Teaching Control Theory Using Problem Based Learning

Anna Hagenblad, Inger Klein

Division of Automatic Control
Department of Electrical Engineering
Linköpings universitet, SE-581 83 Linköping, Sweden
WWW: http://www.control.isy.liu.se
Email: annah@isy.liu.se, inger@isy.liu.se

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Abstract

Problem Based Learning, PBL, has been used for several years, especially in the medical community. At Linkping University, now also the program in Information Technology is taught using this method. We describe how PBL is used in a basic course in control theory, including linear algebra and Laplace transforms. The experience from the first three years of the course is promising. The students are in general more active and more motivated than students in traditional courses. The teachers spend roughly the same number of hours on the course, but the focus has shifted to more contact with the students.

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Abstract

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1. Introduction

Problem Based Learning, PBL, was introduced at McMaster University in Canada in the 70:s [1]. By letting the students discuss situations relevant to their education and future profession in small groups as a starting point for their learning, it is believed that the students will be more motivated and their learning more relevant to their future education. There is to our knowledge no clear evidence that the students will learn better. However, some studies suggest that they will be able to retain the information better, and that the acquired knowledge will be deeper [2]. Often using PBL also means changing the contents of a course in the sense that integration between different subjects is emphasized. The method has been used with good results, especially in medical schools [1].

Recently PBL has also started to be used in other areas, e.g., engineering [4], [5]. The main idea is to encourage the students to seek the knowledge by themselves, preparing them for a professional life where the ability to learn new things is crucial. Another main feature is that the students work in small groups where they have not chosen their group mates. Thus they get training in working in groups, which is also important in the professional life of most engineers.

In this paper, we describe our experiences teaching a course in control theory using PBL. The course also contains some linear algebra and Laplace transforms. In section 2, we describe the PBL method in general. The details of our particular course, including examples of the concepts described in section 2, can be found in
section 3. Section 4 describes a few aspects when introducing PBL in engineering and section 5 our experiences regarding results, including comments from students. Conclusions can be found in section 6.

2. The PBL concept

Since PBL is used in many places around the world, there are several different approaches. Here we describe some general concepts that are often used. The tutorial group meetings are central in PBL, and are described in section 2.1. Other learning resources are referenced in section 2.2. The role of the facilitator is discussed in section 2.3. Section 2.4 describes how different subjects can be integrated in a PBL framework.

2.1. The vignettes and the tutorial group meetings.

A basic element of PBL is the problems, or vignettes, that are used as a starting point for learning. A typical vignette may describe a situation related to the contents of the course, and also related to a professional experience in the future career of the students. The vignette should inspire the students to review their knowledge of the subject, formulate problems, and identify what they need to learn to solve those problems.

Twice weekly the students meet in tutorial groups together with a facilitator. During this meeting they face a vignette as described above. Departing from this vignette, and the goals for the course, the students together formulate learning goals, to achieve until the next meeting. The learning is thus goal driven, and each student takes responsibility for his or her own learning. The course goals are hence very important, and great care must be taken when formulating these.

Often a special model is used for the discussion of the vignette. One example of such a model is shown in Figure 1.

![Figure 1. The problem solving process](image)

The discussion starts with reading the vignette, and clarifying unclear terms. Brainstorming is often a good way to start thinking about the concepts, and get ideas for how to approach the problem. The result of the brainstorming could be a list of words related to the situation described in the vignette.

The third point consists of analyzing the result of the brainstorming. During this phase, the students typically ask themselves questions about the connection between different phenomena. The students also share what they already know about the phenomena. It is natural that different students come to the tutorial group with different preconceptions. This is a chance to share the previously formed ideas and to arrive at a somewhat common ground.

After analyzing the results of the brainstorming, the students decide on one or a few problem formulations. Since the vignette may have spurred several ideas, this limits the scope of the problem. The problem formulation is then the basis for formulating learning goals. The learning goals are also often related to the course goals.
The learning goals are common for the whole tutorial group, but each individual student is responsible for how he or she reaches those goals. This is different from e.g. project work, where the group divides the workload to reach common goals.

When the tutorial group meet again, typically three or four days later, the vignette is reviewed and the newfound knowledge is applied to the problem. The group may then start over with the same vignette, now using their new understanding as a starting point, or discuss a new vignette.

2.2. Learning resources

To assist the students' learning, there are several resources. In general, there is no single given course book, but a literature list consisting of several books, available at the library. The students are also encouraged to search for information on their own. There are lectures, but typically less than in traditional courses. The lectures do not define the course, but present important concepts and/or overviews. In some courses, the students have the possibility to ask for a lecture about a specific subject. It is also common that the teacher is available at scheduled times for the students to ask questions. Another possible resource is to engage an outside expert to answer the students' questions.

2.3. The role of the facilitator

The facilitator that follows the tutorial group during the semester has an important role. He or she should let the students lead the discussion, but still make sure that it does not go too far from the course material. To challenge the students to reflect over their preconceptions, the facilitator may ask questions such as: Why do you believe that? How did you come to that conclusion? The facilitator should also guide the group process, e.g., make sure that everyone is heard. An important part of the group sessions is the evaluation, where the students evaluate how they and the group work, and give suggestions for improvement.

Since the facilitator often follows the tutorial group during several different courses, he or she cannot be an expert in all the different topics. It is however commonly believed that the facilitators should at least have a possibility to understand the discussions. In our case, on the Information Technology program, this means that the facilitators should have a technical and mathematical understanding.

The question of training for the facilitators is often discussed. It is sometimes argued that a background in group dynamics and group processes is desirable. Due to time limits often the facilitators have minimal such training. To our experience this is not a major problem, since the persons willing to become facilitators often have a natural interest in these subjects.

2.4. Integration between subjects

PBL is well suited for integration of different subjects into one course. The vignettes can illustrate the connections between, e.g., mathematics and an applied subject, and thus increase the motivation. PBL also uses the students' different experiences of and perspectives on a subject. The learning goals are formulated by the tutorial group, but since each student may need to work on different parts of the learning goals, the learning is individualized, and leaves room for the students to pursue their own interests within the subject.

3. Using PBL at the program for Information Technology

Our experience of PBL comes from courses in engineering at Linköping University. Linköping University has used PBL in the medical school since 1986, and inspired by this some engineering courses have also been based upon PBL. In 1995 the university started an engineering
program in Information Technology, based on PBL. Section 3.1 describes some details from the course "Linear Feedback Systems". An example of a vignette and learning goals are given in section 3.2.

3.1. Course details

During the sixth semester, the students take the course "Linear Feedback Systems". This is a basic course in control theory integrated with mathematics. Control theory is in itself very mathematical, but in addition some "pure" mathematics, linear algebra and transform theory is included.

There are two responsible teachers, one from the mathematical department and one from electrical engineering. One teaching assistant from each department is involved. The course includes tutorial group sessions, lectures, both in control theory and mathematics, exercise sessions and laboratory exercise. It is a seven-week course, from the middle of March to the end of May, with a two-week Easter break. During the course, the students have four special exercises to turn in. The laboratory exercise is done in a free form, but with a teaching assistant available to help mainly with practical problems. The course ends with an exam, where the students are allowed to use computer software (Matlab, Maple) to solve the problems. Furthermore, most books in the literature list are available at the exam.

Since we believe the use of mathematical software tools to be vital to a control engineer, we have integrated that into the course. Most of the problem solving sessions take place in a computer laboratory, and the students have access to the computers on non-scheduled time. The software is also available at a low cost for the students that have a computer at home.

3.2. Examples of learning situations

The students meet twice weekly in tutorial groups. Older students, who have previously taken the course, and Ph D students from the department of Electrical Engineering or Computer Science, act as facilitators. Some groups will thus have a facilitator who is an expert on the subject, while other facilitators only have rudimentary knowledge about control theory. The facilitators have participated in a four-day training course.

On each tutorial group meeting, the students discuss a vignette. An example of a typical vignette is shown in figure 2.

Modeling of a tank with measured outflow

A tank in the process industry is shown above. The outflow from the tank \(v(t)\) is given by the consumption, that is, cannot be controlled. However, it is possible to measure the amount of liquid pumped out of the tank. Two process engineers discuss how to control the valve automatically.

Maria: We must measure the height in the tank and base the control law on \(h(t)\)!

Frans: No, the most important thing is the outflow from the tank. Of course we should measure the outflow and base the controller upon \(v(t)\)!

Figure 2. Example of a vignette used in a tutorial meeting.

The students discuss the vignette and formulate learning goals guided by the course goals. The learning goals may include things like learning a specific concept, learning what it takes to solve a
problem outlined in the vignette, and solving specific exercises related to the problem.

From the vignette in figure 2 the students can discuss how measured disturbances can be used in a controller, in particular the concept of feed-forward control and compare this to the already known concept feedback control. Furthermore general modeling aspects can be discussed.

At the next meeting the students follow up the learning goals to see if they have acquired the knowledge they needed. If necessary some learning goals are reformulated and used again.

One tutorial group formulated the learning goals for the vignette in figure 2 as follows: How can a PID-controller use $v(t)$?; Alternatives to PID control when $v(t)$ is used; Compare control laws using $v(t)$ with control laws using $h(t)$.

4. Aspects when introducing PBL in engineering

When introducing PBL in an engineering environment, there are certain aspects that have to be taken care of. In section 4.1 certain problems and advantages encountered when integrating different subjects is pointed out, and in section 4.2 we emphasize the importance of developing mathematical skills.

4.1. Integration between subjects

The integration of two subjects can be a difficult task, and requires some work. The involved teachers must believe in the concept, and be willing to sacrifice part of their own independence to integrate different subjects. We believe however that the advantages in form of student motivation and understanding are worth the effort. The key to success in this case is the close connection between control and mathematics; the students can readily use the mathematical tools to solve control problems. We have also found that the integration is facilitated by having one "leading" subject, here control, and one supporting subject. Furthermore it is important not to try to integrate too many subjects at the same time. That would mean too many teachers involved, and it is often difficult to find the close connection mentioned above.

4.2. Developing mathematical skills

PBL cannot be used in an engineering environment without support for the students to develop mathematical skills. The students must be encouraged not only to read and discuss, but also to develop mathematical skills by solving problems themselves. We believe that it is necessary to work actively solving mathematical problems and control problems, not only to develop mathematical skills but also as a basis to develop a deeper understanding. To support this part of the learning process there are exercise sessions as well as the special exercises that the students have to turn in during the course.

5. Experiences and students' opinions

The course has now been given three times, and the first students have started to work as engineers. No official evaluation has yet been performed, and since there are only 20-30 students every year, general conclusions are hard to make. The following are our observations from this limited number of students.

We have found that the students are more active than students studying a traditional curriculum are. The tutorial groups aid the students in planning their learning, and not leaving everything until the last week before the exam. They take responsibility for their own learning, and take
active part in course evaluations including suggestions for modifications to the next year. The impression is that the students want to emphasize the tutorial groups and the work performed there. They appreciate alternative exams, e.g. open book exams and oral exams, in contrast to the traditional written 4-hour exam.

From a teacher’s viewpoint, it is rewarding to work with motivated students. Our impression is that, apart from the tutorial groups, the teachers do not spend more time altogether using PBL. However, the focus has changed so that more time is spent in direct student contact. This is also mentioned in [3], where PBL and a traditional way of teaching at a medical school are compared regarding costs. One could argue that this is a small group of students, and hence the contact between student and teacher will automatically be increased, but to our experience there is still a significant difference compared to other small student groups.

Students who have started their professional life say that they appreciated the training in group work. They also feel that they have learned to tackle new problems and to structure difficult tasks.

6. Conclusions

This paper describes PBL and our experiences using PBL in an engineering environment. In our opinion the key of all teaching activities is to put the student in the center, and we believe that PBL is one way of achieving this. The students become more active taking responsibility for their own studies. Furthermore it is natural to integrate different subjects, giving knowledge not only about the different subjects but also their connections. Most engineers work in project groups, and the experience of group work is highly valued by future employers.

We believe that PBL has something to offer the Electrical Engineering teaching community, and the results from the Information Technology program at Linköping University is promising.

7. References


