World Transactions on Engineering and Technology Education
Vol.1, No.1, 2002

Problem-Based Learning in engineering education: a catalyst for regional industrial development

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ABSTRACT: Two major outcomes from universities are research results and graduates. How can we optimise the usability of these outcomes to society, and to industry in particular? A fundamental prerequisite is a good dialogue between industry and university to improve the university knowledge on what is needed outside the university on the one hand and to improve the knowledge outside the university of the opportunities present within the professional capacity of the university on the other. The dialogue must be able to cope with a dynamic industrial and technological change, which is often very difficult for rigid university planning. The implementation of Problem-Based Learning (PBL), with a high degree of focus on the integration of real-life engineering problems in the study programme, has been shown to be a good way of initiating and maintaining this communication. A case study from Aalborg University, Aalborg, Denmark, also shows how establishing a university in a region with only little industrial activity can stimulate and, to a large extent, be the basis for a development of this region to an industrial community with world class competence.

INTRODUCTION

The development of new industrial organisations require engineers with entrepreneurial skills, with significant communication and persuasion skills, the ability to lead and work effectively in a multidisciplinary team and an understanding of the non-technical forces that profoundly affect engineering decisions. Those abilities and skills are rarely addressed by traditional classroom lectures and instructions.

Students at traditional universities are educated on the basis of basic research carried out in the laboratories, and in this way the graduates will be well educated in theory and reach a high level of academic understanding. Engineering is, on the other hand, based on application and problem solving. Technical universities in particular are now doing more and more applied research in addition to the fundamental research activities, and the introduction of Problem-Based Learning (PBL) has added some additional skills to the profile of new graduates. This paper will focus on one way of implementing PBL in engineering education and the impact on society and industrial development.

FROM SOCIETAL REQUEST TO UNIVERSITY OUTCOME

Knowledge and understanding of the fundamental meaning is the basis for creating new opportunities. In modern times, it is obvious that research results created in university laboratories must be used to create new tools and better conditions for the future living of the human species. Funding good researchers and leaving them alone in well-equipped research laboratories is one way of setting up conditions that will be appreciated by many well skilled professors. But we may also run the risk that the research carried out will be of pure academic interest for no use for society within a reasonable time. The funding of research by private companies or foundations will often only be given if some realistic goals and outcomes are defined within the description of the research project. Of course, private foundations also fund fundamental research, but it is evident that some more immediate results must be achieved.

Research is the basis for educational programmes to facilitate the highest possible degree of theoretical education. In contrast to earlier stages of the educational system, modern graduates are not just educated for an academic career that is for teaching new students. An increasing number of university graduates are needed in industry, but in addition to theoretical knowledge, they also must be equipped with skills in application of their knowledge, cooperation, teamworking skills, social skills, skills in communication and documentation, etc.

Engineering workplaces, their organisation and context have undergone significant changes. In general, companies want to hire engineers with good teamworking skills and entrepreneurial attitudes, which can adapt them to a company's culture quickly, develop engineering solutions to industrial problems, collect the information and data for problem solving, and sell their ideas to different levels of people within the organisation [1].

The ability to solve problems is more than just accumulating knowledge and rules; it is the development of flexible, cognitive strategies that help analyse unanticipated, peculiarly structured situations to produce meaningful solutions. Real-life problems seldom parallel well-structured academic problems; hence, the ability to solve traditional school-based problems does little to increase the relevant, critical thinking skills that students need to interact with life beyond the classroom walls. Well-structured problems with their sterile environments in which there is only one right solution simply teach students about problem solving, not how to solve the problem. Instead, real-life problems present an ever-changing variety of goals, contexts, contents, obstacles and unknowns that influence how each problem should be approached. To be successful in their chosen career, students need to practice solving problems that reflect life beyond the classroom. This skill is the goal of Problem-Based Learning (PBL) [2].

PROBLEM-BASED LEARNING

An excellent way to learn and understand a theory is trying to see whether one can apply the theory. Engineering is problem solving by applying results from engineering research. Therefore, it is obvious to try to combine the fundamental learning process and engineering problem solving. Project organised PBL, as implemented at Aalborg University (AAU), Aalborg, Denmark, is described in the book *The Aalborg Experiment* [3].

The curriculum is organised in semesters. One semester is a 20-week programme at the University. Each semester has its own theme such as Analogue and Digital Electronics (3rd semester), Microprocessor Systems (4th semester), Real-Time Communications Systems (5th semester), etc. The project work - approximately 500 hours of workload for each student - must be within the theme, and some project-related courses are offered to the students. In addition, students must take some mandatory courses such as mathematics, computer science and circuit theory. The load for coursework will normally be another 400 hours each semester.

It is important to note that the PBL practice described in this paper is implemented as an educational methodology and philosophy – not just working with situation specific well-defined problem parameters that lead to predetermined outcomes with one correct answer on classroom basis. This organisation of the curriculum implies that students learn to apply the theoretical courses from the very beginning. Furthermore, mathematics and other fundamental courses are spread over several semesters – before the theories are needed but at a time where students are motivated to improve their theoretical skills in that field.

Real-life problems are not defined in engineering terms. Therefore, *problem analysis, definition* and *formulation in engineering terms* are very important before starting with the problem solving. The *problem solving* part of the project is by far the most demanding part, but it is also very important in that the students learn how to document and communicate the process and results to engineers. At the end of each semester, the students must pass an oral examination based on a report of up to 150 pages plus hardware and software documenting their project. This examination normally takes up to six hours on a group basis that results in individual marks. In addition to this, students must pass individual examinations in the mandatory courses.

The PBL concept (see Figure 1) allows students to develop excellent analytical skills that are complemented with good experiences in coping with and attacking complex engineering problems. In addition to gaining thorough theoretical insight, students become experienced in applying theoretical elements from the lectures in practical engineering problem solving.

A great variety of projects at all professional levels must always be accessible and must be done in cooperation between university (students and researchers) and industry; this is necessary in order to find enough relevant real-life problems. On the other hand, this cooperation will increase the contact and mutual understanding between industrial development centres, students and university professors with benefit to all partners [4].

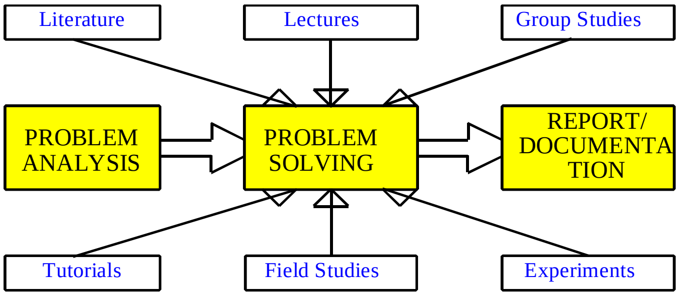

Figure 1: The main principles of PBL [3].

STUDENTS AS DIALOGUE CHANNELS

With 180 engineering student teams carrying out one project each semester, more than 300 project proposals are needed per year – this is the situation for the programmes in electronics and information technology at the AAU. A good dialogue and good personal contacts between professors and engineers in industry is therefore a must: to have enough real-life engineering problems at all levels. Many companies have realised that a team of students can do a great job trying to find a good solution to one of their problems, even though the goal for the students is to learn and the problem is just a tool. However, students do not want to end their work in an unfinished manner. Therefore, their work must do more than just meet the needs to pass the examination; from this they become better engineers.

In this way, very good and intense dialogue will be established between the company and the university. The dialogue involves engineering staff and project managers in the company and from the university both teachers and students. Thus it is not just formal contacts on a management level, but contact that make things happen on the engineering level. The outcome from such teamworking can be:

- A prototype for a new product.
- Ideas for new products.
- Ideas for new projects.
- Ideas for new research.
- Contacts for future networking.
- Contacts for future jobs for the students.
- Job offers for students in their spare time.

Most modern companies organise their engineering work in teams. Even though this can take many forms, students with a PBL background adjust very easily with their job task and are productive from the very beginning.

WORK-BASED PBL

In some countries many engineering students never finish their engineering education. Because of the deficiency of educated engineering staff, still more 2nd or 3rd year engineering students are engaged in local industry – initially on a part-time basis. At first, this is positive for the students, as they earn money to cover their living expenses, and for the local industry, as they have access to dynamic and inexpensive staff members willing to work whenever needed. Some companies even invest in these young staff members by giving them additional company-internal education.

However, there are also severe drawbacks with this trend for students, companies, universities and polytechnics and also for society. For the students it can be difficult to foresee the consequences, but far too many drop out and never graduate. Major companies invest in educating these students to be good staff members, but small and medium-sized enterprises (SMEs) do not have the resources to do that and they could be the losers. Universities and polytechnics invest a lot of resources in those students. Improving the content of the engineering programmes can reduce this waste of resources. In the long run, this situation may result in more company-based education, resulting in a less flexible engineering profession, less usable staff for SMEs and survival problems for some polytechnic and university educational programmes.

It was ascertained from the implementation of PBL in full-time educational programmes that learning by applying the theoretical material in engineering problem solving (development) is a strong way to learn. This is inspired by the everyday learning process in industry – without doing it *on purpose*. Carrying out the engineering task, the engineer might seek information from a textbook, scientific papers, etc, and apply the information to the development task. The purpose here is not to learn but to solve the problem and the increase in the competence level is an attractive side effect. In light of the experiences from this concept, some further development would make it possible to integrate productive engineering and engineering education, as shown in Table 1.

Table 1: Elements of problem solving in different contexts.

Learning by problem solving	Engineering problem solving
• The problem is a tool • Learning is the goal	• Professional skills are the tools • The goal is to solve the problem

TEAMWORKING

It is also important that engineers do not work in isolation – real-life engineering problems are solved in teams of well-skilled individuals who integrate their capabilities into solving huge and complex problems. As such, teamwork has always been a part of the PBL concept at the AAU [3][5].

The pedagogical model, which is centred on problem-based, project-organised teamwork, has been evaluated to be an absolute strength of the educational system [6]. The *group-based project organised teamwork* is a very important element in the learning process. It increases students' skills in professional argumentation, the presentation of proposals for solutions and the critical evaluation of proposals from other students. The preparation of documentation in the form of reports, scientific papers and posters, together with oral presentation, prepares students for future productions of written material and the preparation and performance of oral presentations.

Being part of a team, students learn how to cooperate in solving major engineering problems. They learn how to deal with professional discussions in situations like problem definition and argumentation for their choice of solution. They learn how to sort information and what is needed now and what is nice to know later. Students learn how to argue about and explain in scientific terms what they believe is the right solution – it is not enough to claim you are right, you must be able to convince other group members: a*rgumentation is a good way to learn.*

Students learn how to organise teamwork and that a team does not work if everybody is not doing their part of the job. In this way, students assimilate an attitude to work different from what is possible for students doing traditional university studies on their own. In return, students will get the feeling of safe social surroundings as other students expect them to show up every morning; if they do not, they will probably be contacted to find out what is wrong. Teamwork also has the effect that students motivate each other. Of course, students go for solving the problem - engineering is about problem solving - and they define some sub-tasks for each member of the group. To succeed in the task, students have to read the text, research extra information, read some scientific papers, search the Internet and do some programming or whatever is needed. As students do not wish to end up with a bad solution, they work very hard on their project. The project is the key element in the curriculum; students apply the theoretical courses in problem solving, and can also reflect on their professional work via the project.

CASE STUDY: RADIO COMMUNICATION CLUSTER

The region of North Jutland in Denmark, with Aalborg as the main city, has traditionally been characterised by the highest rate of unemployment in Denmark. The AAU was established in 1974 as a state university and two engineering colleges were integrated into the University with around 200 academic staff members. From the very beginning, the AAU had the potential to become a fairly powerful education and research institution, and there was a good match between the few existing radio communication firms and the profile of the staff in electronic engineering. Before 1974, only the Technical University of Denmark (DTU) in Copenhagen awarded graduates with an MSc in Engineering in Denmark. In the late 1990s, the AAU's share of MSc graduates had increased to around 50% [7][8].

As described above, from the very start in 1974, engineering education was implemented as PBL. The acceptance by industry was very reluctant in the beginning – the impression at that time was still that students should learn by listening to professors lecturing and not by project work in groups. Later on, teamworking skills became a requested skill for engineers, and industry realised that having a group of students working for a semester with one of their engineering problems could be a profitable way to test new ideas and possibilities – and testing potential staff members!

The direct research spillover effect from the AAU to the local radio communication industry did not have considerable importance initially, but the indirect transfer of knowledge via newly graduated engineers was highly important. As more AAU graduates and their professional skills became visible in the industry, the interest from the industry increased and more attention was given to research cooperation.

In the early 1980s, there were four companies in the business of radio communication in the region. Since then, the region has developed into a major centre of competence for wireless communications, ie mobile communications (GSM, GPRS, CDMA, UMTS, Bluetooth, etc), cordless systems, test equipment and equipment for maritime communications such as GMDSS, GPS based equipment, VHF and satellite communications. The region now has around 40 companies within these fields including both locally owned companies and several international companies – the main players in that business. The majority of the companies formed a club in 1997 – now a formal association together with Aalborg University and the science park NOVI. This association, called NorCOM, is one of many professional networks in the region [9].

The capability of Aalborg University to deliver engineers and basic research with a sufficient application-oriented touch is a core asset to the region. A technical university may thus play a rather direct role in the restructuring process of a region previously dominated by traditional industries. What has distinguished this region from others appears to have been a widespread awareness about the importance of further developing the technological basis for the cluster.

ENGINEERING EDUCATION IN THE FUTURE

In the PBL concept, the main goal is to learn – learning by combining courses and engineering problem solving. Problem solving is a tool for learning in the PBL concept – solving the problem is not the primary goal. Combining these two ways of thinking is obvious [10]. The challenge will be to use a modified PBL concept to combine productive engineering and academic learning; it will involve combining industrial tasks for students with their study tasks. Other areas include:

- Substituting university-based projects with company-based projects.
- Substituting teams of students with company-based teams.
- Re-arranging the curriculum into fewer courses and including work-based learning.
- Achieving acceptance among staff and management at the university.
- Achieving support and commitment in industry for the students' learning process in teams.
- Obtaining cooperation between industry and university about projects that guarantee the learning context for the students beneficial for student, company and the university.

CONCLUSION

As part of an international evaluation of engineering education in Denmark, graduates from the AAU were asked about how important they judged several skills to be and what priority they found these skills were given in their education at the AAU. For comparison, the same questions were asked of graduates from a traditional university in Denmark [11]. Very clear differences were found regarding the skills in:

- Communication (written and oral).
- Ability to define engineering problems.
- Ability to carry out a total project.
- Carrying out technical development and research.
- Cooperating with people from different educational and cultural backgrounds.
- Including social consequences of the technical solution [11].

Generally, all were in favour of the PBL approach. These skills were recognised as the results of the pedagogical concept. All these skills were trained in the group-based projects and, as they were very important for engineers in their professional career, graduates from the AAU were better prepared for their first job after graduation.

The PBL process as such calls for a high degree of cooperation between industry and university. This cooperation will be stimulating not only for the students in the learning process but also for the companies. Students are often free to come up with ideas without being tied up with traditional thinking – and some of them might end up with new patents or products.

The experience gained from the North Jutland cluster has shown that a dynamic cooperative process between professors, PhD students, graduates and undergraduates, as well as the involvement of engineers and managers, is a good basis for improvement. It will give valuable inputs for improvement and the re-engineering of the curriculum; it will give good opportunities for setting up research collaborations and has shown to be an asset for the development of the context necessary for a growing industry. It has also been learned that when the professional and academic competence is known to be present at the university, and the university has shown its willingness to be closely involved in cooperation with industry, the international key players in the business will show up and settle in the region [9].

The next step in the university-industry cooperation is to find the best ways of continuing the maintenance and development of the professional competence within the region. Continuing professional development is an increasing task for engineers in a business with very fast innovative processes and hence a new challenge for innovative universities.

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