INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
10-11 SEPTEMBER 2020, VIA DESIGN, VIA UNIVERSITY COLLEGE, HERNING, DENMARK

GOOD IDEA OR BAD IDEA? – TEACHING KNOWLEDGE-BASED ENGINEERING IN A FLIPPED CLASSROOM

Paul Christoph GEMBARSKI
Leibniz University Hannover, Institute of Product Development, Germany

ABSTRACT
The application of computer-aided design (CAD) systems belong to the very basic competences that a design engineer in mechanical engineering is taught. The definition of shape and product properties in such systems is the foundation of virtual prototyping and the later manufacturing as well. Depending on the specialization, there exist different capstone courses in engineering design. At Leibniz University of Hannover, the Knowledge-based Design Lab was conceived as project-based learning environment for design automation and product configuration. Its aim is to provide profound knowledge about creating highly flexible but robust CAD models that can self-adapt to changing requirements to automate routine design tasks. Although already highly activating for the students, input and setup were organized traditionally, i.e. professional skills were developed mainly in the ten attendance phases of the class and the overall course of action has only minor degrees of freedom. This was changed in 2018 when the Knowledge-based Design Lab was transformed into a flipped classroom. In the present article, the author reports about the according transformation process, discusses both the traditional and the flipped classroom and compares the learning outcomes and competences of the graduates of the different formats. To avoid cohort effects, the results of the last three semesters are averaged.

Keywords: Knowledge-based engineering, computer-aided design, flipped classroom, project-based learning

1 INTRODUCTION

Computer-aided design (CAD) systems belong to the very basic software applications that students in mechanical engineering get in touch with. The definition of shape and product properties in these systems is foundational for virtual prototyping and the manufacturing documentation [1]. Depending on the later specialization, students may take different capstone courses involving CAD. One possible setup is design automation and product configuration. At Leibniz University of Hannover, the Knowledge-based Design Lab was a project-based learning environment, which provided profound knowledge about creating highly flexible but robust CAD models that can self-adapt to changing requirements [2]. Although already highly activating for the students, input and setup were organized traditionally, i.e. professional skills were developed mainly in the ten attendance phases of the class and part of the presence was used for lecturing. The students then had to follow up on the contents in preparation for the next class. Additionally, a joint design automation project was carried out where all the students had to contribute features and sub-assemblies for a configurable product in group work. In 2018, the lab was transformed into a flipped classroom lecture. Using a flipped or inverted classroom means to exchange content and purpose of in-class and outside of class activities. Passive activities like listening to lectures are performed outside of class, active ones like laboratories or discussions in-class [3, 4].
Since the basic structure, the major part of the learning material and the educational goals are equal, the question was raised if the change to the new format encourages different competences of the participants at the end of the course and if one major objective, i.e. to work in a team of knowledge engineers, can still be achieved. To give answers to this, the author and his team observed and evaluated the course participants of three consecutive semesters and compared this to the results of the original Knowledge-based Design Lab.
The paper is organized as follows: In the following section 2, a brief theoretical background focusing on the flipped / inverted classroom concept, problem- and project-based learning and the context of

knowledge-based engineering is presented. Afterwards in section 3 and 4, the *Knowledge-Based Design Lab* and the lecture *Knowledge-Based CAD 1 – Configuration and Design Automation* are presented as teaching concepts, the first without, the latter using the flipped classroom. Section 5 provides a comparative analysis before section 6 concludes the paper.

2 THEORETICAL BACKGROUND

2.1 Flipped Classroom

Although shifting lecture time and passive learning activities outside of class is widely known from distance learning, the concept of flipping or inverting the classroom must be understood as a different pedagogical approach [3]. The main idea is to exchange in-class and outside of class activities, i.e. passive learning activities like listening to lectures are shifted outside of class, active ones like laboratories, discussions and more complex problem-solving take place in-class [4]. Literature reports about different possible benefits that result from flipping the classroom [3-7]:

- *Independent from time and place:* The consumption of the learning material is detached from class, the student choses his/her own learning environment and pace.
- *Better use of contact time between teacher and student:* In opposite to traditional teacher-centric lectures where usually only a minor subset of students is actively involved and weak students hide, presence time can be spent for in-depth learning activities or with students that are struggling.
- *Highly motivating also for peer-to-peer activities:* Especially in combination with problem-based learning, group collaboration and a high responsibility for their own learning process encourages students to better explore the course content compared to a traditional lecture.
- *Fits to different learner types:* Since learning material, collaborative work and teacher-student interaction are altogether diverse, different types of learners (e.g. teacher-dependent, independent, collaborative) are attracted.

The flipped classroom concept dates to the end of the 1990s but becomes more popular with the intense use of the internet since asynchronous teaching materials can easily be delivered online and via learning management systems. Still, the flipped classroom’s use in engineering disciplines is not widespread and comparatively little research exists regarding its impact on engineering education [6].

2.2 Problem- and project-based learning

Problem- and project-based teaching are both inductive teaching methods that aim at transferring the responsibility for the learning process and the content to the learners and that both are used in engineering education [8]. The first approach dates to the end of 1960s and early 1970s and was initially implemented in medicine with a focus on knowledge acquisition [9]. The learning process is organized in three stages: (1) Confrontation with a real-world problem and development of reasoning steps under guidance of a tutor; (2) self-directed study of the learner for knowledge acquisition relevant to solve the particular case; (3) knowledge application, case solution and reflection of the learning process [8]. Compared to problem-based, project-based learning is of a wider scope usually incorporating multiple problems and leads to a discreet result (a design, a model, etc.). The relevant and new knowledge, which is necessary to finalize the project, can be taught e.g. in accompanying lectures [10]. For a detailed discussion of inductive teaching methods in engineering disciplines, refer to [11].

2.3 Knowledge-Based Engineering

Knowledge-based engineering (KBE) is a set of techniques to establish product models that are easy to adapt to new requirements and which can be used for (partial) automation of design tasks [12]. The application of KBE is interesting not only for activities that involve a lot of routine design tasks or for e.g. mass customization business models which use product configuration systems but for decision support and co-creation as well [13, 14]. An underlying concept of KBE is the implementation of two very basic kinds of knowledge [15]: (1) Domain knowledge, coded e.g. in parameter constraints, formulae, design rules and templates, which is linked with a product model, sets up a solution space in which a particular solution for a defined set of requirements can be found. (2) Control knowledge expresses how this solution space is explored and embodies reasoning. Today, computer-aided design (CAD) systems offer different possibilities to create knowledge-based product models [16]. Knowledge engineering, i.e. acquiring relevant knowledge from human and non-human resources and formalizing it according to the later purpose, and building knowledge-based product models require theoretical knowledge, but rather experience and skills in working in teams, project management and communication as well [17, 18]. To be relevant, a corresponding teaching set-up must consider such educational objectives which only can be dealt with by doing [2].

3 THE HANNOVER KNOWLEDGE-BASED DESIGN LAB

The Knowledge-Based Design Lab was designed basically as a project-based learning environment. Students could take the course from the fifth Bachelor semester onwards. As it was designed as expert course in computer-aided design, the completion of the foundational design projects of the bachelor studies as well as the completion of the advanced CAD tutorials were mandatory requirements. Depending on the number of tutors, 20 to 30 students were accepted for a class, divided into groups of four to six. Each group was led by a tutor who also assumes the role of project leader for that group. Considering that the teachers also contribute to the design project, the design automation task takes about 800 to 1200 working hours in total. The lab was divided into 10 sessions of ninety minutes of presence time each. The same time was recommended as preparation and follow-up for each group outside of class. The first three sessions dealt with the theoretical background and closed exercises like creating parametric part families and simple spreadsheet-driven designs. From the fourth session on, a joint design project was carried out where all groups had to agree on assembly structure, knowledge implementation and control concept and contribute sub-assemblies for later implementation.

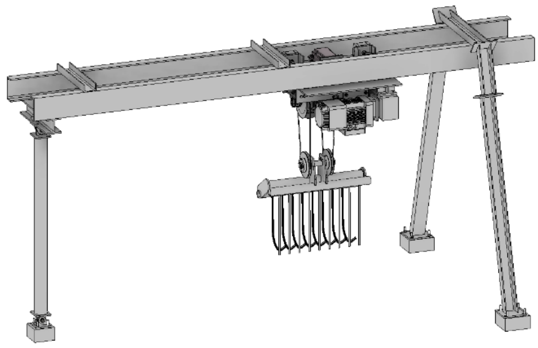

Figure 1. Configurable trash rack Cleaner

Exemplarily shown, the design project of the 2017 Lab was a configurable trash rack cleaner (Figure 1) which was implemented by 24 students and 5 tutors. The model can handle different layouts (straight line with portal or gantries, L- or Z-pathway) and it self-calculates the necessary cross-sections for the supports. Regarding the lift unit, the user may configure either single winch or pulley and the model dimensions the hoist afterwards according to the relevant standards. Within the teams, the students had autonomy for organizing within their groups and matching their individual contributions to the project. Top-level project management and coordination of the system implementation was done by the lecturer. The Knowledge-Based Design Lab had been taught for five years before the curriculum at Leibniz University of Hannover changed in 2017.

4 KNOWLEDGE-BASED CAD 1

In 2018, the topics knowledge-based CAD and design automation got a more prominent place and were transformed into two full lectures of 5 ECTS points each. While the second lecture aims at the integration of artificial intelligence in virtual prototyping (e.g. case-based and probabilistic reasoning, multi-agent-systems), *Knowledge-Based CAD 1 – Configuration and Design Automation* is the successor of the Knowledge-Based Design Lab. In comparison, the basic learning objectives didn't change and the lecture still addresses the five major topics *parametric CAD models and part families*, *advanced assembly control via skeleton techniques*, *spreadsheet-driven design*, *knowledge engineering and methodologies* as well as *product configurators and expert systems*. For each of these topics, the learning material was updated and matched to the flipped classroom, i.e. lecture slides were transformed into commented screen casts and single learning videos. The content itself was not deepened.
Presence time was extended to 10 sessions of 150 minutes each. According to the flipped classroom concept, the teacher engaged the students at the beginning with a little warm up task that targets at the prepared course material without repeating it. Afterwards, modelling tasks for the corresponding topic are carried out in groups of three to five students. Meanwhile, the teacher moderates and accompanies

the learning process of the groups. Each session is closed by a wrap-up and the students then upload their results to a learn management system so that all participants can access them. Where suitable, the teacher drops in impulse talks (e.g. "What is a model?") and starts and moderates discussions. An exception to this template is the topic *knowledge engineering and methodologies*, where the students must prepare a poster session for a specific method in group work which are presented and disputed in a gallery walk.

After session five, the accompanying semester project is negotiated and then completed. In contrast to the Knowledge-based Design Lab we changed from one joint project, where all participants must contribute, to single projects that are worked out by tandems or triplets of students. We did this to reduce the coordination effort within the student teams and allow more freedom of choice for the projects. As a result, the projects are widespread in the learning field of design automation (Figure 2) and range from Excel-based CAD configurators over plug-ins for the CAD system to engineering environments for automatic dimensioning and design that integrate e.g. MATLAB and Autodesk Inventor.

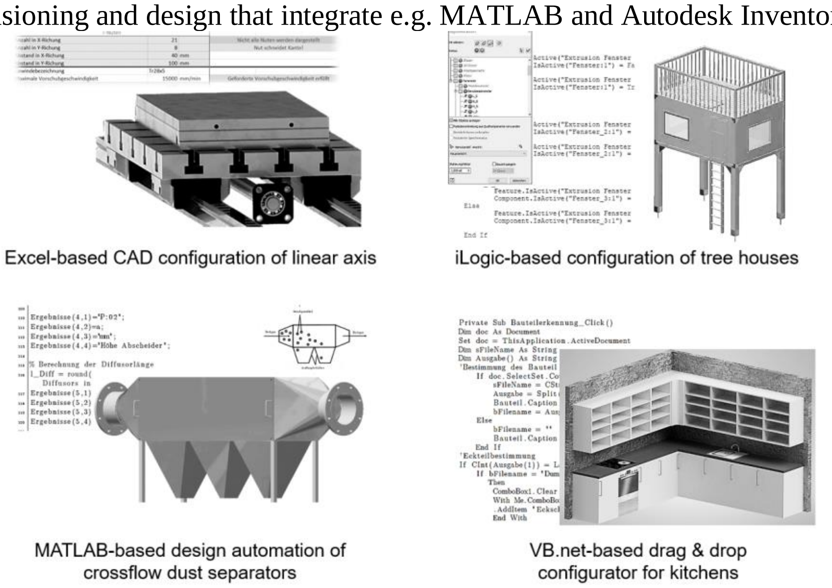

Figure 2. Student Projects from Knowledge-based CAD 1

To introduce another degree-of-freedom in the lecture itself, the students can make suggestions and chose the topic for the last, but one session based on the experience they made in the projects. In two of three semesters they demanded more background for *project management and team coordination* in knowledge engineering projects. The final session then contains a gallery walk of the student projects and the final reflection of the lecture. Assessment is two-fold: First, the student projects are evaluated by the teacher and second, each student must perform in an oral examination.

5 COMPARATIVE ANALYSIS

To exclude cohort effects, the observations of three consecutive semesters of lecture participants are averaged. The control group is the average of the last three semesters of the Knowledge-based Design Lab. Regarding the number of participants, it decreased from averagely 23 to 19 but the student numbers in mechanical engineering decreased in general due to a bit smaller semesters. In the evaluation set-up, one issue was monitored: In the last run of the lecture, a student enrolled that had only basic competences in 3D CAD since he was trained in 2D which is fundamentally different. We wanted to know if it is possible to achieve acceptable learning outcomes with such preconditions as well. For closing the gap to the other participants, the student was equipped with additional learning material and video tutorials. To survey all students, different techniques were used, i.e. evaluation sheets, a midterm teaching analysis poll, interviews and the results from examinations and semester projects.

5.1 Student performance

The student performance must be judged diverse. What we have found is that with respect to the project management experience, the old Knowledge-based Design Lab necessitated the students to manage design interfaces and knowledge artefacts more rigorously than in the smaller projects. But is must be considered that top-level project management and coordination was done by lecturers instead of the students. In contrast, in the new lecture the students achieved better methodological competences for knowledge engineering, an improved depth of knowledge especially in special fields of knowledge implementation into CAD systems, a better awareness for design automation potentials and a far wider spread of the semester projects. The students could further develop their knowledge in areas they wanted, as was presented in the last section. In the examinations, the students showed a wider content coverage and had better design problem-solving capabilities compared to the Knowledge-based Design Lab. The average grades are about 20 % better and distributed more homogeneously. What was remarkable is that some students struggled with their motivation for consuming the videos as passive learning material. To support those students, an additional one-pager was created with guiding questions for the learning material, questions and feedback section. Regarding the student who had to catch up with 3D modelling, he met the basic learning objectives. Although the semester project and the models from the in-class activities were simpler compared to the average, the understanding for parametric design, assembly control and the implementation of reasoning was on an above average level. For us this is an indication at least to think about relaxing the entry requirements.

5.2 Student satisfaction

Student satisfaction was evaluated to be *good* to *very good* in both learning setups. It must be mentioned that at our university such teaching concepts are still comparatively rare. So, the students also stated that they were attracted simply by the lecture being very different to what they have encountered so far. This is also mirrored by the fact that our students felt a bit lost in the first weeks since they had to get used to the formats and tried to figure out the limits regarding moderate class preparation. Also, in both cases, the students mentioned that the expenditure for the courses was high compared to other lectures in the curriculum. But we made it clear from the very first minute that this is how it will be, and this was at least noticed. Nonetheless, the retention rate was about 15 %.

What was perceived differently in the new lecture format was the teacher-student interaction which was said to be more intense. This has two reasons: In-class time was indeed used to help struggling students and discuss within the groups while modelling on the one hand, but on the other hand contact time was raised compared to the Knowledge-based Design Lab. Also positive was the students' involvement in knowledge creation and setting learning objectives during the lecture.

In both setups, the students felt *well* to *very well* prepared for the work as knowledge engineers.

5.3 Teacher performance

With respect to teacher performance, the results of the evaluation differ more than estimated. In the new lecture format, the students rate the teacher's professional and interaction competencies higher and value the high degree of interaction although the Knowledge-based Design Lab also enabled such interactions within the single groups. Basically, this corresponds to the wider spread of projects and implementations where the teacher must react spontaneously within the situation and give immediate feedback during contact time.

6 CONCLUSIONS

This study was directed towards the question whether it is a good or bad idea to teach knowledge-based engineering in a flipped classroom. The answer is as often: It depends. In both setups, the students gained profound knowledge about design automation and reached the respective educational goals. Retrospectively, in the case of the *Knowledge-based Design Lab* the focus was more on implementation of knowledge towards a predefined and concrete project task which resulted in good professional skills in working with the tools and contributing to a joint project. This is satisfactory for a CAD capstone course.

The lecture *Knowledge-based CAD 1* introduced more degrees-of-freedom for the students in choosing their own focus and motivated them to try out different ways of design automation which resulted in better problem-solving competencies and a higher awareness what different tasks can be automated in mechanical design engineering. What was surprising is the fact that the spread of projects got that high. In the current implementation, students engage additionally in software engineering, creation of simulation tools, etc. which is highly beneficial for the work as knowledge engineer. For the teacher this means a higher challenge since he or she must have according competencies or the ability to moderate the students to make their steps forward and critically reflect their achievements.

The effort for creating the videos and interactive material was comparatively high, as often reported in literature. However, applying a mixture of videos, interactive learning material and traditional scripts or excerpts from scientific literature worked very well.

The authors do not think that flipping the classroom is the only reason for the observed change in student competencies. It has also to be considered that contact time was raised about 50 % and that major degrees-of-freedom were introduced on the project side. Nonetheless, the new format achieved one noticeable effect: Besides transferring knowledge and professional skills, the students developed rather real and sustainable interest in the topic of design automation.

A question that follows is if the flipped classroom is beneficial for basic CAD courses as well. Compared to a mere online course based on video tutorials the amount of time for student interaction will rise. Regarding quality of the designed models, it could help to prevent students from taking shortcuts and focus on modelling strategies and planning.

REFERENCES

[1] Stroud, I. and Nagy, H. *Solid modelling and CAD systems: how to survive a CAD system.* 2011 (Springer, Berlin Heidelberg).

[2] Gembarski, P.C., Lachmayer, R. The Hanover Knowledge-Based-Design-Lab: A Project-Oriented Capstone Course in Engineering Design. In *Proceedings of the 20th International Conference on Engineering and Product Design Education (E&PDE2018).* 2018, pp. 662-667.

[3] Enfield, J. Looking at the impact of the flipped classroom model of instruction on undergraduate multimedia students at CSUN. *TechTrends.* 2013, 57(6), pp. 14-27.

[4] Akçayır, G., Akçayır, M. The flipped classroom: A review of its advantages and challenges. *Computers & Education*, 2018, 126, pp. 334-345.

[5] Blair, E., Maharaj, C., Primus, S. Performance and perception in the flipped classroom. *Education and Information Technologies,* 2016, 21(6), pp. 1465-1482.

[6] Kerr, B. The flipped classroom in engineering education: A survey of the research. In *2015 International Conference on Interactive Collaborative Learning (ICL)*. 2015, pp. 815-818.

[7] Gannod, G., Burge, J., Helmick, M. Using the inverted classroom to teach software engineering. In *2008 ACM/IEEE 30th International Conference on Software Engineering.* 2008, pp. 777-786.

[8] Perrenet, J.C., Bouhuijs, P.A.J., Smits, J.G.M.M. The suitability of problem-based learning for engineering education: theory and practice. *Teaching in higher education*, 2000, 5(3), pp. 345-358.

[9] Borrows, H.S. Problem-based learning in medicine and beyond: A brief overview. *New directions for teaching and learning*, 1996, 1996(68), pp. 3-12.

[10] Mills, J.E. and Treagust, D.F. Engineering education—Is problem-based or project-based learning the answer. *Australasian journal of engineering education*, 2003, 3(2), pp. 2-16.

[11] Prince, M.J. and Felder, R.M. Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of engineering education*, 2006, 95(2), pp. 123-138.

[12] Verhagen, W.J.C., Bermell-Garcia, P., van Dijk, R.E.C., Curran, R. A critical review of Knowledge-Based Engineering: An identification of research challenges. *Advanced Engineering Informatics*, 2012, 26(1), pp. 5-15.

[13] Gembarski, P.C., Lachmayer, R. Business Models for Customer Co-Design. In *Proceedings of the 7th International Conference on Mass Customization and Personalisation in Central Europe (MCP-CE 2016).* 2016, pp. 76-83 (Faculty of technical sciences, Novi Sad).

[14] Li, H., Gembarski, P.C., Lachmayer, R. Template-Based Design for Design Co-Creation. In *Proceedings of the 5th International Conference on Design Creativity (ICDC2018)*, 2018, pp. 387-394.

[15] Milton, Nick. R. *Knowledge technologies*. 2008 (Polimetrica sas, Monza).

[16] Gembarski, P.C. *Komplexitätsmanagement mittels wissensbasiertem CAD – Ein Ansatz zum unternehmenstypologischen Management konstruktiver Lösungsräume*. 2019 (TEWISS, Garbsen).

[17] Stokes, M. *Managing engineering knowledge: MOKA: methodology for knowledge-based engineering applications.* 2001 (Professional Engineering Publishing, London).

[18] Chandrasegaran, S. K., Ramani, K., Sriram, R. D., Horváth, I., Bernard, A., Harik, R. F., Gao, W. The evolution, challenges, and future of knowledge representation in product design systems. *Computer-aided design*, 45(2), 2013, pp. 204-228.