ENHANCEMENTS IN ENGINEERING DESIGN EDUCATION AT AUSTRIAN HTL

Probst, Andreas (1); Gerhard, Detlef (2); Ramaseder, Norbert (1); Ebner, Martin (3)
1: HTBLA Linz LITEC, Austria; 2: TU Wien, Austria; 3: TU Graz, Austria

Abstract

In Austria there is a unique curriculum of technical education which is taught at Federal Secondary Colleges of Engineering, commonly known as HTL. This paper gives an overview about continuous research activities together with TU Wien (Vienna), best practises and methods, planned enhancements and the gained experiences concerning PDM (product data management) and systems engineering as well as the impact to daily engineering education.

Keywords: Design education, Education, Product Lifecycle Management (PLM), Vocational secondary engineering schools, Collaboration

Contact:
Andreas Probst
HTL Linz LITEC
Mechanical Engineering
Austria
Andreas.Probst@eduhi.at

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 9: Design Education, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION

In 2007, a research partnership program between Austrian schools and universities called "Sparkling Science" was founded by the Austrian federal ministry of Science, Research and Economy (Birke, 2013). The main objective has been to bring science and schools together, in particular, to increase interest for STEM subjects (Science, Technology, Engineering and Mathematics). The reason for this project is because of huge demand for engineers both in Austria and in Europe. Through such projects, students of Austrian schools are able to work together with scientists of universities or universities of applied sciences on defined project tasks (Probst *et al.*, 2016). Since 2007 the Austrian vocational school HTL Linz LITEC has conducted three Sparkling Science projects with TU Wien, with two projects focusing introducing product data management (PDM) to engineering design education and the other project focusing on systems engineering.

2 TECHNICAL EDUCATION AT AUSTRIAN HTL

2.1 Technical Education at Austrian HTL

The technical Secondary Colleges of Engineering (called HTL) in Austria, a job-focused vocational education of 10 semesters for students aged between 14 and 19, aim to convey entrepreneurial and innovative thinking and acting based on solid business skills as well as legal competence. Thereby a high level of technical and methodological competence for further studies and deeper general and conceptual knowledge required for independent training as well as specialised knowledge and skills necessary for professional life are provided. A key goal in education is to offer entrepreneurial and innovative thinking and acting based on solid business skills as well as legal competence.

In order to meet the general educational goals, the engineering education covers the following fields:

- General education
- Theoretical training
- Practical training

Basic and job-orientated scientific knowledge and IT- competencies are taught, completed with A-level exams and classified as short cycle tertiary education with ISCED-Level 5.

The necessary legal business skills as well as entrepreneurial competencies are conveyed for obtaining a business licence.

Currently, more than 60,000 students attend a HTL, and about 8,000 young engineers leave HTL every year (Zafoschnig and Pachatz, 2011). There are more than 20 specialization areas, e.g. Mechanical Engineering, Mechatronics Engineering, Civil Engineering, Chemistry & Chemical Engineering. For Mechanical Engineering Education at Austrian HTL, one of the main subjects is engineering design, which is taught by using different CAD systems at a high skilled level, comparable to industry requirements. One success factor is the fact that faculty members of HTL have to work in industry for several years before becoming a member of staff. With new teachers having worked in industry, there is a constant flow of current state of the art technology in daily lessons.

Curricula at Austrian HTL include educational and occupational standards which have been developed together by HTL and Federal Ministry of education. The description of the educational standards is based on the taxonomy of learning which consists of 6 levels and was developed by Benjamin Bloom at the University of Chicago and then developed further by Anderson and Kratwohl (Zafoschnig and Pachatz, 2011).

2.2 Didactics and Methods

Looking at a typical mechanical engineering design project at a HTL or university, the project is done alone or in groups of two. In industry, working within interdisciplinary teams consisting of engineering (mechanical, electrical and IT), purchasing, sales, is standard, especially in companies that are working in high tech fields. Collaborative work has to be supported adequately with special tools, e.g. PDM systems, which are commonly used in industry. Table 1 shows possible forms of engineering design education projects and how frequently they are used from the authors' experiences in teaching, as well as the demand for collaboration tools such as PDM.

Table 1. Different forms of engineering design education

Engineering design education form	Remarks	Frequency	PDM needed
Project for one student	classical engineering design education	frequent	no
Project for a student group	solving tasks together	frequent	yes
Interdisciplinary project	project includes mechanical, electrical and IT engineering tasks	seldom	yes
Project across schools	e.g. two HTL working on a project	seldom	yes
Project across institutions nationwide	e.g. a HTL and a university working on a project	seldom	yes
Project across institutions internationally	e.g. several vocational schools, universities working on a project	seldom	yes

It is noteworthy that the methodology of first two project types, which are frequently used in engineering education, is not sufficient for the industry's needs. Another aspect is the type of typical mechanical engineering design project, which is quite often a new design project. Figure 1 shows the assignment of design types to the design phases according to VDI2210. Projects in industries such as automotive or aerospace are very often variant design projects. Especially OEMs, which involve working together with suppliers, use collaboration tools like PDM for technical data management. Comparing this with current educational design projects, there seems to be a need for future research activities. In the last two years of HTL education, a switch from conventional new engineering design projects to interdisciplinary and variant design projects with input from industrial companies is advantageous for both students and companies. Bitzer (Bitzer *et al.*, 2008) stated that for technical education at universities. Gerhard (Gerhard and Grafinger, 2009) describes a national wide project across institutions called PDM-UP with five Austrian HTL and TU Wien acting as project lead, Zavbi (Zavbi *et al.*, 2009) describes the international project European Global Product Realization (E-GPR), conducted with students and several universities.

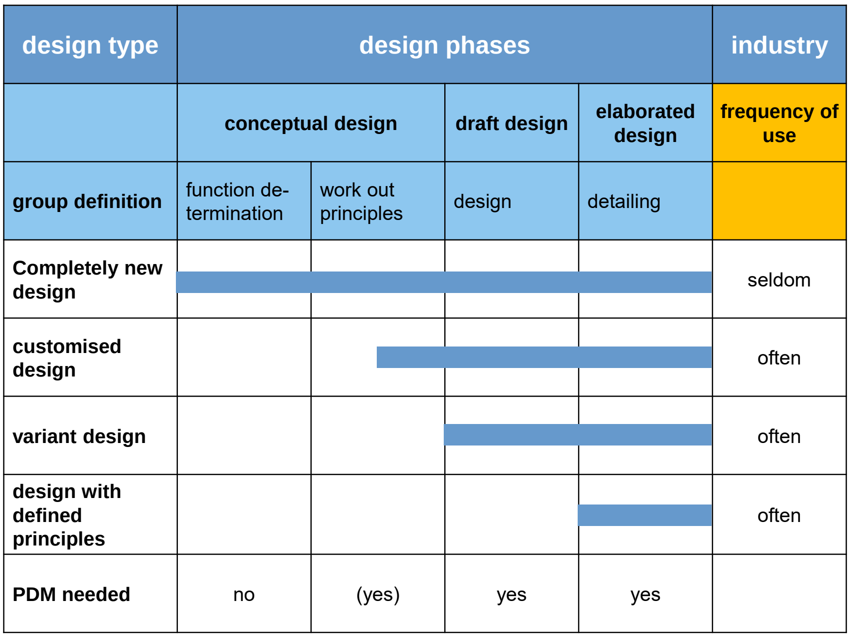

Figure 1. Assignment of design types to the design phases (according to VDI-2210)

3 CHANGING SITUATION IN ENGINEERING DESIGN

3.1 Changing demand of Industry

The influences of new technologies such as 3D printing, extensive information technology integration, Internet of Things (IoT) development and other phenomenon of recent times lead to pervasive computing capabilities (Ferscha, 2007) of products and systems. This imposes significant changes of engineering design processes in the sense of "Smart Engineering" (Anderl *et al.*, 2012). In essence, a paradigm shift from discipline oriented to multi-disciplinary engineering based on computer integrated methods and tools is required. Studies with industry representatives prove that knowledge beyond the design theory in the strict sense become increasingly important for development and engineering design work (Winter, 2012):

- Knowledge of manufacturing technology
- Knowledge of electrical engineering and mechatronics
- Computer science and programming skills
- Material science and material knowledge

In a wider sense in the context of "Industrie 4.0", autonomous capabilities and adaptability of products lead to an increased complexity and the necessity that different states and behaviour of technical systems as well as advanced logics and reasoning has to be modelled and verified in the engineering design process. The more it is possible to create a coherence between the individual disciplines, the better it is to master this complexity and its challenges, and to be able to verify and validate the real behaviour of complex technical systems by means of different simulation applications on a multidisciplinary level (Gerhard, 2016).

The major developments and technological advances in the recent past, particularly the ubiquitous connectedness and accessibility to information have also influenced the way current and future generations of engineering students learn and develop the required skills. In the past, the focus in engineering design education was primarily put on deep and basic domain knowledge. Recently, a significant shift to include more design thinking and professional practice elements can be observed. Engineering design graduates have to be able to think critically, holistically analyze problems, and communicate effectively in teams. To a large extent, students need to understand that their role in a project team in industry will not end after design validation and verification. Design engineers are often responsible for tasks included in the design transfer to subsequent phases such as manufacturing. Therefore, an understanding of manufacturing operations allows engineers to modify designs to ensure that the product can be produced for instance at reasonable cost (Goldberg, 2013).

Project-Based Learning and Problem-Based Learning (PBL) address some of these challenges and requirements. PBL is a comprehensive approach to teaching and skill development that aims to engage students in the investigation of authentic problems. Students participate in hands-on activities and thereby become active learners, while lecturers provide guidance to students during their project work instead of just lecturing (Smith *et al.*, 2010). In Project-Based Learning, instructors become facilitators to provide resources and guidance to students as they develop content knowledge and problem solving skills (Perrenet *et al.*, 2000).

3.2 Engineering design in 2025

In June 2016, the Federal Austrian Ministry of Education organized an expert talk with CAD - companies (Dassault, PTC, Autodesk and Siemens) and several HTL teachers concerning the questions "How will we develop products in 2025?" and what are the requirements on engineering design education. Product development has changed over the past decade from technical drawing to 2D-CAD to fully 3D product modelling, using powerful calculation and analysis systems. With the latest developments in IoT technologies, 3D printing etc., the next 10 years are likely to show major developments as well. Despite individual strategies, all companies stated that PDM or product lifecycle management (PLM) software will be the central platform for new techniques and tools in engineering design. Administrating engineering design data like 3D models, drawings and calculations is done currently by PDM systems. The future task of PDM systems will be administration of all kind of technical data, for example service data information. For the management of service cases in the future, it will be necessary to document all possible states of the products such as new condition, repair mode, test mode, fault mode. To handle these different modes a system like systems engineering is required, which is linked to a PDM system in order to gain the advantages of a central worldwide accessible data management.

3.3 Changing Demand in Engineering Design Education

Looking at necessary changes in engineering design education two major issues can be identified:

- Need for design education in interdisciplinary teams (Bitzer *et al.*, 2014)
- Establish and teaching new techniques like PDM, systems engineering and 3D printing

Although PDM and PLM techniques are taught in lectures at technical universities and universities of applied sciences, at Austrian HTLs theory and practical usage of PDM in students' engineering design projects is not common. Only a few HTLs have taken part in the two PDM projects with TU Wien, and these ones do use PDM software with selected students; however, there is no common understanding of the advantages of using PDM software amongst the other HTLs. Despite using PDM software, working in a team give the students the opportunity to develop their collaboration skills (Probst, 2015).
Due to this, the main targets for introducing PDM into design lessons are:

- Creating an appropriate collaborative PDM environment for students
- Developing students' collaborative engineering competencies
- Preparing students for company's demand for collaborative engineering skills
- Train engineering design educators with PDM and PLM techniques

Techniques such as PDM or 3D printing can be taught and trained within the first three years of basic education, establishing good knowledge on the methods needed for solving problem based tasks. In the last two years of education this could be switched to interdisciplinary project based tasks. Concerning 3D printing Schön and Ebner (Schön *et al.*) started a very interesting initiative the Maker Days which teaches 3D printing at the young age of 10-14 years old (Ebner *et al.*, 2016).

4 RESEARCH ACITVITIES CONCERNING ENGINEERING DESIGN EDUCATION

Figure 2 gives an overview about continuing joint research activities of TU Wien together with Austrian HTL within the Austrian Sparkling Science framework. Two surveys covering all three projects that have been carried out; a survey about PDM activities at Austrian HTL is planned for 2017.

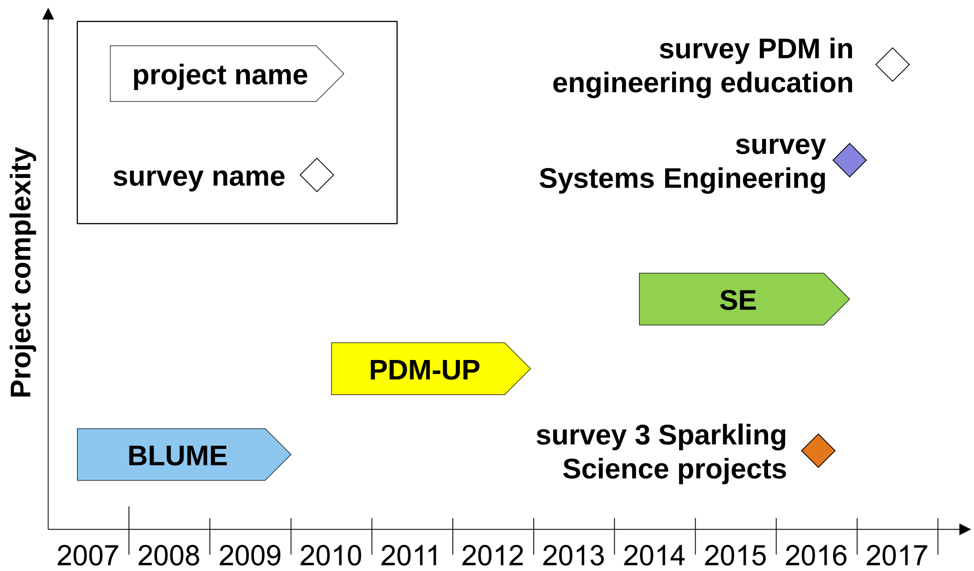

Figure 2. Overview about joint research activities TU Wien and Austrian HTL

4.1 Introducing a PDM system to Engineering Design Education at HTL

Despite accumulating approximately 500 hours of design lessons within 5 years of education, every student at an Austrian HTL has to write a diploma thesis in groups of two to five students. The minimum workload of a diploma thesis at a HTL is about 180 hours per student, and has to be done in the students' spare time. In mechanical engineering education, a diploma thesis includes engineering designs with lots of calculations, the building of 3D-models and manufacturing drawings (Reisinger et al., 2015). This leads to the need to introduce PDM software in order to support students' work in collaborating on mechanical engineering design lessons and design part of diploma thesis. Otherwise students would run into typical problems like overwriting files, uncertain valid file version or unclear project structure.

The first activities to support collaboration of engineering design education started in 2006, with the aim of introducing PDM at Austrian HTLs. Since the complexity of PDM systems is quite high, as Feldhusen (Feldhusen et al., 2007) references the effort to set up and maintain a PDM system for universities, a research partner was found with TU Wien. Two research projects to setup and maintain a PDM system were conducted. The first research project BLUME (Basis PDM Lern- und Projekt-Umgebung für ganzheitliche Mechatronische Produktentwicklung in German; in English, the learning and education environment for mechatronic product engineering) had following targets and outcomes (Gerhard and Grafinger, 2009):

- Set up and maintaining a PDM/PLM Server: to provide PDM functionality for students and educators.
- Develop and distribute templates for educational usage: to provide teachers and students with suitable templates for classroom projects as well as company projects.
- Maintain collaboration mechanical engineering design in a Multi-CAD Environment: a real product had to be designed through collaboration of students distributed in their own schools.
- Develop and distribute learning material like training videos or instruction manuals: to support students to compensate the additional effort of learning PDM techniques.

In 2010, another research project was set up, known as PDM-UP (UP – Umweltgerechte Produktentwicklung, in English the "Design for Environment – DfE", also referred to as Ecodesign or green design), which aimed to give students the possibility to work with additional functionalities which take into account the environmental factors of their engineering designs, something which the different CAD systems used by students cannot provide (Gerhard and Rahmani, 2012). Targets and outcomes were:

- Analyse the environmental impact of the engineered products: to support students in learning discovering the environmental impact of their designs, by using Life Cycle Assessment (LCA) methodology, connected to the existing PDM system.
- Incorporate the existing environmental database Ecoinvent into the PDM system: to have access to and be able to use environmental impact indicator values and life cycle inventory data, to compare different designs and to analyse their effect on the environment.
- Collaboration of design projects amongst schools: a wireless drill was designed and virtually assembled by groups of students collaborating with one another using the existing PDM system. Students from different schools worked together, with each school having their own specific design task.

4.2 Research activities to Systems Engineering method

Since mechanical engineering education in HTL has a particular focus on engineering design combined with dimensioning the critical parts, the aim of the latest research project "Systems Engineering" was to extend the designing knowledge for the early stages of the product development process with systems engineering methods. This gives all project members the opportunity to deal with increasing product complexity on a higher abstraction level in the early phases of product development. Therefore, students and teachers get used to "Model Based Systems Engineering" (MBSE) and the methodology. In order to allow practical MBSE experience, software partner PTC provided a state-of-the-art modelling software tool, ATEGO. To give the project a practical aspect, students and teachers learned to use ATEGO within two workshops and practice gained knowledge of the development of a model of a 3D printer (Probst *et al.*, 2016).

4.3 Evaluating the projects of Sparkling Science Programs

In spring 2016, a survey for the past three research projects was carried out, whereby 68 people participated in the survey, answering 18 questions overall. The main research question asked "Do the projects conducted by the Sparkling Science program influence teaching practices in engineering education at participating Austrian HTLs and the project members' perception of the program itself?".

Survey groups were consisted of current and former students, HTL teachers and TU researchers, both those that had and hadn't taken part in either one or more projects. Figure 3 gives an overview of the influence of the Sparkling Science program.

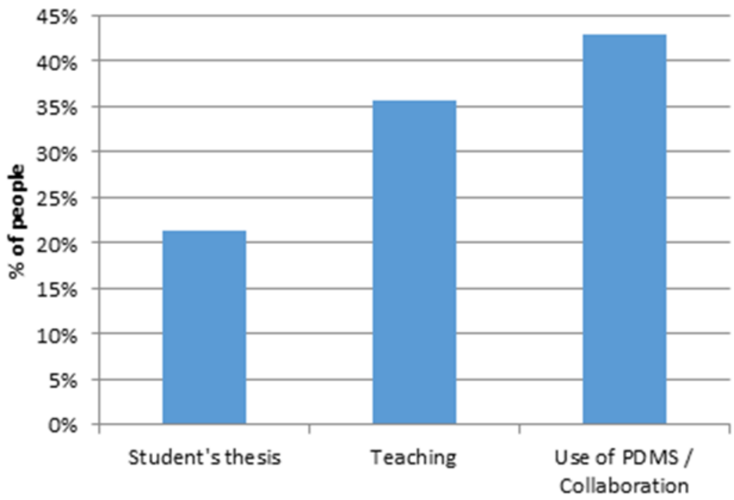

Figure 3. Influences of the Sparkling Science Program

The importance of collaboration between TU Wien and Austrian HTL is valued as important by 52.3% of the survey participants (30.8% found it very important), while the development of teaching content within such projects was valued as important by 57.8% (for 7.8% it was very important).
Overall, the results from the survey, conducted in spring 2016, encourage the continued effort of cooperation between HTLs and TU Wien (Probst et al., 2016).
For further research, it seems absolutely necessary to evaluate the participants' knowledge of project topics at the beginning, during and at the end of upcoming projects to get an idea about the change in knowledge.

4.4 Research and survey about effectiveness of using PDM in engineering education

As PDM is standard in industry but not in engineering education, there seems to be a lack of scientific research about effectiveness of using PDM systems in education. Therefore, within the academic year 2016/17 a research study was started to figure out how to enhance collaboration between students by using this kind of software. The study consists of two parts addressing different target groups. The first part of the study, called "HTL internal" will be done by approximately 100 students and their corresponding teachers of several HTLs throughout Austria. The main task is a short collaborative engineering design task by designing shafts and gear-wheels into a given gearbox by groups of up to four students. During these tasks, all students have to make notes concerning frequency of arising problems such as overwriting files or interface problems, as well as the necessary time to solve these problems. Additionally, their teachers are documenting the design task and the occurring problems such as non-working computers. Finally, there will also be a measurement of the degree of collaboration by evaluating the PDM database. The second part is a survey amongst HTL students, teachers and industry stuff with collaborative and PDM background to find out about the importance of PDM in collaborative engineering. Qualitative interviews are carried out to get a clear picture of industry's demands of collaboration education. The research and survey results will be presented in an upcoming paper and discussed with members of the Austrian national wide HTL working group for mechanical engineering design (http://www.3d-cad.at) and may influence the next generation of HTL curriculum.

5 CONCLUSION AND OUTLOOK

In this paper, ways of enhancing of engineering design education at Austrian HTLs have been presented. Thanks to the Sparkling Science program, students can use PDM for collaboration tasks in their mechanical engineering design lessons. Despite having to learn how to work with complex PDM software, the advantages for students are obvious. Based on the experiences made so far, the authors of this paper are convinced that the quality of engineering design education will improve and be closer to demands of the industry's needs.

REFERENCES

Anderl, R., Eigner, M., Sendler, U. and Stark, R. (2012), Smart Engineering: Interdisziplinäre Produktentstehung, *acatech DISKUSSION*, April 2012, Springer, Berlin, Heidelberg.

Birke, B. (2013), "Evaluierung des Förderprogrammes ‚*Sparkling Science*, Endbericht August 2013", available at: https://repository.fteval.at/38/1/Evaluierung%20des%20F%c3%b6rderprogrammes%20Sparkling%20Science.pdf.

Bitzer, M., Burr, H., Eigner, M. and Vielhaber, M. (2008), "Integrated Concepts of Design Education", *paper presented at E&PDE 2008: Engineering and Product Design Education 2008*, available at: https://www.designsociety.org/download-publication/28078/integrated_concepts_of_design_education.

Bitzer, M., Handschuh, S. and Langlotz, M. (2014), "Virtual Product Engineering Network crosses Industry and University Chasm", in Bohemia, E., Eger, A., Eggink, W., Kovačević, A., Parkinson, B. and Wits, W. (Eds.), *Design education & human technology relations: Proceedings of the 16th International Conference on Engineering and Product Design Education, University of Twente, Enschede, the Netherlands 4th - 5th September 2014*, Institution of Engineering Designers; Design Society, Westbury, Wiltshire, Glasgow.

Ebner, M., Schön, S. and Khalil, M. (2016), "Maker-MOOC – How to Foster STEM Education with an Open Online Course on Creative Digital Development and Construction with Children", in *Proceedings of the 19th ICL Conference, Belfast, UK*, Springer, pp. 1233-1244.

Feldhusen, J., Löwer, M., Nurcahya, E. and Macke, N. (2007), "Advances in Collaborative Engineering Education", *paper presented at ICED07: 16th International Conference of Engineering Design*, available at: https://www.designsociety.org/download-publication/25483/advances_in_collaborative_engineering_education.

Ferscha, A. (2007), "Pervasive Computing: connected > aware > smart", in Mattern, F. (Ed.), *Die Informatisierung des Alltags: Leben in smarten Umgebungen*, Springer, Berlin.

Gerhard, D. (2016), "Daten- und Informationsmanagement PDM/PLM", in Lindemann, U. (Ed.), *Handbuch Produktentwicklung*, Hanser, München, pp. 215–246.

Gerhard, D. and Grafinger, M. (2009), "Integrative Engineering Design using Product Data Management Systems in Education", *paper presented at E&PDE 2009: Engineering and Product Design Education 2009*, available at: https://www.designsociety.org/download-publication/28904/integrative_engineering_design_using_product_data_management_systems_in_education.

Gerhard, D. and Rahmani, T. (2012), "PDM based Lifecycle Analysis - A Case Study", in Stelzer, R., Grote, K.-H., Brökel, K., Rieg, F. and Feldhusen, J. (Eds.), *Entwerfen, entwickeln, erleben: Methoden und Werkzeuge in der Produktenentwicklung*, Paper-Nr. 205, TUDpress, Dresden.

Goldberg, J.R. (2013), *A Hands-On, Active Learning Approach to Increasing Manufacturing Knowledge in Engineering Students*, paper ID 6230, paper ID 6230, Atlanta, USA.

Perrenet, J.C., Bouhuijs, P.A.J. and Smits, J.G.M.M. (2000), "The Suitability of Problem-based Learning for Engineering Education. Theory and practice", *Teaching in Higher Education*, Vol. 5 No. 3, pp. 345–358.

Probst, A. (2015), "Introducing PLM at Austrian Secondary Colleges of Engineering", *paper presented at ICL2015 18th International Conference on Interactive Collaborative Learning*, Florence, Italy.

Probst, A., Gerhard, D., Bougain, S. and Nigischer, C. (2016), "Continuous Research and Development Partnership in Engineering Education", in *Proceedings of the 19th ICL Conference, Belfast, UK*, Springer.

Reisinger, J., Plakolm, J., Gurtner, G., Schachermair, K. and Probst, A. (2015), "Introducing PLM to engineering design education at Secondary Colleges of Engineering - a students' view", *paper presented at ICL2015 18th International Conference on Interactive Collaborative Learning*, Florence, Italy.

Schön, S., Ebner, M. and Reip, I., "Kreative digitale Arbeit mit Kindern in einer viertägigen offenen Werkstatt", pp. 1–20, available at: https://www.researchgate.net/profile/Martin_Ebner2/publication/300634456_Kreative_digitale_Arbeit_mit_Kindern_in_einer_viertagigen_offenen_Werkstatt/links/570ab07c08aed09e9171477b.pdf.

Smith, P., Adank, R., Sigurjonsson, J. and Shekar, A. (2010), "The continuum of design and engineering educaton: Competencies in final projects", *paper presented at E&PDE 2010: ENGINEERING AND PRODUCT DESIGN EDUCATION 2010*, available at: https://www.designsociety.org/download-publication/30193/the_continuum_of_design_and_engineering_educaton_competencies_in_final_projects.

Winter, M. (2012), "Interviews mit Ingenieuren aus Industrie, Hochschulen und Verbänden sowie Studenten der Ingenieurswissenschaften", in Alber, A., Berend, D. and Sven, M. (Eds.), *Konstrukteur 2020. Wandel der Tätigkeitsfelder und Ausbildungskonzepte von Konstrukteurinnen und Konstrukteuren in Entwicklung und Produktion (acatech STUDIE)*, Springer Berlin Heidelberg, pp. 47–86.

Zafoschnig, A. and Pachatz, W. (2011), “Education standards and competence-oriented curricula – the Austrian Technical Colleges pursue a new way into the future!”, *paper presented at 2011 14th International Conference on Interactive Collaborative Learning (ICL)*, Piestany, Slovakia.

Zavbi, R., Kolsek, T. and Duhovnik, J. (2009), “Virtual Product Development Study Courses Evolution and Reflections”, *paper presented at ICED09: 17th International Conference on Engineering Design*, available at: https://www.designsociety.org/download-publication/28874/virtual_product_development_study_courses_evolution_and_reflections.

ACKNOWLEDGEMENT

The work presented in this paper has been funded by the Austrian Federal Ministry of Science and Research within the Sparkling Science Program (http://www.sparklingscience.at).