate engineering course for the U. S. Air Force Academy [7]. The cadets who studied in the PBL environment improved their problem identifying and solving skills during the first year as much as the older cadets in three years of traditional education.

Severiens and Schmidt studied the effect of PBL on academic and social interaction, and the study process as a whole [8]. The study was conducted on 305 first-year psychology students, studying in three different curricula: traditional lecture-based, lectures combined with some activation techniques (e. g. group work on a practical assignment), and a full-fledged PBL curriculum. Students studying in the PBL curriculum achieved more credits than the students in the other two curricula.

On the basis of the above-mentioned studies, there are clear factors that encourage the use of PBL also in engineering education at LUT. PBL should lead to better problem solving skills and to better self-efficacy, which are important skills for students during their studies, but also in the working life after the university. However, there is some criticism against PBL.

Colliver [9] has evaluated articles about PBL and PBL as a learning environment on the basis of results published in the articles. Colliver concludes that PBL is a more challenging, more motivating and more enjoyable way to study, but on the basis of the studying results, the superiority of PBL is questionable question, especially when the massive amount of work needed to change a curriculum to be PBL-based is taken into account. According to Colliver, there are no clear results that PBL improves basic knowledge or clinical skills. Even though the articles Colliver evaluated considered PBL in medical education, they should be kept in mind when engineering education is considered.

Sahin [10] studied the effects of a PBL-based physics course on the opinions and learning outcomes of first year electrical and electronics engineering students. According to Sahin, PBL had no effect on the physics results, and it had no effect on what the students thought about physics or physics studies, either.

Moust et al. [11] discuss experience-based knowledge for the reasons which lead to erosion of PBL and impaired learning results. They mention such things as lack of funding, failure of the faculty and students to understand the fundamental principles of PBL, faulty methods to "improve" the process, and excessive focus on contents instead of the process itself.

Despite the criticism, PBL seems to be suitable for engineering education also at LUT, and at least it seems to be worth trying. In this article we describe how an already existing graduate engineering course taught by the Laboratory of Fluid Dynamics was modified so that it can be taught using PBL. The renewed course was held for the first time in the fall of 2010.

## Course design

Partial PBL has been implemented in Mechanical Engineering and Biomedical Engineering at Technische Universiteit Eindhoven [12]. Their foundation is a PBL process which has been adapted to be more suitable for engineering education. Inter alia, the adapted features include the following: the aim of the process is on applying and integrating the knowledge; as a result the students give a presentation or a written report; the selection of suitable literature is strongly advised; the tutor has also the role of an assessor; and the course still has lectures and exercises.

In addition to the critique mentioned above, Moust et al. [11] present ways to slow down the erosion of the PBL process. Among others they mention that it is paramount that the fundamental principles behind PBL are thoroughly explained to the students, and that the self-study skills of the students are advanced and encouraged. They also mention that new ways of assessment should be considered.

Azer [13] has studied the challenges and barriers that are present when a PBL curriculum is designed and implemented. Although Azer's work considers only medical curricula, many of the problems seem to be universal. Azer mentions, among other things, personal and organisational factors, i.e. how a person or an organisation as a whole is disposed to changes. Some of the other things mentioned are the time and resource intensiveness of the method, choice and actions of the tutor, and possible problems in group dynamics.

PBL has also been used on a large (approx. 50 students) chemical engineering course [14]. When Woods used PBL in a single course in an otherwise traditional curriculum, he noted that the students did first the work, assignments and tests needed for other courses before focusing on the PBL assignments. Woods tackled this problem so that more and smaller problems were used, and the students needed to hand back their assignments rather quickly. This way the students had no time to procrastinate on the PBL assignments.

Dahlgren and Öberg [15] studied how the setup of the PBL case, i.e. how the initial problem is presented, affects the questions that arise in the students. They mention that the complexity of the problem is a major factor. The more complex the problem is, the more deeply the students work on the issues, but mere complexity is not enough. The best were the problems which were provocative or emotional.

Group dynamics, including the tutor and the students, are discussed in [16], and it is mentioned that the competence of the tutor is a key issue. The possible success of PBL depends heavily on the competence of the tutor, the problem at hand and, the functionality of the group.

Different strategies for the tutor to use in the guidance of the students are mentioned in [17]. Even though the article is about medical education, the strategies seem to be quite universal. Things mentioned are, among others: open questions, requiring explanations, summaries, etc. It is mentioned that considering different strategies for different parts of the problem helps an inexperienced tutor to learn how to tutor.

It is important that all the students in the group take part in the discussions, and it is paramount for the success of the studies that the tutor encourages everyone to participate from the beginning [18].

## DESIGNING AND IMPLEMENTATION OF A PBL COURSE AT LUT

There was no need for a completely new course in the Laboratory of Fluid Dynamics at this point. Instead, it was decided that an already existing course would be chosen and altered so that it could be held using PBL.

Course feedback questionnaires, filled in by students after each course to receive information and find out possible weaknesses in different courses at LUT, have indicated that in general the education in the Laboratory of Fluid Dynamics is in good order. General averages from different courses are usually between 3.5...4 (on the scale of 5), so there were no outdated courses needing a major overhaul. The questionnaires offered no help for the selection of a trial course, so the authors used arbitrary methods, and simply selected the gas dynamics course as the trial course.

Gas dynamics is a graduate course held biannually, and it is recommended that students take the course in their fourth year, i.e. the first year of their M.Sc. studies. The course description before the reform is presented in Table. 1. In the old version of the course, there were four separate joint study sessions, lasting four hours each. They were a combination of lectures, exercises, and different small group work. As such, there was nothing wrong with the course, but there were a few simple reasons for choosing the gas dynamics course. First of all, the course was held in the autumn, in the beginning of the academic year. As the planning was mostly done during the summer, it was feasible to select a course which was held right in the beginning of the academic year. Secondly, the responsible lecturer of the said course was also familiar with PBL, and more importantly, thought that it would be a good idea to try it. Thirdly, past experience told that the number of students who took the course at LUT was moderate. It was expected that approximately ten students would participate in the course.

Table 1. Gas dynamics before the reform.

| Gas dynamics (4 cr.) | |
|---|---|
| Aim: | Students learn about the different phenomena in compressible flow. |
| Contents: | Basic differential equations in compressible flow, Mach number, shock and expansion waves. Flow through nozzle and diffuser, supersonic wind tunnels. Lift and drag in supersonic flow. |
| Modes of study | Independent studies 32 hrs, joint study sessions 16 hrs, laboratory assignment and exam. |
| Assessment: | Final grade: 0-5, exam 100%. Tests done during study sessions affect the final grade |

As the number of credits the student achieves from the course would not change, it was decided early on that the hours in the course would remain the same. The foundation of the renewed course are the lectures, and there are 7 x 2 hours of lectures [1]. In addition to lectures, there are two separate PBL problems during the course. Each PBL problem comprises two joint sessions, three hours each. This, combined with the lectures, means that there are in total of 20 hours of contact education in the renewed course. This means that there are 26 hours for independent studies. The amount of independent studies is divided

[1]At LUT the academic year is divided into four periods, each seven weeks long.

so that there are 10 hours for each PBL problem. The remaining six hours are assigned for getting prepared for the test.

There is no traditional exam in the renewed course, and it is assessed by the written reports each student prepares in the independent study section on both PBL problems. These two short written reports account for 80% of the final grade. The remaining 20% come from a simple test held at the end of the course. Only these two components affect the final grade, i.e. the group accomplishments are not assessed. During the planning it was thought that the test would be either a short and simple exam done traditionally, tests held on the Internet, or problems requiring calculus. The last method was used in the pilot course. There were three problems which required calculus and use of the taught theory. The students were given one week to solve each of these problems. The basic principle of the renewed course is presented in Table. 2.

Table 2. Gas dynamics after the reform.

| Gas dynamics (4 cr.) | |
|---|---|
| Aim: | Students learn about the different phenomena in compressible flow. |
| Contents: | Basic differential equations in compressible flow, Mach number, shock and expansion waves. Flow through nozzle and diffuser, supersonic wind tunnels. Lift and drag in supersonic flow. |
| Modes of study | Lectures 14 hrs, PBL assignments 12 hrs, independent studies 26 hrs. Test. |
| Assessment: | Final grade: 0-5, PBL tutorials 80% and test 20% |

## The setup of PBL problems

The setup of the two PBL problems in the course is challenging. During the planning, the first step was to draw general lines on the subjects which the problems and therefore the setups would be linked to. When the aims of the course were studied, it seemed feasible that the general categories should be e.g. shock and expansion waves, supersonic wind tunnels, lift and drag, and so forth.

The general text books on the subject of gas dynamics have a great number of illustrations, where different objects in a supersonic flow are presented. These kind of photos would make good setups for the problems.

Two different photos were chosen for the course. For the first problem the setup was a photo featuring a conical wedge in supersonic flow. The photo was found in a text book, and it has been taken with Schlieren optics, so the shock and expansion waves are visible. The second setup was a photo found on the Internet, featuring a jet fighter entering supersonic speed.

## The renewed course in practice

The joint sessions were similar for both problems. The first sessions, preceding the independent studies, began with the selection of a chairman, a secretary, and an observer. The task of the chairman was to ensure that the time reserved for the discussion was not exceeded, and that the discussion advanced. The chairman also ensured that the secretary had enough time to write down the ideas and thoughts (and that every idea was recorded) and that everyone had their say in the discussions. The secretary wrote down all the ideas arising from the students, and the observer observed the participation of everyone and gave individual feedback to everyone afterwards. The main task of the observer was to encourage everyone to participate by his/her presence.

After the roles were assigned, the tutor presented the setup of the problem (in our case the above-mentioned photo). After the problem was presented, the first phase was brainstorming. During the brainstorming, the students discussed what ideas and thoughts the problem invoked in them. When there were no new ideas anymore, the next phase began. In this phase the students discussed the ideas and thoughts they had. Ideas were criticized and commented on, and at the end of the second phase the best ideas (around five) were selected (e.g. by voting) for further analysis.

In the third phase, the selected best ideas were discussed in more detail. The students commented on the selected ideas and whether they provoked any new insights and thoughts. During the third phase the students also considered the aims of the studying: what they needed and wanted to learn about the subject. In the end of the third section, the best ideas were selected once again.

In the last phase, the students defined the problem which they addressed during the independent studies. In this phase the last remaining ideas were discussed, bearing in mind the learning goals they had formed during the previous phase. By means of discussions and voting the students had formed the problems, and this case the problems the students formed for themselves to solve were the titles for the written reports. From the first setup the student formed the title: "The effect of shock waves on the flow field", and from the second setup "Phenomena in the flow field when transferring from sub-sonic flow to super-sonic flow".

The students were required to familiarize themselves with the written reports of the other students before the succeeding joint session.

The latter joint sessions began also with the selection of a chairman, a secretary and an observer. In the first stage of the succeeding session the students commented on the reports in general, and highlighted any interesting and important points in the reports. After the discussion the best and most relevant points were selected for more detailed discussion, and this was continued similarly to the preceding joint session. In the end of the second session the students had a list containing the most important and relevant points from all the written reports.

During the different phases the tutors oversaw the discussions and interfered only where appropriate. Mostly the tutors asked simple questions just to get the students to think about the problem from a certain point of view, or to encourage them to continue in a certain direction.

In addition to the PBL problems, there were three different calculus problems for the students to be solved. The topics of these problems were one-dimensional compressible flow with heat transfer, oblique shock waves and expansion waves, and converging-diverging nozzle. These problems supported the knowledge learnt in the lectures. The students performed well in these problems, and the problems showed that the students were able to use the methods introduced in the lectures to practise. The grades for these problems were better than the overall grades of the course given to the students.

### Schedule of the renewed course

The course lasted for seven weeks. The first joint session of the first PBL problem was held after the second lecture, on the second week of the seven-week course. This way the students should already have basic knowledge about the shock waves before the session. After the joint session the students were given two weeks to finish their written reports, and then they had a few days to familiarise themselves with the written reports of the other students. The second session of the first problem was held two weeks after the first session. The schedule was similar for the second problem, and its first session was held a week from the second session of the first problem. This enabled the whole course (apart from the test) to be held in the time frame of seven weeks.

## FEEDBACK FROM THE STUDENTS

The renewed course was held for the first time in the fall of 2010 (Sept-Oct), so there is no official course feedback available yet to assess how successful the alterations were. Six students participated in the course this time, so it would be pointless to make far-reaching conclusions on the basis of the course feedback results, even if they were available.

After the course, informal discussions were held with the students. In this discussion the students indicated that they liked the idea of PBL. According to the students it was a refreshing change in an otherwise traditional curriculum. The students also stressed the point that it is indeed paramount that the idea behind PBL and the process are explained in detail before it is used, especially when this kind of learning method is used for the first time. The idea of PBL was explained to the students, but they still told that it should have been explained in more detail. This lack of knowledge of the idea behind PBL was quite clearly seen in the first PBL problem and the written reports the students made. These reports reflected the students' idea of what the lecturer would want them to write in this work rather than what the students were interested in or what new information or knowledge they wanted to receive. The students told that the second problem went much better, because they already knew what was coming, and these reports were better.

In the discussion the students also pointed out that they felt that their theoretical knowledge after the course was deeper compared to the courses taught in the traditional way. However, the students felt that their calculation routines were not as good as they would be in traditional teaching. There were no practise sessions in this course and the mechanical calculus was left for the students' own activity and test problems. This problem could be solved by having exercises or by giving the students more than three tests requiring calculus.

When asked, the students admitted that they did not use all the time that was reserved for the independent studies effectively. When the matter was discussed in more detail, a few main reasons were discovered. The first reason was the combination of defective instructions and confusion about a new learning method. As mentioned above, the tutors should have been more thorough when describing the ideas and principles behind PBL. The tutors should also have given more information and instructions for the students to use more literature references and to what kind of literature they should use. One reason was that during their studies, the students are mostly told in detail what is expected of them during any course. In this case the students formed the problem by themselves, and during the independent studies they tended to think about what was the minimum requirement and worked with that in mind. The last problem could have been avoided if the principles of the method were clearer for the students.

In the discussion the students assured that if PBL was used again, the independent studies would be more thorough, as they would understand what the idea of PBL is. As mentioned above, this was seen to some extent during the second problem, but the students still admitted that the time could have been used more effectively.

## CONCLUSIONS

In this article, the feasibility of using problem-based learning in graduate engineering education at Lappeenranta University of Technology, and the design of a PBL-based course was discussed. On the basis of the literature survey, PBL seemed to be worth trying also at LUT.

An existing course held by the Laboratory of Fluid Dynamics was chosen and reformed to be taught using PBL. The renewed course comprises lectures and two PBL tutorials. There are 14 hours of lectures, 12 hours for joint sessions of PBL tutorials, and 26 hours for independent studies. The independent studies are divided between PBL problems (10 hours each) and independent studies for the test (6 hours). The renewed course is assessed on the basis of the two written reports (80%) and the test (20%).

According to discussions held with the students, it seemed that the students liked the general idea of PBL, and believed that it was a right way to develop the education. Even though the feedback was informal, and the number of students was low, this encourages the authors to use PBL at least on the gas dynamics course in the future, and probably to try it on some other suitable courses in the near future.

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