# AN OVERVIEW OF THE SITUATION OF PROJECT-BASED LEARNING IN ENGINEERING EDUCATION

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**ABSTRACT**

Project and problem-based learning are gaining a solid ground in engineering education. There are well-known communities such as the CDIO organization that promote a certain curricular framework for projects. There is also a large but scattered research literature that reports various ways of implementing projects. However, a comprehensive situation analysis is still waiting to be written. This paper aims to draft an overview of the current situation in Europe. A recent research review by Chen, Kolmos & Du has collected a considerable amount of scholarly articles on the subject, however, much of the current practice is not included or exposed in their paper due to the focus on challenges. We attempt to enhance the understanding of the current situation by adding information that is found in conference papers such as of SEFI annual conferences, university publications and web-sites, Erasmus project information, and so on. The scholarly literature covers only a part of the practice because most of it is ongoing activity that is not organized as research projects; therefore, to understand the situation various kinds of sources of information are needed. Our goal is to increase understanding of how PBL is reported, experienced and developed in European universities, based on previous studies and our own explorations.

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# 1 INTRODUCTION

## 1.1 Aims

Project and problem-based learning are gaining a solid ground in engineering education, particularly in some geographical areas such as Northern Europe. There are well-known global communities, most prominently the CDIO organization that promote a certain curricular framework for projects (http://cdio.org). Additionally, the project-based approach promoted by the Aalborg University has a base of followers. The extensive research literature that reports various ways of implementing projects is scattered in journals and conference proceedings of many sub-fields of education and engineering. This paper specifically aims to outline an overview of the current situation in Europe. A recent research review by Chen, Kolmos & Du [1] has collected a considerable amount of scholarly articles on the subject with an emphasis on challenges and difficulties. Nevertheless, much of the current practice is not included or revealed in their paper. The scholarly literature covers only a part of the educational practice because most of it is not organized as research projects; therefore, to understand the situation also other sources of information are needed. We attempt to enhance the understanding of the current situation by adding information that is found in conference papers such as of SEFI annual conferences (http://sefi.be), university publications and web-sites, Erasmus and EU project information, and so on. Our goal is to increase understanding of how PBL is reported, experienced and developed in European technical universities, based on previous studies such as the work by Chen et al [1] and our own explorations.

## 1.2 Related studies and reviews

The common acronym PBL could refer to project-based learning, but maybe more often it refers to problem-based learning. These two approaches sometimes overlap even though the motivations and pedagogical thinking differ, which will be discussed later in this paper. Problem-based learning has a long history in medical education and in primary and secondary schools [2]. It has its own journals such as The Interdisciplinary Journal of problem-based learning and The Journal of Problem Based Learning in Higher Education. We do not intend to define what is understood by project-based learning, which is a rather vague concept, instead, we rely on the reports by the universities themselves. Moreover, there are several other terms that refer to approaches that include similar ideas and practices such as supported collaborative learning, inquiry-based learning, and team-based learning.

Edström & Kolmos have written a thorough comparison of the two major solutions for higher education (HE) project-based learning, namely the “Aalborg model” and the CDIO initiative in engineering [3]. Therefore, we do not repeat the details of the models here, but refer to their paper, and numerous other articles covering the motivations and findings of either of those solutions, some of which can be found in the references of this paper. A brief outline is given in the chapter 3 that presents the different ways to include projects in the curriculum.

### 1.3 Sources of information

This paper aims to shed light on the phenomenon of project-based learning, particularly in recent years in Europe. It is based on a variety of sources: literature surveys on scholarly articles, other published materials, visits to several universities, collaboration in EU funded projects and exchange programs, and meetings in various conferences on engineering, education and for information technology professionals. The authors have been active participants in a number of EU funded and Erasmus projects and programs over twenty years, which has helped to build a network of colleagues and get insights to practices in European countries (https://ec.europa.eu/programmes/erasmus-plus/projects/). Because the home base of the authors is in Finland, Finnish universities are used as examples for various practices. As Finland has a small population of less than 6 million, but a large land area, it has relatively many technical universities (7) and universities of applied sciences (18). They collaborate widely in developing the education, and therefore share many best practices, some of which are described here.

## 2 WAYS OF IMPLEMENTING PROJECT BASED LEARNING

### 2.1 Motivations for projects as parts of curriculum

The motivations to start using projects in higher education are varied, starting from educational ideas to purely commercial aims. Professional practices in engineering have inspired many project courses, where the intention is to build professional skills. Engineering practices include much project work, and whenever a new product is built, the process is organized as a project: It could be a construction project, software project, designing an aircraft project, and so on. Therefore, learning about problem-solving through projects is an essential part of professional competence and needs to be a part of any engineering curriculum. [4] [5]

Engineering faculties have been involved in research and development (R&D) work and collaboration with companies for decades. Universities strive to build collaboration with local and also global companies for several reasons. Sometimes they are promoted by government policies, or the goal is to improve employment possibilities of their students, sometimes simply to make money in a situation where funding is insufficient. The collaboration may take many forms, one form being student projects where a company acts as a client. The so called innovation centres and labs are the latest trend in these activities. Collaboration with industries is typical in cities that have large manufacturing and R&D facilities, such as Stuttgart in Germany (car manufacturing) or Espoo, Oulu and Tampere in Finland that had Nokia R&D centres. In Jyväskylä in Finland, the university and IBM have a shared innovation hub. The Metropolia University of Applied Sciences has an R&D unit called Electria which started with a sterile manufacturing lab and RFDI development before expanding to scaffolding start-ups under the Turbiini project.

Pressures from the government and local actors include programs by European Regional Development Fund (ERDF) and the *European Social Fund* (ESF) that encourage involvement with city planning, and civil society. Technical universities act together with cities and NGOs to develop new solutions in projects where also students participate. When the primary goal of projects is something else than education, the additional value for students would probably need more attention than it usually gets. However, efforts such as the European Network of Living Labs (ENoLL) strive to combine innovation activities with solid educational principles. (http://enoll.org)

Additionally, universities are expected to provide entrepreneurial skills to students. Hands-on experience is definitely the most efficient way to get an understanding of entrepreneurship. Universities have established business incubators, innovation laboratories, etc. where students can experiment with start-up business in instructor-led projects. Often this is organized as multidisciplinary work with other fields of study where technical skills can be combined for instance with health care or environmental expertise. The Oulu University of Applied Sciences in Finland has developed a prototyping program called OAMK LABs. The LABs are structured as interdisciplinary, full-time programs that bring together teams to develop new products and start-ups. The Oulu EduLAB brings teams together to develop global education technology solutions, many of which are educational game prototypes [6]. Sheffield Hallam University in the UK is another case that widely applied collaboration projects with local entrepreneurs. [7]

Internal motivations for curriculum development include efforts to improve retention, which has been a longstanding challenge at technical universities. Even half of engineering students drop out from their studies at some universities. Numerous efforts to remedy the situation have been tried and reported. Student motivation has suffered from initial physics and mathematics studies that lay ground to scientific understanding but are demanding and the connection to professional practice has remained unclear for the students. Student projects have been an effort to make the studies more engaging. Projects that combine various skills have been one way to soften the beginning of the studies and to increase the motivation. The CDIO initiative can be considered as one of the major efforts to tackle this issue. [5]

### 2.2 New learning technologies

Online learning platforms include increasingly sophisticated tools for collaboration and project work. Moreover, many business oriented applications are suitable for team efforts in distance learning. These enable various experiments with international student groups from several universities, which have also been reported in research literature usually as case studies. A large number of them are connected to EU funding (Erasmus) that requires partner collaboration in several countries. On the other hand, open virtual universities apply platforms where project or team work is one optional mode of instruction.

Moreover, there have been projects that have particularly aimed at developing virtual collaboration tools that support project work. Early efforts include the Netpro in 1998 supported by EU by the EVTEK University of Applied Sciences in Finland in collaboration with several other European universities [8]. It was later followed by Knowledge-Practices Laboratory (KP-Lab) with University of Helsinki and 20 other

European universities in 2006-11. As a theoretical innovation, the KP-Lab represented an approach to human cognition that went beyond acquisition and participation metaphors of individual learning into shared knowledge-creation processes. The KP-Lab organized courses that focused on solving complex problems for professional communities in participating companies. The KP-Lab built reflective social practices around shared knowledge artefacts of technology-enhanced learning. [9]

### 2.3 Educational goals and backgrounds

Educational ideas, based on cognitive science and learning theories, have inspired new methods frameworks for improving learning such as the KP-Lab described above. The idea of problem-based learning is partially related to critical pedagogy by Paolo Freire, whereas project-based learning is anchored in the constructivist theory of learning and cognitive learning theories that originate in Vygotsky's thinking and cultural historical activity theory developed by Leontjev, Wertsch and Lave. [2, 10] Nevertheless, project-based learning efforts in engineering seldom are that well informed on human cognition and learning, as the instructors tend to have less background knowledge in educational theories, having technical professional education themselves, and less regularly pedagogical training. Many efforts are built on "best practices" kind of thinking, and new ideas are found by benchmarking other institutions. [11]

### 2.4 Educational theory

Collaborative learning and problem-based learning are strongly anchored to educational research, cognitive psychology and theories of social construction of knowledge.
Inquiry-based learning and trialogical learning are related concepts that have been referred to in various implementations of project-based learning. The technical university of Eindhoven calls its approach Challenge Based Learning (CBL) [2]. Learner-cantered approaches are supported by the current knowledge of human cognition by neuroscience. Humans build their knowledge in continuous interaction with the environment, other people and learning artefacts. Learning is an active process of problem-solving, adoption and creation of knowledge and skills, based on existing competences. At universities, the knowledge creation process is additionally connected to expert communities and social networks. [9]

## 3 RESULTS

### 3.1 Various types of implementation

The implementations of project-based learning can be roughly categorized as follows:

1) Full immersion, full-time project-based learning
2) A project based curriculum that includes at least one large project every study year
3) Projects running along other study modules (half-day, one day/ week)

4) Capstone design courses & projects that take place at the end of studies

The categories 3 and 4 are very common all over engineering institutions. As individual courses are abundantly reported in the literature, we just refer to Chen et al [1] and other sources for more detailed accounts and discussions on findings. Categories 1 and 2 are further described below.

### 3.2 Summary of curriculum level implementations

Even though Maastricht University in Netherlands is not in engineering education (it offers Data science and knowledge engineering & Business engineering), it deserves to be mentioned because of its influence to other universities in Europe. It has applied problem-based learning since 1974, later enhancing and developing the education in some programmes with project-based learning and other student-cantered methods. [2]

Full immersion, full-time projects during the entire curriculum, in at least one faculty, are given in the following institutions: in Denmark Aalborg University, and DTU in Copenhagen [12]; in Finland Metropolia University of Applied Sciences, Lapland University of Applied Sciences; in Netherlands Twente University and Amsterdam University of Applied Sciences. [13] [14]

In the case of Metropolia UAS in Finland, the transition to a full-time project-learning curriculum was implemented in 2014. In engineering departments, a large number of smaller study units were combined into four modules for each study year. These 15 ECTS modules take 8 weeks, and each incorporates theoretical as well as practical subjects, most of which were included in the module project. Because all departments and programmes had freedom to plan their modules independently, the practical implementations varied widely. In some programs, teachers embraced the possibility to get involved in team teaching and project facilitation, whereas in some others they kept a more conventional approach with lectures and individual laboratory exercises with small projects. Nevertheless, the amount of project and team work for students multiplied with promising results, causing a significant increase in accumulated study credits. [15] [16]

### 3.3 The universities with yearly projects

Project-based curriculum in some kind of form that includes several integrating projects is implemented for instance at University College London, at Aston University, Birmingham, in the UK, and LINEACT, CESI in France. They are also members of the CDIO consortium universities where at least three project courses are included in the curriculum. Members include 75 universities in Europe, around 50 in Asia-Pacific, 19 in North America and several in Latin America and Africa as of March 2020. The member list includes many universities in Sweden, Finland, Russia, Netherlands, Denmark, UK, and Ireland. There are a couple members in France, Spain, Portugal, and Italy; however, Germany and Austria are completely missing. Presumaby, that does not indicate total lack of project-based learning in those countries; rather, it may be a language-area issue. (http://cdio.org)

The review by Chen et al [1] as well as other earlier reviews cited here report only journal articles in English. Therefore, studies that have been published in other languages (French, German, Spanish, Italian, Russian or smaller languages) remain non-reported. Nevertheless, based on our experiences in European countries, it is not probable that any significant, large-scale implementation of project-based learning would go unnoticed, rather, it is a question of different teaching traditions.

## 4 DISCUSSION

As described above, the two major initiatives on project-based learning, CDIO and the Aalborg model, have produced substantial literature that reports the achievements and challenges of their approach. The models have been developed with a systematic follow-up and evaluation. They have been able to show benefits in terms of student retention and motivation. The universities that have reported various kinds of implementations, in particular types 1 and 2 where projects are regular and all students conduct several projects during their studies, have reported successful results. Improved motivation, student commitment and higher professional skills are typical outcomes. Many of these universities are considered among most appreciated in their countries [14]. As they continue the project mode of teaching, they obviously find it rewarding. In case of Metropolia UAS in Finland, the collection of feedback and results has been systematic over six years [15].However, even with this one university case, the implementation of the model has taken many forms in various programs, all implementations being not comparable.

When the faculty members have acquired sufficient level of knowledge and skill in supervising and instruction, the results have obviously improved. Therefore, the CDIO consortium has built a development path for newcomers who join the effort and start reshaping their curricula. It gives guidance for staff development, and outlines phases of implementation (http://cdio.org).

In addition to the above-mentioned, well-documented models, numerous case studies have been published over the years in professional journals and conference proceedings. A meta-analysis of these case studies would be rather challenging for various reasons. Firstly, it is not known what the sample represents: is it a balanced collection of experiments or does it represent successful cases that were felt worth of publishing and leaving the failures out? This positive case bias is a recognized phenomenon in science publishing. Another serious challenge is the lack of standard in reporting. Certain settings of trials usually are included in the papers such as the composition of student groups, the location of the project in the curriculum and the contents of the implementation. However, some other questions are less frequently reported such as the experience and training of the instructors, or a comparison with other implementations or cases. [1]

Chen et al [1] summarize positive and negative outcomes of project courses, as well as problems that have been experienced. They have classified the papers in various ways. There are apparent difficulties in assessing individual case studies: firstly, they do not follow any kind of established standard, and tend to report results without systematic comparison to other cases. Often, the cases are not repeated in successive years, or they are repeated in a modified format. On the other hand, the background of staff professional capacities, as well as student experiences, might be insufficiently described in the papers.

Issues discussed in project course evaluations usually include the types of project assignments: whether they are problems given by teachers, results of student idea generation or industry or community problems with real clients. These depend much on the motivation for the project course as discussed in chapter 2.1.

Project work and team work regularly encounter problems such as the organization and support of the collaborative effort, and the evaluation of teams. These difficulties tend to be satisfactorily solved in well-established project work settings and with experienced academic staff. Similarly, the concerns of instructor workload in a new kind of curriculum decline with accumulating experience. [16]

The question of student learning and do they achieve the same skill level or possibly better competences than with more traditional and individual learning methods is crucial. Several reports such as the survey among Birmingham graduates among others support this view [17].

## 5 SUMMARY AND CONCLUSIONS

The goal of this treatise is to clarify the picture of developments around project-based learning in technical universities in Europe. We hope that it is one step forward in understanding the manifold forms that engineering education currently takes and how wide the field is. We acknowledge that we could not fully cover existing implementations but sincerely hope that this mapping of practices will continue by the community of engineering educators, and universities can in the future develop their education based on firm evidence on benefits and challenges of different approaches.

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