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Process Competencies in a Problem and Project Based Learning Environment

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Abstract
Future engineers are not only required to master technological competencies concerning solving problems, producing and innovating technology, they are also expected to have capabilities of cooperation, communication, and project management in diverse social context, which are referred to as process competencies. Consequently, engineering education is facing challenges regarding how to facilitate students with scientific-technological competencies as well as process competencies. Problem based learning (PBL) as an educational model is regarded as an effective example regarding preparing students with the expected professional competencies. Based on the educational practice of PBL Aalborg Model, which is characterized by problem-orientation, project-organization and team work, this paper examines the process of developing process competencies through studying engineering in a PBL environment from the learners' perspective. Empirical evidence of this paper is partly drawn on previous work on the development of process competencies and partly on the fieldwork of a Ph.D. study. The analysis of the empirical data lead to the discussion in the following aspects: 1) How do engineering students develop process competencies through doing problem and project based work in teams? 2) How do students perceive their achievement of these process competencies?

Key words: process competencies, engineering education, PBL Aalborg Model

1. INTRODUCTION

As an integral part of a global society, future engineers are expected to master a combination of diverse capabilities. As the National Academy of Engineering points out in the report The Engineer of 2020 [1], engineers will be expected to possess skills as strong analytical skills, practical ingenuity, creativity, communication, business and management, understand the role of leadership, high ethical standards, professionalism, flexibility and life long learning. These are all skills that are already now on the agenda, however, in 2020 the complexity of knowledge and by that the complexity of these skills will increase.

In additional, future engineers are also expected to have capabilities of problem solving skills, innovation, cooperation, communication, project management, and ability to be a life-long learner in diverse social and globalized settings. In order to do that, they must possess the ability to analyse, develop, create and being part of cognitive and social interrelations among human beings in order to facilitate and analyse the development of technology and its impact on society. This is the overall definition of process competencies [2] [3].

Engineering educational institutions are responsible for preparing young people with engineering competencies for the future workplace. Accordingly, educational transformation is an ongoing activity in all engineering education in order to address future needs for technological capacity.

In the past years, some actions have been taken in different engineering educational institutions in Denmark in the transformation process. Firstly, new study forms have been developed to establish student-centred and workplace-imitated learning environments. Secondly, new programs have been introduced to enrich the contents of engineering disciplines. Thirdly, new expectations have been set up to broaden the engineering skills and competencies, which are indicated in the principles of the framework provisions for the engineering study programs. Indicators are the new vocabularies like 'creative

problem-solving', 'communication', 'co-operation and group work', 'management' 'international work environment', etc. in addition to 'understanding of science theories', 'application of modern information technology', 'logical reasoning', 'tackle new problems'. A general trend of increasing diversity in the development of engineering education in Denmark can be witnessed from these undergoing changes [3].

Problem and project based learning can be an answer to these challenges. In this paper we will provide evidence for this. Problem-based learning has become more and more accepted as a useful concept in education, in that it can be employed as a contextualized approach to instruction as well as be implemented as example of student-centred learning environment. The advantages of problem-based learning have specially become the articulated outcome of engineering education to prepare students with the expected professional competencies [4]. The application of PBL at the engineering programs at Aalborg University, Denmark (PBL AAU Model) is characterized by problem based, project-organized groups. This means that in addition to disciplined knowledge, learning in PBL, AAU demands a variety of abilities like effective cooperation, communication, management, reflection, and self-evaluation.

This paper aims to examine the learning process of engineering students in two aspects: 1) How do students develop process competencies through doing group-organized project work? 2) How do students perceive their achievement of these process competencies?

Empirical evidence in this paper is drawn from previous empirical work on process competencies and fieldwork in a Ph.D. study in the context of PBL study environment at different engineering programs at Aalborg University, Denmark. The discussion of the analysis leads to the following conclusion: 1) Studying engineering in the PBL environment involves an active learning process whereby students learn to take initiatives, set up learning expectations, formulate learning goals, seek various resources for learning, developing strategies to communicate and collaborate with group members as well as supervisors, and evaluate learning outcome. This process involves the management of learning both cognitively and affectively and leads to the development of process competencies. 2) In the learning process, students play an active role by taking the responsibility of their own learning, which provides possibilities for them to appreciate the meaningfulness of learning. 3) The progression of process competencies needs to be facilitated by reflection and experiments on an aware level of learning.

2. THE APPLICATION OF PBL CONCEPT TO ENGINEERING EDUCATION

The theoretical departure for the understanding of PBL derives from the constructivist-sociocultural approach in terms of understanding and examining learning and education. In the past decade, this approach plays an increasingly prominent role in the educational development [5]. The general belief is that learning takes place from the interaction between the individuals, and it is a changing process in a certain sociocultural context. In addition, in relation to a setting of formal education (for example engineering education), the discipline and learning contents also play an important role.

In practice, the constructivist-sociocultural perception of learning has focuses on: 1) the process of learning; 2) consideration of the institutional and societal settings; 3) recognition of the identity construction and transformation process; 4) identification of changes that are involved in the learning and transformation process. This means that the constructivist-sociocultural is approaching education as a system where both structures and actors have to be taken into consideration. In relation to the application of PBL concept in engineering education, this approach helps to promote the recognition that learning processes in educational institutions will cover the formation and transformation process of a self, and with knowledge and ability of cooperating, reflecting and coping with society in general [6]. In this way, education and learning is related to a broader social transformation in the process of globalization and in the development towards a knowledge society.

The PBL concept has various definitions and ways in application, ranging from problem-oriented lectures to completely open experiential learning environments aiming at improving interpersonal relations [7]. The practice of problem-based learning varies from country to country, from institution to institution [8]. In the past two decades, PBL has received a large amount of research attention and positive evidences have been found specifically in profession-based education [9]. In relation to engineering education, PBL concept is regarded as a successful and innovative educational method for engineering education [10].

Responding to this, most of the engineering educational institutions in Denmark are in an undergoing process of transformation from traditional paradigm, which is discipline-oriented, basic and applied technical knowledge-based, and lecture-centred, to a new paradigm, which is more interdisciplinary, contextualized, a complex understanding of technological knowledge-based, and student-centred, through implementing a problem-based and project-organized curriculum [11] [12]. This is because the most important innovative aspect of PBL educational concept is 'the shift from teaching to learning, and consequently the task of the teacher is altered from the transferring of knowledge into facilitating to learn [13].

De Graaff and Kolmos [4] and Kolmos et al. [14] have formulated three common approaches characterizing PBL: learning – content – social approaches.

The **learning approach** as problem and project-based learning means that *learning is organized around problems.* It is a central principle for the development of motivation. A problem makes up the starting point for the learning processes. It can be any type of problem, for instance a concrete realistic problem, or a theoretical problem. The problem serves as the basis for the learning processes because it determines the direction of the learning process and places weight on the formulation of a question rather than an answer.

Integrated in the problem approach is *learning in context.* The formulation of problems allows the learning contents to be related to the context, which promotes student motivation and comprehension.

Experience learning is also an implicit part of the formulation of problems and especially important in relation to which problems the students are attracted to and which problems the student formulates on the basis of his/her own experiences and interests.

The **content approach** concerns especially interdisciplinarity, exemplary learning and the theory-practice relation.

Interdisciplinary learning relates to the dimension of knowledge as the solution to the problem formulation, which may span across traditional subject-related boundaries and methods. This principle is critical for the organization of the teaching because teachers often consider objectives within the known subject-oriented framework, rather than problems or situations.

Exemplary practice is concerned with ensuring that the student's learning output is exemplary in accordance with the framework of the objectives. This is an extremely central principle because the student must engage in a deeper understanding of the selected complex problem formulation. *Theory-practice* means that the students gain abilities to analyze problems by using theories. During the entire learning process, they learn the art of analysis as they are required to analyze problems, analyze solutions, develop solutions, and analyze the impact of given solutions.

The **social approach** is the last core principle – this means team-based learning in which the majority of the learning processes take place in groups and teams.

The *team learning aspect* underpins the learning process as a social act where learning takes place through dialogue and communication. But the students are not only learning from each other – they also learn to share knowledge and organize the process of collaborative learning. Process skills are therefore implicitly developed in order to handle group co-operation processes.
The social approach also covers the concept of *participant-directed learning*, which indicates who has the ownership of the learning process and, especially, the formulation of the problem.

In the context of Aalborg University, Denmark, the learning principles of PBL Aalborg Model is founded on problem-based project work, in which approximately one half of the students' time is spent on project work in teams, whereas the other half is spent on more or less traditional lectures. All project work is made in groups, and the same model is followed from the 1st semester until the completion of a masters' degree. During the span of the university degree programme, the groups normally become smaller, starting with typically 6-7 students in the 1st year and reduced to approximately 2-3 students in the final semester.

There are two types of courses offered to students at Aalborg University - those that are directly related to the students' project work, and those which have nothing to do with the project work in terms of subject matter.

The project work is formulated within the framework of the given theme, related to the overall educational objectives, which can be a broad, open theme or a subject-related limited theme. The students are allowed to formulate their project proposal themselves, but there will always be a supervisor, who approves the proposal.

Each group has one or several supervisors. The role of the supervisor is to give response to the students' project process along the way and not least to run the examination.

3. STUDIES ON THE EFFECT OF PBL

Several studies have been conducted concerning the efficiency of PBL at institutions where there has been a transformation process from traditional teaching to PBL.

Dochy et al [15] has made a literature review of all evaluations made during the 90's. Their main conclusion is that the use of PBL has an impact on improvement of skills development such as process competencies or skills. The impact on knowledge acquisition is missing or not significant. However, PBL students do not acquire less knowledge compared to traditional educated students.

Several studies do have the same result – that there is no significant improvement of knowledge acquirement, but significant improvement of skills. The result concerning the knowledge factor may have to be seen in the light that the concept of knowledge that are used for measurement is the knowledge concept from traditional educations. So the PBL-systems are compared to values in the old system and not according to a more complex knowledge concept as the one used in the PBL-studies.

Nevertheless, this article is addressing the process competencies – and studies are documenting that there is a significant improvement of that part. Faland and Frenay [16] has conducted an empirical study of a transformation process at one particular institution. Their main conclusion is the same, that students do obtain process competencies. Crosstwaite [17] documents that the students' own perception of the achievement of skills significantly had improved by the PBL-students.

Our empirical work can explain why there is an improvement of process competencies.

4. EMPIRICAL WORK

Empirical evidence for this paper draws on: 1) previous research work on the development of process competencies (1996 – 2002) [18]; 2) data from the empirical work of a Ph.D. study [19]. Both of the resources were from the context of an engineering education in Denmark.

The aim of the first work on development of process competencies was to investigate how to develop process competencies in a PBL-curriculum. Longitudinal studies showed that students develop process competencies during the PBL-curriculum, however, without any reflection and conscious experimentation, the students' knowledge and awareness of own capabilities remained at a tacit level. The graduates were capable of doing the co-operation, but they were not aware of this on a conscious level, what they were doing – they had no words or developed terminology for what they were able to do. Action research methods were used to develop methods for progression of process competencies.

The second data source - the Ph.D. - study was comparatively new. One of the aims of the Ph.D. study was to examine the roles of PBL environment on the learning process of engineering students, in particular, regarding the development of process competencies such as collaboration, communication, cooperation, and project management. Two engineering departments were chosen for research sites: 1) Electrical, Electronics and Computer Engineering (EE), which can be seen as a representative of traditional hardcore engineering discipline; 2) Architecture & Design (A&D), which is a comparatively new engineering discipline with the ideology of combining technology with creativity and design.

In the Ph.D. study, data were collected and analyzed based on the principles of in-depth interviews and participation observations. In each department, around 30 students at 6^{th} or 8^{th} semester and around 5 teaching staff members were interviewed. Selected project groups were followed for observing their lectures, group meetings, supervision meetings and

social activities. In this paper, selected research findings that are related to the assumptions and questions are presented and discussed.

5. FINDINGS AND DISCUSSIONS

By locating problem based projects and team work as the core of the guiding principles, it is designed to create an active learning context and to stimulate the interests of learners and provide an opportunity for developing process competencies of the learners. In the following, this paper will discuss how engineering students in a PBL environment experience their learning processes with a focus on the development of process competencies. This discussion falls into two parts: 1) the development of the process competencies; 2) students' perceptions on the achievement of these process competencies.

5.1 How do students develop process competencies?

The first evidence is the system and the structure. From the social-constructivist point of view the structure is of importance. For engineering students in the PBL environment, the core of the learning process is to do projects in groups with the aim of solving problems. Based on the learning principles of PBL concepts, the Ph.D. study made an assumption that the learning resources for studying engineering in the environment of PBL, Aalborg Model is mainly derived from three areas (see figure 1): process of problem-solving and doing project in groups, attending lectures, and getting guidance and assistance from supervision. This could be expected from the formal level. The empirical work from both departments has shown that these three aspects played constructive roles as the major learning resources for students to study engineering. In addition to these, the research findings illustrate more resources than these three aspects.

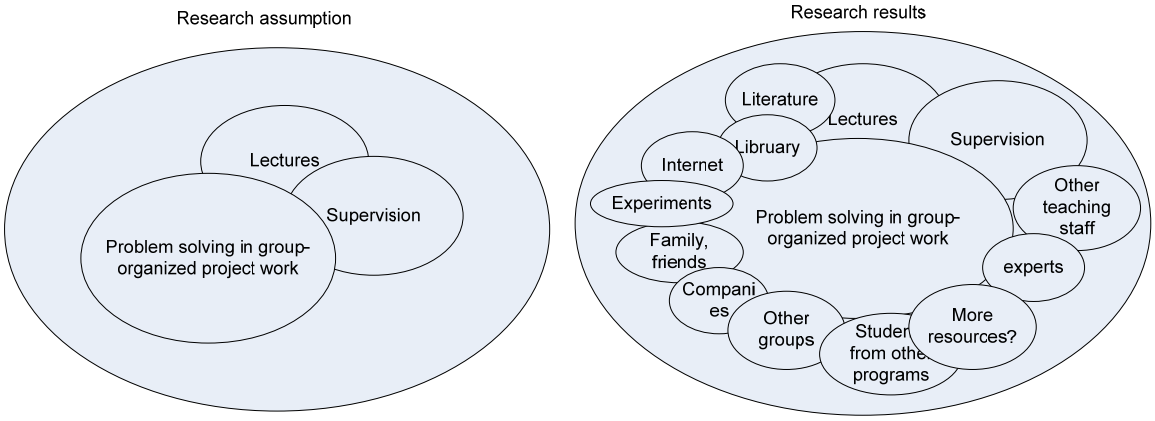

Figure 1 multiple learning resources in the learning processes in the PBL

During the 5-year education, students are expected to do about 10 projects before they are awarded a maters' degree. At the beginning of each semester, students form project groups based on their shared interests in solving professional problems. To get the project started, students need to search for the information on the background and context, to find relevant literature, to read theoretical articles, to discuss with supervisors or people who know the area, and they might also need to contact industries or companies for interviews or observations to gain field knowledge. When they have collected enough material, they start to analyze the situation and formulate the problem. The next stage is to find out how to solve the problem and choose one of the solutions, and this involves same procedures of searching, reading, discussing and writing. In this process, they are facilitated with the knowledge from the literature, lectures, and supervision; however, they are expected to relate these different knowledge resources to their project. They need to develop different strategies to gain theoretical knowledge, methods, and context knowledge in order to solve the problem. Instead of following the procedures designed by the teachers, students are expected to manage the project planning on their own.

During the first year program, the students attend a course on development of process competencies called Cooperation, Learning and Project Management (CLP). This course provides a lot of tools and methods for cooperation, planning of learning process and how to handle and develop own project management systems. In addition to the technical report, each group submit a report on their process reflecting what they have been doing, what went well and what can be changed next

time. The CLP-lectures during the semester gives input to experiment with different kind of systems, and especially to encourage the students to develop their own systems and to reflect on the systems they are using. These kinds of reflections give students awareness of controlling the process on a much more aware level – not only during the first year program, but also during the rest of the semesters.

To make a project efficiently, students experience that the best group size is 5 to 6 persons who divide the work into different tasks. Therefore, doing group work in groups incorporated doing individual work, working in sub-groups and working in the project group. Many groups put both long-term (normally a semester, for the whole project) and short-term plans (either one week or two weeks) on the wall in their group room. For the long term plan, they signify some milestones in a semester calendar, which might be kept flexible for modification along the way. For the short term plan, some groups draw time tables on a blackboard (it is normally the task of the group leader), and in the group meeting they fill in things that need to be done before they discuss who will do them. Some groups make a list of tasks in the group meeting and then discuss who would like to do what and how long it will take (see picture 1).

Picture 1 project management

This is also an interactive process both within the group and with the real world. For example, group work involves discussing, reaching agreements, writing, etc. which demands the awareness and skills of communication, collaboration and management (see picture2 and 3). In addition, they share experiences and resources with other project groups, they turn to other supervisors or experts when they need more information than what can be provided by their supervisors, they use personal network (family, or friends) to build up contacts for research, and so on. Project works normally involve across discipline knowledge, which in turn, involve searching resources of information from different areas.

Picture 2 collaboration in the team work

Picture 3 communication in the team work

Studying engineering in the PBL environment, at first, students as newcomers need supports for all phases of doing project in groups, especially how to formulate and analyze research questions and how to manage the project process. Gradually, they begin to take on responsibilities for the project work, like taking turns to be group leaders, participation into dividing and fulfilling different parts of work. The collaboration in the group work also helps to promote the sense of responsibilities, to develop the readiness for commitment to the communities' practice and to make different contributions to ongoing activities as they transform their participations.

They gain deeper understandings of the project work and play more active roles in designing and planning of the projects. Project work proceeds with their growing interest, active involvement, and flexible and positive attitudes to make adjustment in the carrying-out process. They bring in different values into the shared practices from the reflection on their past experiences in different contexts.

To summarize, research findings illustrate that when studying engineering in the PBL environment students take active roles in developing learning strategies and take responsibilities of managing their own learning. This is also a process in which students manage their own learning with self-awareness of learning goals and expectations. The multiple learning resources provide chances to develop process competencies. Studying in this imitated work place environment, students are also provided chances to develop professional competencies as well professional identities of being engineers.

5.2 How do students perceive their achievement of process competencies?

In general, similar pictures can be witnessed in several departments regarding students' strong awareness of reflecting on learning based on their experiences as well as their perceptions on learning. Their reflections on learning can be summarized in the following aspects.

1) Learning is more than the reception of factual knowledge or information; rather, it involves more aspects such as goals, expectations, understanding, application, meanings, insights, values and so forth. As the students reflected, at the beginning of each project, they would talk about their own strengths, weaknesses and expectation of the new project.

> 'We talked about many things from the beginning so that we knew what each other were good at, and what we could learn from each other and what we could like to learn through doing the project. We want to make it possible that we can learn from each other and everybody can learn what they want to learn.'

In the processes of studying in PBL, students gained strong awareness of setting up learning goals, exchanging explicit information about their strengths as well as their expectations. In this way, they distributed group tasks with strong awareness and a clear goal.

2) The process of seeking understanding, meanings and values is closely related to practices and activities in a context, which involves participation, communication, interpretation and reflection. Management and organization are of great importance for effective learning. As students reflected, how much they could learn in each project to great extent depended on how they could manage to work together by choosing specific methods, organizing group cooperation and managing the project.

> 'We can learn the professional knowledge no matter by doing groups work or individually, however, the social skills in the group work will improve the learning process. It will be more fruitful with better social activities.'

This process involves developing skills in plan-making, agreement-achievement, work-division, cooperation and communication. Social and communicative skills played an important role on building up a supportive and motivating atmosphere, which could lead to effective learning.

3) Peer learning through shared practice in the community is appreciated as an efficient learning strategy in terms of sharing information resources and getting inspiration. Positive collaboration and constructive support in team work is considered as an efficient way of learning technology and preparing themselves for the workplace culture. As one female student said,

> 'I am not good at technology, but I find it interesting to see how things work, so being in a group helps me to learning this. Besides, working in a group helps to keep people from dropping out. You don't lose your interest and drop out after you miss one month's education for example, because the others in the group will help to keep you up at the same level. At the same time, you have the responsibility for the group, and it is a duty to come to work everyday…'

Good atmosphere and successful cooperation in the community of practice is recognized as motivation to get work done and to achieve the goal of learning. Working in groups can bring about mental supports as well as develop responsibilities in the learning process.

4) There was a progression during the study going from experience in the first year program where the students were struggling with cooperative problems to the integrated cooperation in the last semester where the students did not even discussed what they were doing but they just did it. However, interviewing students at late semesters showed that they were able to reflect on the more integrated cooperation.

To summarize, for results cross investigations, studying engineering in the PBL environment, it is rather essential to take consideration of methods and strategies of gaining knowledge, the application and context of knowledge, and the meanings of the knowledge. Drawing upon multiple learning resources, students take active role creating learning opportunities and managing their own learning. This indicates a process of seeking meanings as well as appreciating of the meaningfulness in the learning processes.

6. CONCLUSION

This paper discussed the development of process competencies in the learning processes of studying engineering in a PBL environment. Other studies document the improvement of process competencies. Furthermore, the empirical studies from Aalborg University give the evidence, that a student-centred learning environment can prepare students with more chances to gain not only scientific knowledge, technical skills, but also capabilities of managing project and team work as well as professional responsibilities in order to prepare themselves for the workplace. It also provides a milieu where learners can interpret their experiences in the learning processes as meaningful. This indicates a match between the theoretical design of PBL environment and the learning experiences of engineering students in practice. Students' perception of learning and their active learning process fit into the learning principles of the PBL concept and expectations of the educational designers at Aalborg University. Therefore, the PBL environment can be regarded as a friendly learning environment for engineering education with regard to providing learning opportunities of mastering technological knowledge, developing process

competencies and seeking the meanings of learning. However, the progression of developing process competencies needs to be facilitated by reflection and experiments on an aware level of learning; otherwise the learning outcome will remain at a tacit level. Therefore, the establishment of structures is only one step – students' own reflection and documentation of their development of process competencies benefit efficiently to learning of process competencies and the ability to transfer these competencies to workplace.

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