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Does Productivity Apply to PBL Methods in Engineering Education?*

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The dominating trend in most educational programs today is converting traditional classroom teaching to variants of Problem or Project Based Learning (PBL) methods. In most programs the general experience is increased motivation among students as well as teachers. However, most programs do at the same time experience problems regarding productivity in terms of the applied teaching resources. Consequently, many programs limit the PBL elements to the senior courses and keep the freshmen courses as traditional classroom teaching. One can ask whether it is possible to run a PBL program that is competitive in terms of both quality and spending of teaching resources. Can PBL programs be competitive throughout the whole program? This paper presents experiences from initiating and driving such continuous improvement efforts in a PBL program at Aalborg University in Denmark.

INTRODUCTION

THE DOMINATING TREND in most educational programs today is converting traditional classroom teaching to variants of problem or project based learning (PBL) methods. In most programs the general experience is increased motivation among students as well as teachers. However, most programs do at the same time experience problems regarding productivity in terms of the applied teaching resources. Consequently, many programs limit the PBL elements to the senior courses and keep the freshmen courses as traditional classroom teaching.

In many cases the transition to PBL is driven by fiery souls that are willing to put a lot of extra energy into the programs. This makes the implementation possible and keeps the development of the programs going. However, also in these cases there are problems regarding productivity and the programs tend to be vulnerable and dependent on a few persons.

One can ask whether it is possible to run a PBL program that is competitive in terms of both quality and spending of teaching resources? Can PBL programs be competitive throughout the whole program? This paper presents experiences from initiating and driving such continuous improvement efforts in a PBL program at Aalborg University in Denmark.

BACKGROUND

Aalborg University in Aalborg, Denmark was established in 1974 as an experiment within higher education. It is the newest Danish University and started with approximately 900 students. Now, twenty-six years later there are approximately 12,000 students of which more than 4000 are engineering students. The Faculty of Technology and Science has about 700 faculty, 200 Ph.D. students, and 150 staff positions.

The pedagogical concept revolves around project-based learning and cooperative learning. Today, nearly 26 years after the establishment the whole engineering curriculum is extensively project-based with project work counting for approximately 50% of the credit hours [1].

Recently, the whole mechanical engineering curriculum has been reviewed and adjusted according to industrial feedback. Only minor changes were requested and implemented. However, we still see a major challenge in further developing the concept of project-based learning and particularly to move our focus towards a continuous improvement process of both the curriculum and the basic teaching and learning system.

LEARNING IN PROJECTS

The Aalborg University model of project-based learning comprises the concepts of problem-based learning and project work.

Both problem-based learning and project work are international educational trends which inspire the development of educational practice at many engineering institutions and the differences seem more complicated and incomprehensive than they are. The ideas of problem-based learning and project work support each other and emphasize different aspects of learning.

The initial German ideas of problem-based learning or experience-based learning were in the

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beginning of the 1970s transformed into a more or less Danish model of problem-based learning including [2]:

- problem orientation
- experience-based learning
- interdisciplinary
- gradual specialization
- project work in groups.

The main idea behind both project work and problem-based learning is to emphasize learning instead of teaching. Learning is not like pouring water into a glass; learning is an active process of investigation and creation based on the learner's interests, curiosity and experience and should result in expanded insight, knowledge and skills. As with more traditional educational systems some of the important questions are:

- How to motivate the students?
- How to determine the elements in the curriculum?
- How to balance the different elements in the curriculum?

Since the most important innovative aspect of problem-based learning is the shift from teaching to learning, the task of the teacher is to some degree altered from the transferring of knowledge into facilitating to learn. Some important questions related to the role of the teachers are:

- How can we make the teacher/student contacts most efficient?
- How does the teaching task comply with the research task?
- How can we achieve integration between different teaching subjects?

The questions listed above are all open-ended. Any educational institution has to deal with these questions and the concern has to be of a continuous nature due to the changes in environment and requirements. The project-based learning model at Aalborg University does not provide a magic solution to the questions. However, particularly the project dimension seems to facilitate adaptability in the educational system. In the following example we will discuss this further.

THE PROJECT CONTEXT

The project context is described and discussed under the following headings:

- overall structure
- organizing the curriculum into themes
- project work
- the teacher role
- project examination
- overall structure.

The Mechanical, Manufacturing and Industrial Engineering Program share the first five semesters. After the fifth semester a further specialization takes place according to the programs mentioned above.

The overall structure of the shared program is a one-string system aiming at gradual specialization. The content of each semester is controlled by themes (see below) that are set by the study board and included in a study regulation. The study regulation has to be approved by the University as well as the Ministry of Education. Each theme contains a heading and a further description of content and learning objectives.

The headings of the themes are listed below for the first five semesters. Further descriptions are reported in Creese [3]. In the first and second semester the students are introduced to general study techniques and basic mathematics and physics.

Semester/theme

1. Basic studies program
2. Basic studies program
3. Basic mechanical functions
4. Process realization
5. Production realization

The one-string approach means that the students are not given the options to choose from courses. The options to individualize are fulfilled by the projects.

In each semester 50 % of the time is spent on project work, 25% on courses related to the projects, and 25% on general courses related to the curriculum. The project period is 15 weeks followed by 4 weeks with examinations of both the courses and the project. In terms of credit hours the project counts 15 credit hours and the block of courses counts 15 credit hours. One credit hour equals 20 hours of confrontation and 10 hours of preparation.

Due to the nature of the project work the semester is divided into three periods where the first five weeks are very course intensive and

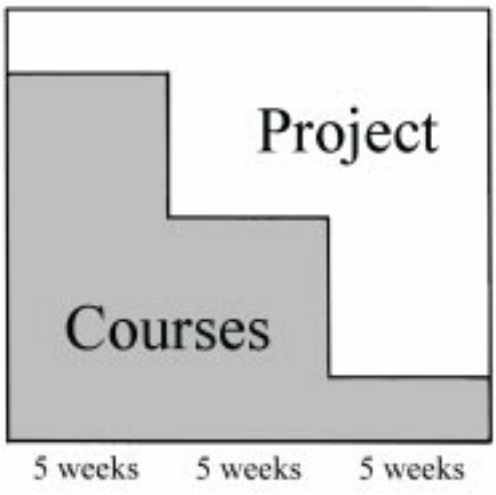

Fig. 1. Three periods of five weeks with change in the ratio between course and project.

the last five weeks are very project intensive (see Fig. 1).

Organizing the curriculum into themes

The projects in the Mechanical Engineering Program are controlled by themes. As described above each semester has its own theme ensuring the gradual specialization.

The themes should ensure studying of the core elements of the subjects included (through the courses given) as well as explore (through the project work) the application of the subjects in professional practice and society. Therefore the themes are chosen and organized according to the following requirements [1]:

The themes must constitute the professional profile of the curriculum.

- The themes must be organized in such a way, that increased knowledge and cognition can be obtained with progression during the study process.
- The themes must have a general expression in order to provide for a broad range of subjects for the project work carried out on the specific theme.
- The themes must have a delimited professional approach in order to provide for teaching the necessary disciplines through courses and for fixing the professional perspective of the project work.

Project work

The courses are taught and examined traditionally on individual basis. The projects are elaborated in groups of 4–6 students. Each group has assigned office space with full access to the Internet and the University Intranet. Today the university comprises more than 1300 offices for student purposes. The groups have assigned one supervisor who guides the group through the project work process and finally he is responsible for the examination (see further below).

The project work process will normally go through a number of generic steps [1]:

- **Problem analysis:** Here the problem is presented, described and assessed in a broad context. The relevance of the problem is evaluated and strategies for standard solutions are worked out. The problem is now to be finally formulated. The project work at this stage is based mainly on discussions, studies of relevant literature and maybe preliminary interviews with key persons in order to confirm the relevance and reality of the problem posed.
- **Problem solving:** Here the criteria of evaluation are laid down, using relevant scientific theories, and possible ways of solving the problem are evaluated. According to the nature and complexity of the problem, there may be a need for further development of existing theories or even for developing new theories. The problem may be divided into partial subjects to be investigated separately, and in detail, using relevant scientific methods. Here the supervisor has an important task of guiding the choice and methods, similar to the research process. The problem posed may call for the use of case studies, experiments, quantitative or qualitative empirical investigations, logical analysis and construction concepts, etc. Here the point is that the choice of methods must be explained and be acceptable according to the problem posed. The results of the investigations are evaluated, compared to the consequences, and again compared to the posed problem. At this stage the project work is characterized by professional absorption through lectures, methodological analysis, fieldwork, etc.
- Report: Here the group has to review the project, set up conclusions, and complete the project documentation. The report will present the studies carried out. It will prove the knowledge established and also how this knowledge was produced. At the final stage the project work is mainly characterized by the tension of approaching deadlines—like in practical engineering. The final result of the project is normally a written report of approximately 120 pages and additional appendixes.

The teacher role

The teacher's role in the project-based learning context is different from the teacher's role in traditional education [1]. Therefore the term 'supervisor' is preferred instead of teacher. The supervisor has the responsibility of guiding the students to complete the project work on time, and in a satisfactory way according to methodological and scientific requirements. Pedagogical skills for guiding the use of scientific theories, and methods for analyzing the problems and elaborating the solutions are therefore essential. This means that the traditional role of the teacher has changed from 'Lord of the lectern', to 'Coach on the side'.

The close contact and the immediate response from the students also facilitate a constant change of the course content. Students tend to apply the most updated theories and techniques in their projects and this forces a corresponding update of the courses. This supports a continuous professional development of the faculty.

However, the experience so far indicates that there has to be a critical focus on the use of teaching resources. The process of supervision can be very labor-intensive and it is easy for the supervisor to be more involved, simply because the problems are exciting and of practical relevance.

Project examination

The emphasis at the examination is on the written report submitted by the students. At the examination, the group makes a collective presentation of the project and each member of the group presents and/or discusses a part of the project. The presentation can be accompanied by demonstration of programs and prototypes.

A discussion and evaluation of the project follow the presentation. The purpose of the examination is to examine the knowledge possessed by the individual student about the project and the connected academic disciplines as well as their broad insight and professional knowledge.

The supervisor conducts the examination and the whole process normally lasts between 5 and 7 hours.

The examination system thus allows for the control of professional relevance and academic standards as well as control of the entire educational program. At the more important examinations including the thesis, the Ministry of Education appoints the examiners from industry and other universities. Examiners at the remaining examinations are appointed among the university's faculty.

THE FIFTH SEMESTER

The Mechanical Engineering Program has a gradual specialization. In the first semesters the students have been introduced to basic engineering and mechanical courses, such as mathematics, physics, materials science, statics, dynamics, strength analysis, and technology processes. The fifth semester is based on these courses, but is more comprehensive including the notions of time and costs. In short the students are to formulate a business plan for the establishment of a small enterprise mainly based on one specific product [4].

The fifth semester involves between 50 and 120 students a year. These are divided into between 8 and 20 groups. The project includes elements such as:

- product analysis
- function analysis
- material analysis
- customers survey
- market analysis
- operations analysis
- operations process charts
- assembly
- cost estimation
- time measurement techniques
- product and process redesign
- creativity techniques
- design for assembly
- design for manufacturing
- choice of machines and equipment
- make/buy analysis
- facility layout
- production planning
- Gantt-chart techniques
- production control techniques
- storage and purchase optimization
- organization
- working environment
- organization theory
- business economy
- budget techniques
- accountancy.

The subjects are individually taught in the associated courses and applied in the one comprehensive project. In the following section the fifth semester is analyzed in more details and discussed in relation to productivity and the continuous improvement efforts for the past five years.

CONTINUOUS IMPROVEMENT EFFORTS

The capability and the quality of the educational system are evaluated within the educational system itself. This is done by a system of internal monitoring.

Internal monitoring serves the purpose of quality management with regard to the relevance and quality of the courses as well as the quality of the entire semester concerning supervising, organization and resources. A monitoring report is presented by the students in co-operation with the teachers. This report is assessed by the Study Board and is used to prepare and improve the same theme the following year.

The theme and the heading of the courses for each semester are fixed and can only be changed with approval from the Danish Ministry of Education. In the following some of the past improvements influencing both productivity and quality are discussed:

- selection of one common project assignment;
- appointment of one coordinator;
- coordination via intranet/Internet;
- monitoring of student groups;
- selection of one common project assignment.

Traditionally the different student groups have worked with different projects suggested by their individual supervisors. The whole team of supervisors then coordinated their suggestions immediately before the semester starts and lay out common guidelines for the project. This approach has many advantages. Especially that the supervisor has good knowledge about the project and often has close contacts to a company involved in the project. These advantages have been important in the process of establishing a project-based learning environment since the results have seen a rich variety of projects. However, after some years signs of fatigue begin to occur (like in any educational system):

- the projects tends to be more stereotypic;
- the projects can vary significantly from group to group in terms of complexity and difficulty.

To challenge these emerging problems it was decided to offer only one project each year. There was some reluctance among supervisors but it was decided to run the experiment.

The first common project was a lifeline to be used on board small sailing vessels mainly in rough

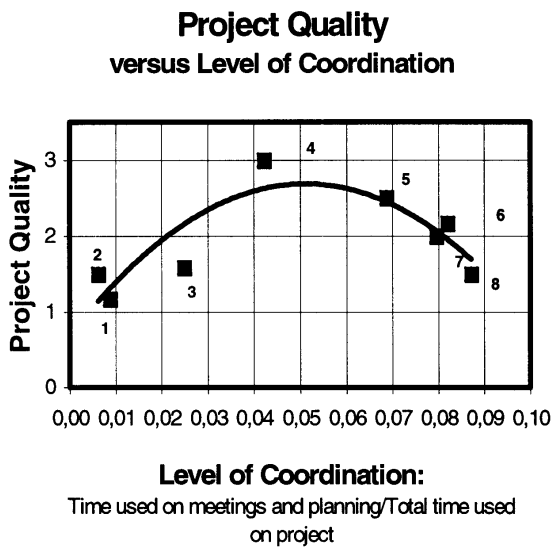

Fig. 2. Level of coordination against the project quality.

weather. The special feature of this belt is that it can vary in length and is self-winding. Furthermore, a patented locking mechanism enables it to be adjusted to different lengths.

The inventor, who is an experienced yachtsman, has produced the lifeline but has not succeeded in turning it into a sales success. Obviously, the students were encouraged by the fact that the product was a real-life product and that their suggestions could potentially be implemented.

Twenty-two groups of students had the same lifeline assignment. It turned out that the groups made 22 very different projects in terms of both product and production improvements. Furthermore, the product was later commercialized, based on the suggestions from some of the projects.

The evaluation of the experiment was very positive from supervisors as well as students and it was decided to continue with only one common project assignment on a permanent basis. The major advantages include:

- better and more reliable background information about the products;
- only real-life products;
- equal opportunities for all groups.

Since this initial experiment each fifth semester project has had one common project. The crucial success factor is to find a new product each semester—new product where there is no known solution so the students as well as the supervisors can be challenges.

In terms of productivity the time for preparing the semester has gone down significantly. This is achieved in parallel with quality improvements.

Appointment of one coordinator

One of the critical issues about project-based learning is the consumption of teaching resources. Normally the supervisor has several functions, first to be a discussion partner for the group, second to ensure a sufficient high level content of the project assignment, and third to take care of practical problems during the project period. The third function can be quite labor-intensive, especially in real-life projects where companies are involved.

The second function is the most critical since it requires broad knowledge of the different courses offered at the particular semester. Furthermore, supervisors are often associated with up to three different semesters at a time.

To challenge these inexpediences a new role of 'coordinator' was introduced in the fall 1995. In short the coordinator took over all functions except the role as discussion partner for the individual groups. The experience so far has been very positive. Since the coordinator takes over the functions with variable and unpredictable loads the load of the each supervisor is limited to scheduled weekly meetings with the groups. This implies more coherent and predictable times for research purposes.

The most important implication of the introduction of the coordinator role is however, that the responsibility for the continuous improvement process as well as the innovation process is assigned unambiguously to the coordinator.

Coordination via intranet/Internet

Following the two above-mentioned initiatives it was a natural development to move all documentation and information related to the projects to the intranet/Internet.

The first attempt was made in 1995 and following a major investment in updating servers and networking technology, the full-scale system was launched in 1996. In the fall of 1997 the system contained:

- project assignment
- course descriptions
- syllabus
- copies of overheads
- technical support information
- schedules
- group formation
- weekly project bulletin.

The coordinator edits the system and the weekly project bulletins make close support possible. This includes information from the associated company and requests from individual groups for specific information.

In 1998 the system was supplemented with a newsgroup option that facilitated collaboration between the student groups. In 2001 this option will be strengthened with introduction of a more dedicated software for collaborate work.

The initiative with one common project assignment, one coordinator, and the coordination via the intranet/Internet also make distance collaboration possible. In 1997 one Danish college has participated in the same project and the intentions for the future is to continue the distance

collaboration with Danish as well as international colleges and universities.

Monitoring of student groups

When the project assignments of the groups are identical it is natural to ask why some projects become significantly better than others. A number of factors might explain this and since 1996 a number of variables has been systematically collected from the groups. Each group fills in a weekly activity log report and this is supplemented with a number of interviews during the project period.

The weekly log reports and the interviews cover variables such as:

- time spend on main activities
- individual experience
- team experience
- supervisor experience
- level of formalization in groups
- level of centralization in groups
- communication tools applied
- decomposition of the project in subtasks
- coordination mechanisms applied:
- schemes
- project plans
- meetings
- coordination roles

The monitoring of the teams in 1996 focused primarily on their ability to coordinate the activities within the groups. By means of the weekly log reports and the interviews we were able to set up measures for the time spent on formal coordination activities and to compare this with a comprehensive quality measure of the project reports turned in. The result of comparing these two variables is shown in Fig. 2.

In terms of explicit coordination Fig. 3 indicates three classes of groups with different level of coordination and different project quality:

- A: Groups 1, 2, and 3: Low project quality and low coordination level.
- B: Groups 4 and 5: High project quality and medium coordination level.
- C: Groups 6, 7, and 8: Medium/low project quality and high coordination level.

Apparently there is no simple explanation in terms of the application of one superior coordination mechanism in the best performing projects.

The process of monitoring the groups has been continued and a number of new variables have been added. Among these is the use of the team-building test developed by Belbin [5]. The results have been presented to the groups in the initial phases of the projects, and based on the recognition by the groups a number of workshops have been arranged to improve some of the assumed weaker roles in the groups, for example, creativity workshops.

CONCLUSION

The paper presents elements of a continuous improvement approach in a project-based learning engineering curriculum. It is argued that there are several options for improving the productivity of a PBL program. Though the project-based learning program faces the same challenges as more traditional engineering program the paper illustrates that the project-based learning program is fast adaptable and that inexperience can be resolved quickly.

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