Multidisciplinary Learning Model in Product Development for Students of Technology and Business

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Abstract

This paper introduces an educational model which is used to apply a real industrial multidisciplinary project based working process in product development for students of technology and business. In the model, the boundaries of different courses, degree programmes and faculties are crossed by a comprehensive approach. This approach begins with a real product development need and extends into the control and understanding of the combination of technological, industrial and business issues. The essential objective is to expand traditional project-based learning models towards a comprehensive industrial productizing model with technological and business aspects. The model is developed as a cooperative effort of the School of Technology, School of Industrial Engineering and Management and School of Business in Lappeenranta University of Technology (LUT).

Keywords: Multidisciplinary, interdisciplinary, project-based learning, multilateral engineering education.

1 Introduction

Interdisciplinary and team work based solving of technical problems is the core of technical competence orientated engineering. The needs of real world customers are satisfied only by comprehensive understanding of the combination and interactions of functionality, manufacturability and business within products. A combination of theoretical knowledge and professional practice needs to be incorporated with skills in human and team relations especially due to the continuing changes in technology and organizations. The role of commercial realities should also be understood as an essential player in the decision-making process related to design and manufacturing.

In engineering education, students should be prepared for modern work in industry with its growing demands. Nevertheless, students seem to be less and less shaped by technological experience due to tightening graduation deadlines. This challenge has been addressed around the world with different student-centered learning methods and project work models with real or emulated engineering problems. These pedagogical strategies have been studied and presented widely in engineering education during the past two decades (Savery, 2006).

Typically, these implementations and models at higher education institutions are carried out in a single subject or single course of one degree program with a homogeneous group of students. This feature may lead to a lack of the potential embedded in the diversity and dynamics of real interdisciplinary team work. There are also examples of comprehensive approaches where the curricula of most of the programs of institutions are based on the student-centered learning methods. The Aalborg PBL model is a well-known example of that (Kolmos, Fink, & Krogh, 2004). Nevertheless, also in these implementations the projects are usually carried out separately for different student groups of different years, major subjects and faculties. Therefore, there is a need to contribute to the PBL method with expanded interdisciplinary and multilaterality in order to demonstrate and study the relations between higher education and the working with its modern and complex requirements (Helle, Tynjälä, & Olkinuora, 2006).

1. 1 Background

During the self-assessment process in the year 2010, the engineering teachers of Lappeenranta University of Technology (LUT) noticed that serious development work is required to improve the students' project work skills and their problem solving capabilities. As concrete results of the self-assessment process, two new course modules based on the project work model were presented and generalized. Observations about the development work of Master's degrees programs were reported by Eskelinen & al. (2011). The results and observations were contrasted with known aspects and viewpoints of project-based learning (PBL) and the opinions were compared with the contents of the Engineering criteria of the Accreditation Board of Engineering and Technology (ABET) as well with the fundamentals of the CDIO model (Conceiving - Designing - Implementing - Operating). The pedagogical approach which was referred to

as constructive alignment (Löfström & al., 2006) and which included the principles of meaningful learning (Jonassen, 1995) was used as a guideline when the new project work model was developed for engineering education.

As a part of the new educational model in 2011, teachers from LUT presented a concrete model for content and language integrated learning (CLIL) in SEFI's conference in Greece (Haapanen & al., 2012). One objective was to establish what mechanical engineering education would gain from the CLIL model and how the model could be integrated with a project-based learning environment. In addition, a cost estimation model for such CLIL applications was formulated.

The new results and models presented in this paper sheds light on continuous development in the field of PBL, and the viewpoint is extended towards the development of a comprehensive interdisciplinary PBL environment.

2 Motivation and Pedagogical Approach

Engineering education is assumed to provide knowledge and skills required by an engineering profession. However, there is a generally recognized need to improve several issues within this interaction of education and profession. Traditional engineering education does not always satisfy the expectations and demands of work in industry, especially issues dealing with social and cognitive skills such as communication with its different subcategories, interactions, co-operation, negotiation skills, project management, presentation skills and team or project leading. Traditional and formal classroom learning provides limited and sometimes poorly motivating practices to respond to these challenges set by a dynamic global work environment (Tynjälä, Välimaa, & Sarja, 2003). Also practical learning at work is a limited possibility for many of students due to growing demands for graduation deadlines set by ministries of education and society.

Due to these circumstances, new proposals for and expansions of learning models should be implemented in higher education. Behind these models there must not only be an understanding of the changes of working life and globalism but also deep knowledge of human beings as learners. Learning theories such as behaviorism, cognitivism and constructivism have been widely studied and are well-known among educational professionals. Traditional engineering education has much been based on behaviorism, where the student is essentially passive, only capable of meeting the learning outcomes by responding to environmental stimuli. As a result, the graduating student does not possess sufficient capabilities in initiative, responsibility and creativity needed in modern interdisciplinary and complex problem solving processes and projects.

The ability to create new applications by using the easily accessible massive amounts of information is in the core of learning rather than just gathering information and using it for exactly conditioned tasks. Therefore, learning theories, especially constructivism, which support self-regulated problem recognizing, understanding, conditioning and solving are used in student-centered learning methods (Bigg, 1996; Dym, Agogino, Eris, Frey, & Leifer 2013; Hendry, Frommer, & Walker, 1999; Helle, Tynjälä, & Olkinuora, 2006; Savery, 1995). Different cognitive skills are needed and developed during the constructive solution seeking process where existing knowledge is expanded and deepened with learning by doing. Success in a global engineering environment is absolutely dependent on the active search for development drivers and an efficient procedure in creating sufficient solutions with technological and economical points of view. Significant development in different areas of technology provides completely new needs to be met by novel means of engineering. Finding solutions requires a well-constructed combination of modern engineering knowledge, versatile thinking, a vision and highly developed cognitive skills.

Regarding project-based learning, there are several closely related student-centered instructional strategies, such as problem-based learning and inquiry-based learning, which are used to motivate students towards self-directed learning. Similarities and differences among these approaches have been explained by, for example, Savery (2006). The model introduced in this paper represents project-based learning with a desired end product. However, the specifications of the end product are not necessarily exactly defined, providing twist to the problem-based learning. The different student-centered educational approached have been evaluated and the advantages as well as challenges of the methods have been analyzed during at least the past two decades. Also different strategies, principles, methods and descriptions of the implementation of the methods have been presented by many different universities and education units. For this reason, those aspects are not in the focus of this report. Generally speaking, the model proposed in this report is more practical than theoretical. However, the relevant pedagogical aspects are considered during the model establishing process.

According to de Graaf & al. (2003), learner-centered education such as PBL builds on the students' background, expectations and interests. Compared with traditional teaching methods, it is common for students to be motivated to work much harder with the PBL model, and in general, students spend more time on their studies when working with a PBL model. The key finding by de Graaf & al. was that there is a connection between the teaching method and the depth and complexity of the learning. The student may be expected to reach an analytically complex level of comprehension through project work, which would not be possible in traditional classes. However, while students are reaching this deeper level of learning, they may miss part of the broader perspective or breadth of knowledge. It is therefore an important part of PBL pedagogy to ensure that the student is in a position to fill in any potential subject area gaps, if or when at a later point the need arises (de Graaf & al., 2003).

Furthermore, an important trend in engineering education has been the development towards education that stresses engineering fundamentals in the context of Conceiving - Designing - Implementing - Operating (CDIO) real-world systems and products. In general, CDIO has four themes including curriculum reform, improved teaching and learning, experiential learning environments and effective assessment methods (Berggren & al., 2003; Gunnarsson & al., 2007). The most essential aspects in the model proposed in this paper are the following: practical and constructive PBL, multilaterality, interdisciplinary, real world conditions and interactions, team work with a company-like hierarchy, Design for Manufacturing and Assembly (DFMA), Concurrent Engineering (CE) and the combination of technology and business with a reflection of usability.

2.1 Utilizing Principles of DFMA and CE Design in the Proposed Model

One part in the multilateral model of PBL is the practical realization of the teamwork which aims towards satisfying the requirements of products' DFMA aspects. The justification to include DFMA so strongly into the proposed model came from the fact that through the history of DFMA, one powerful tool to support DFMA approaches has been so-called concurrent engineering. Concurrent engineering design (CE design) is a term that formally describes a set of technical, business, manufacturing planning and design processes that are concurrently performed by elements of the manufacturing organization. The CE design process, in its simplest form, is the integrated execution of four business and technical processes at the same time. These processes are process management, design, manufacturability and automated infrastructure support (Eskelinen, 2012). These viewpoints perfectly match the PBL model presented in this paper.

The field of DFMA includes several important personal contacts between different players, such as production managers, design managers, suppliers of materials and components, workshop and factory managers. In addition, the connections in the "real" world include the interfaces with business-oriented partners, such as subcontractors, customers, finance directors, etc. Our model provides ten different DFMA approaches, based on the results presented by Eskelinen (2012), to support design managers' and production managers' work. We let the managers freely decide in what ways they handle the product's design task itself and how they handle and organize the field of tens or even hundreds of contacts with different players in the field. Table 1 illustrates these DFMA approaches and the assumed key contacts integrated with them.

Table 1: DFMA approaches and the assumed key contacts integrated with them

	DIFFERENT PLAYERS IN THE FIELD OF CONCURRENT ENGINEERING									
DFMA APPROACH	production managers	design managers	suppliers of materials	suppliers of components	factory managers	subcontractors	finance directors	marketing managers	project managers	customers
1. DFMA rules and guidelines applied to different	●	●	●		●				●	

manufacturing technologies										
2. Utilization of DFMA evaluation forms and production (including assembly) time calculation techniques	●	●		●	●	●	●		●	
3. Utilization of modularization and standardization in DFMA	●	●		●		●			●	
4. Utilization and development of advanced manufacturing processes to support DFMA	●	●			●		●		●	
5. Recognition of the most suitable manufacturing technology for the product based on analytic or empirical DFMA equations	●	●	●		●				●	
6. Utilization of feature based systems to support DFMA	●	●	●	●		●			●	
7. Integrated DFMA approaches for managing both the design and assembly processes and their costs	●	●					●	●	●	●
8. DFMA approaches considering the development of material science and new material alternatives	●	●	●						●	
9. DFMA approaches considering feedback from maintenance	●	●						●	●	●
10. DFMA approaches based on a common platform technology	●	●		●		●			●	

3 Multilateral Model of PBL

The core of the proposed multilateral model of PBL is based on the imitation of elements of industrial and business work. The idea is not just to implement the main principles of PBL in order to complete design and manufacturing processes as a team project. Essential features involve, for example, different roles due to the hierarchy of the project groups, management, subcontracting with bidding, co-operation not only between group members but between groups from different areas of technology and business, company mentoring and dynamic project environment for PDM, communication and overall control of projects. These expansions enable the realizing the potential of diversity and dynamics of truly multidisciplinary project work, obtaining realistic experiences of multilateral work and self-directed recognizing of personal missions as a modern member of a productizing group. In the following, two models of PBL implementations at LUT are expressed.

3.1 Implementation in the LUT School of Technology of LUT within Two Degree Programs

This implementation was carried out on five courses from the degree programmes of mechanical engineering and electrical engineering. The model represents the basic level implementation of an interdisciplinary project-based learning model. The project overview with related courses is shown in Figure 1. In the project, an energy efficient electric vehicle was designed and manufactured during one academic year. The statistics of the courses are shown in Table 2. The special features consist of different roles and responsibilities of Bachelor's and Master's level students from different degree programs. The students were divided into one main group and its subcontractor groups. A bidding procedure was established between the subcontracting groups in order to emphasize marketing, interactions, communication and business thinking. The model does not involve a special project course. Instead, it combines several separate courses. An example of the product designed and developed during the project is shown in Figure 2.

Table 2. Statistics and descriptions of the courses involved in the two degree program project learning model

Name of the course	**Number of credits and number of students**	**Year**	**Role of the students in the project**
Introduction to Engineering Design	7 cr, 40...45	2nd	Specialist in mechanical design (4...5 per group) Design manager (1 per group)
Project Managering in Machine Design	4 cr, 6...10	4th	Project manager (1 per group)
Laboratory Course in Manufacturing Systems	6 cr, 6...12	4th...5th	Manufacturing specialist and manager (1 ...2 per group)
Electronic Equipment and Systems Design	4 cr, 5...10	4th	Specialists in electrical design (1...2 per group)
Power Electronics Project	6 cr, 5...10	5th	Design manager (1 per group)

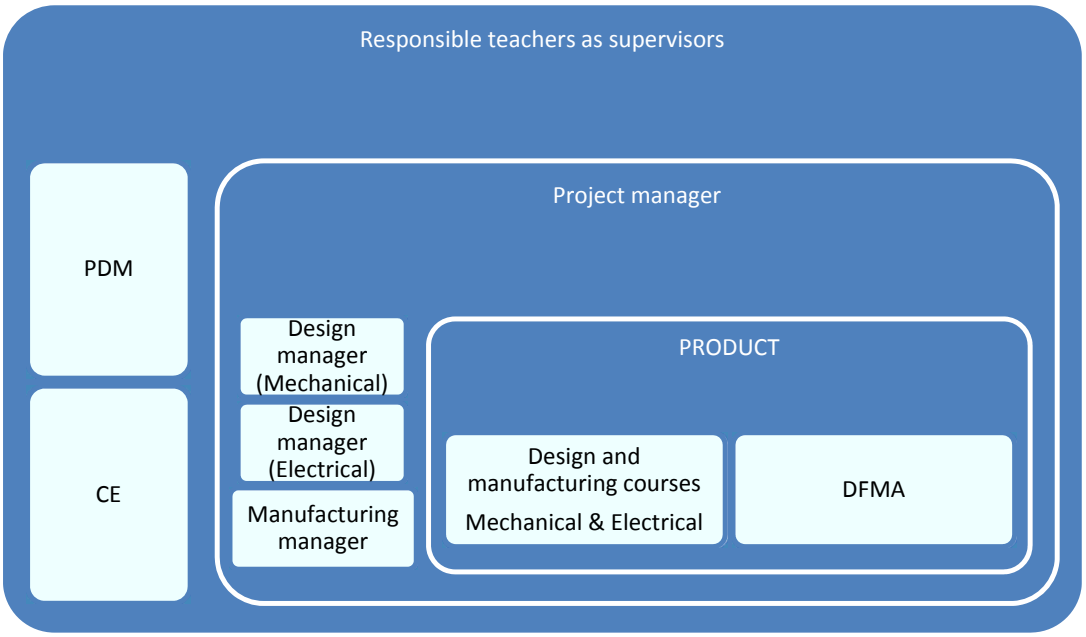

Figure 1: The implemented model in the LUT School of Technology

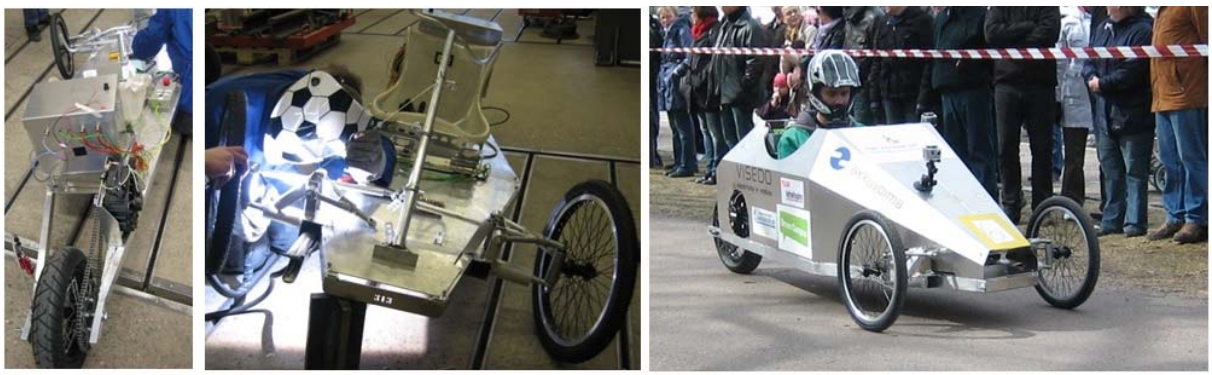

Figure 2: An electric vehicle designed and manufactured during the project

3.2 Proposed overall PBL Approach of Technology and Business

This implementation will be carried out in several courses of the Schools of Technology, Industrial Engineering and Management and Business in the academic year 2013-2014. The schematic construction of the overall model is shown in Figure 3. The statistics of additional courses compared to the previous model are shown in Table 3. The additional elements introduce a comprehensive approach with versatile and realistic interactions of a real productizing process at the level of a small company with innovative sustainability related products. In order to manage a complex network of different players in the project, a tailored network based project environment application will be needed. Also communication with real companies is to be strengthened by using company mentors as supervisors and by choosing the projects according to their visions regarding future products needed in sustainable engineering.

Table 3. Statistics and descriptions of additional courses involved in the proposed PBL approach

Name of the course	Number of credits and number of students	Year	Role of the students in the project
Business Project Course	6 cr, 5...10	2nd...3th	Specialist in business tasks (1...2 per group)
Business Project Management	6 cr, 5...10	4th...5th	Business manager (1 per group)
Usability	Under construction		Specialist related to usability and user interfaces

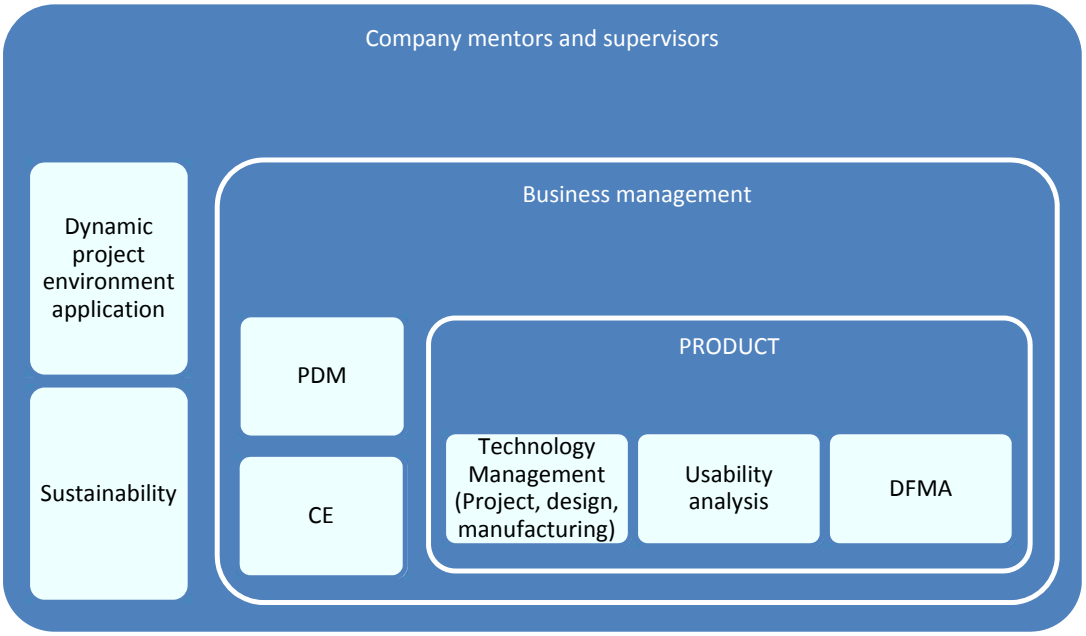

Figure 3: The proposed multilateral PBL implementation

4 Evaluation of the Models and Recognized Challenges

The two degree program PBL model shown in Figure 1 demonstrates the power and also challenges of expansions to traditional PBL implementations. The effect of immersion into the realistic project work with its different features was strongly experienced. As expected, the senior students as managers of different levels had high motivation towards the project. Based on general observations, second year students could be divided into two categories: hard-working individuals with a strong understanding of way of working in PBL, and those who focused on complaining instead of working. It is important to note that in the implementation there were, in fact, reasons to complain: the work load

was not evenly distributed, communication failed from time to time, bidding between subcontracting groups had a negative impact on motivation, etc. Some students failed to understand that problems are not a reason to give up but to try harder. Motivation and an aspiration to avoid frustration are two of the most critical aspects in PBL, according to Bucher & al. (2002). There are significant differences in the maturity of second year students. Some students are able to see the advantages in the development of technical and cognitive skills in project work even though the work load per credit is higher than in regular courses. The most impressive students were able to work for the group and for the project – not only carrying out their own tasks but helping and supporting the others.

It takes time for students and supervisors to adapt to the role of supervisors as facilitators and coaches. Challenges were identified especially in communication and getting in touch with the most independent groups. Feedback from the groups was difficult to obtain in time and it was noticed that groups which faced unexpected problems sometimes failed to inform the supervisors and spent a great deal of time and energy on finding the guilty party instead of a solution. Some challenges also involved conveying the right type of information within the team and to the teachers and the manufacturing workshop. Issues regarding the roles and responsibilities of students, teachers and administration have been discussed for example by Yusof & al. (2004).

Students who worked as production managers were asked to prepare a written report of their experiences. Firstly, they were asked to describe the main DFMA findings in the project from their own viewpoint. Secondly, the students were asked to explain what challenges they faced when trying to organize networking between different players (see Table 1.). It was interesting to notice that students were able to shift the responsibility in a flexible way either to the production manager or to the design manager, depending on the knowledge required to solve the prevailing problems in production. However, the project manager was at times found to be a bit too distant in terms of practical production problems. Basically, students who worked as production managers liked the multilateral PBL model a great deal and stated that the model gave a good impression of the environment in a real industrial company.

One concrete result was the finding that the principles of concurrent engineering (CE) could be implemented in the model, no matter which DFMA approaches were selected to support the integration of the manufacturing and design stages of the product. However, students needed advice on how they should apply the principles of CE and how they should handle the contacts between different players in the project team.

The proposed model shown in Figure 2 will be implemented for the first time in the academic year 2013-2014. The model requires careful preparation, and special attention must be paid to the coherence and consistency of the implementation. The network-based project environment plays a significant role as a vital connection between different players in the PBL implementation. Aspects such as the use of virtual money in the business model and sustainability are essential features of the proposal.

5 Conclusion and Future Work

This paper introduced a project-based learning model with expansions. The model of two degree programs was evaluated based on implementation at LUT and a comprehensive technology and business model was presented. The main idea of the model is that education should equip the students with knowledge and skills needed in modern industrial work. This can be accomplished with hard work and initiative in real-live project work, improving students' problem-solving skills as well as their self-confidence.

The research-oriented and pedagogic development of the proposed model requires the systematic gathering and analysis of feedback and statistics from the implementations. In the future, research will also be conducted on the PBL-related course contents and need to update them based on the project outcome. The course contents involved will be developed depending on the requirements of the project to provide space for creativity, association and heuristic strategies. The model of two degree programs demonstrated the power and challenges of interdisciplinary implementation. The proposed comprehensive model will shed light on the responsibility, understanding and attitude of educators towards future multidisciplinary education and future influential professionals – today's open-minded students.

References

Berggren, K. & al. (2003). CDIO: An international initiative for reforming engineering education. World Transactions on Engineering and Technology Education, 2(1), 114-124.

Bigg, J. (1996). Enhancing Teaching through Constructive Alignment. Higher Education, 32, 1-18.

de Graaff, E. & Kolmos, A. (2003). Characteristics of Problem-Based Learning. International Journal of Engineering Education, 19(5), 112 - 118.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2013). Engineering Design Thinking, Teaching and Learning. Journal of Engineering Education, 94(1), 103-120.

Eskelinen H. (2012). Advanced Approaches to Analytical and Systematic DFMA- Analysis. Acta Universitatis Lappeenrantaensis 509, Lappeenranta, ISBN 978-952-265-366-6, ISBN 978-952-265-367-3 (PDF) ,ISSN 1456-4491.

Eskelinen H. & al. (2011). Specialized Interview Procedure of Self-Assessment Process Led to Novel Project Work Model in Engineering Education. The European Society for Engineering Education, Proceedings of the World's 1st Engineering Education Flash Week, Lisbon 26-30 September 2011, Track 8, Accreditation and Quality Assessment, 394-400, ISBN 978-2-87353-004-5

Gunnarsson, S. & al. (2007). Large scale use of the CDIO Syllabus in formulation of program and course goals. In Proceedings of the 3rd International CDIO Conference (MIT, Cambridge, Massachusetts, 11-14 June 2007).

Haapanen, P., Erent, D., Eskelinen, H., Wunderlich, J. & Varis, J. (2012). Development and Analysis of a Professional-Oriented CLIL Model for University Level Mechanical Engineering Education. In Proc. 40th Annu. Conf. 2012 Engineering Education 2020: Meet the Future, Thessaloniki, Greece. 146-147, ISBN: 978-2-87352-005-2

Helle, L., Tynjälä, P., & Olkinuora, E. (2006). Project-based learning in post-secondary education - theory, practice and rubber sling shots. Higher Education, 51(2), 287-314.

Hendry, G. D., Frommer, M. & Walker, R. A. (1999). Constructivism and Problem-based Learning. Journal of Further and Higher Education, 23(3), 359-371.

Jonassen, D. H. (1995). Supporting communities of learners with technology: a vision for integrating technology with learning in schools. Educational Technology, 35(4), 60 - 63.

Kolmos, A. Fink, F. K. & Krogh, L. (2004). The Aalborg PBL Model. Aalborg: Aalborg University Press.

Löfström, E. & al. (2006). Laadukkaasti verkossa. Verkko-opetuksen käsikirja yliopisto opettajalle. HUT, Helsinki. In Finnish.

Pucher, R., Mense, A. & Wahl, H. (2002). How to Motivate Students in Project Based Learning. IEEE Africon, (1), 443-446.

Savery, J. R. & Duffy, T. M. (1995). Problem based learning: An instructional model and its constructivist framework. Educational Technology, 35, 31-38.

Savery, J. R. (2006) Overview of Problem-based Learning: Definitions and Distinctions. Interdisciplinary Journal of Problem-based Learning, 1, 8-20.

Tynjälä, P., Välimaa, J., & Sarja, A. (2003). Pedagogical perspectives on the relationships between higher education and working life. Higher Education, 46, 147-166.

Yusof, K. M. & al. (2004). Problem Based Learning in Engineering Education: A Viable Alternative for Shaping Graduates for the 21st Century? Proceedings of Conference on Engineering Education, Kuala Lumpur, Dec 14-15.