INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
6 & 7 SEPTEMBER 2018, DYSON SCHOOL OF DESIGN ENGINEERING, IMPERIAL COLLEGE, LONDON, UNITED KINGDOM

IMPLEMENTING PLM BY USING A PDM-SYSTEM IN UNIVERSITY EDUCATION - EVALUATING 3 YEARS OF TEACHING

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ABSTRACT
The future generation of mechanical engineers has to meet a broad range of exigencies concerning their skills. Today's product development processes are becoming more complex. The requirements of modern products no longer focus mainly on the mechanical design of the components. Many of the upcoming product demands have cyber-physical aspects as well. The knowledge about the electric, electronic, and mechatronic components and their interaction needs to be addressed in today's student classes. The present paper shows our way of conquering this challenge. In the context of a large-scale Bachelor course at university during the fifth semester, the basics for the development and design of new products are focused. The concept provides a closed learning cycle between theory and practice. It combines deductive (explanation-based) and inductive learning (learning by example or learning by observation) in order to combine the benefits of both learning strategies. In the lecture, the students get to know the theory of today's design methodologies. The students use this theoretical knowledge for a practical exercise, where small student design teams solve a real-life engineering design problem.

Keywords: Product Data Management System, Windchill, Mechanical Engineer, Practical Exercise

1 INTRODUCTION

The course is divided in a 45 min lecture, a 45 min lecture exercise with application examples, and a 90 min practical exercise. In the contemplated practice-oriented lessons, the students deal intensively with a specific everyday life product during the semester. First, the students have to disassemble the product completely. The disassembling serves several purposes: first, a deeper understanding by touch and second, an active experience of the application of design methods in real products. A group of five to six students' works on a product assigned to them. After an in-depth analysis of the actual design situation (building structure, implemented functions, detailed design of individual components, etc.), the groups redesign one modular component of the product. Figure 1 shows the schematic sequence of the practical exercise from the idea to the concept phase, the design, the documentation of the results and the subsequent evaluation of the concepts.

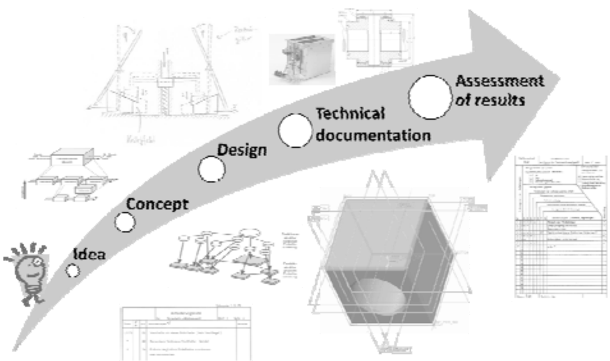


Figure 1. Concept of education

The objective is to generate an innovative benefit on a technical problem and at the same time strive for cost-optimised product design. This breaks the curve from practice to theory and closes the learning circle.

2 STATE OF THE ART

Today's product development processes are becoming more and more complex due to the extensive implementation and integration of software, electronics and mechanical parts. Traditional handling of design information during product development processes, like the former concept of morphological boxes [1], is not suitable to handle the tremendous amount of data produced by today's design steps and the underlying software-tools (e. g. CAD, FEM, CFD, etc.) any more. Therefore, software tools for data handling during the design and development process have been developed [2]. Those tools, called "product data management systems" (PDMS), provide the possibility of managing concurrent design tasks (so called "workflows") as well as different domain data (e. g. MCAD, FEM, et cetera) and additional meta-data (e. g. materials) [3]. PDMS represent today's standard in handling engineering design data on enterprise level. While most system vendors integrate the combination of modern MCAD software tools with PDMS data management strategies today, e. g. Siemens [4] or PTC [5], the methodological design approach throughout the whole design process is not self-explaining. In the past, various design methodologies have been evolved to help the product developer finding the best way to determine, create, and handle all the information throughout the whole product design process [2] [6] [7]. At RWTH Aachen University, the methodology of Pahl and Beitz [2] has been taught in various lessons for over one decade to educate the product designers of tomorrow.

3 THE EDUCATIONAL EVENT

In semester 2017/2018 ten closed tasks were given to the students, each task representing one work package in the concept of education (chapter 1). The tasks were defined according to the teaching concept into requirements list, function structure, product structure, principle solution, preliminary design, evaluation, overall design, and documentation. The tasks were published on an electronic learning platform. Students at RWTH Aachen University have the possibility to carry out bonus tasks, which may value up to 20% of their exam in advance by writing their own homework during the semester to prepare for the exam [8]. The didactic advantage of processing the bonus tasks lies in the fact, that the students can have their learning performance reviewed by the course advisors. In this way, examinations can be submitted and evaluated step by step. Besides, the bonus points allow for an improvement of up to two grades in the overall result, so that a better final grade can be achieved.

3.1 Using a Product-Data-Management-System

Within the course, subsequent handing in the single tasks to each group-member has been realised via PTC's PDMS Windchill (version 10.2). For individual weekly submissions, each student was granted an individual account. However, the students had to work together in terms of concurrent engineering. For the semester-concurrent processing, each student group had a working folder with its group number. Within their folder, the students were allowed to freely organise themselves. For individual tasks, public "submission" folders had to be shared with all users. The management of data and task workflows had to be done by the group participants independently. The students were supported by a written guide to manage PDMS tasks like e. g. the creation of new documents, see Figure 2.

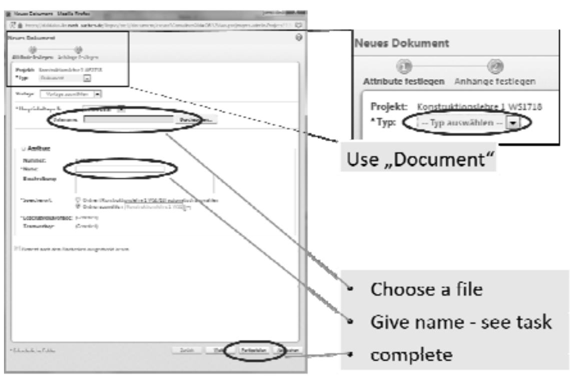


Figure 2. Excerpt from PDMS: Create documents

If a group successfully completed a task, the students were rewarded with credits that were added to their final exam's score at the end of the semester. The correction was done exclusively digitally and the results were subsequently made available to the students in the individual group folders, including the comments of the advisors.

3.2 The Systems of Credits

The possibility to collect credits for the final exam has been perceived differently by the students. The evaluations of the courses of the past three years have shown that in 2015, which was the first year of application of the described concept, 223 students were registered for the event. Of these, 77% (172) took the extra effort to gain additional credits for the final exam. It is striking that the enthusiasm for bonus point tasks has already dropped in the second year. Participation of 55% (140 out of 253 students) in semester 16/17 and 47% (129 out of 272 students) in semester 17/18 suggests a long-term participation of about half of the registered students. The effort, possibly not knowing about the existence of such bonus points, a late start to the semester and thus the missed chance of participation or disinterest are assumed as possible causes for these values.
However, a post evaluation of the course showed that participating students rated the practical exercises very well. Frequently written statements were "good", "example from practice / industry" and "a lot of extra input from a professor - experiences as well as anecdotes". The explanations of the practical example and the group work in the practical exercise were positively highlighted by most of the participants.

4 COURSE EVALUATION

During the observed three years of education, an average percentage of 84.7% male participant students have been registered. Most of the students were Germans (average of 84.4%), while an average percentage of 10% of the students came from non-EU home-countries, seen in Table 1.

Table 1. Participant's diversity

semester 15/16		**semester 16/17**		**semester 17/18**	
80% Men / 20% Women		89% Men / 11% Women		85% Men / 15% Women	
German	86%	German	84%	German	83%
EU	7%	EU	7%	EU	3%
Non EU	7%	Non EU	9%	Non EU	14%

In the following paragraphs, it is shown how the presented teaching concept affects the students and their achievements. First, the students' success rate of each bonus task is discussed. Second, the relationship between bonus credits and exam grade is evaluated.

4.1 Success rate of bonus tasks

Only three percent of the students participating for bonus tasks from semester 15/16 have received the full score of the bonus points. From $90 \geq x < 100$ points, 17% of students have successfully completed the tasks, whereby x is the achieved amount of points in this range. $75 \geq x < 90$ points were achieved by 43% of the students. In the area $50 \geq x < 75$ points, 27% of the participating students were able to score. For the area $25 \geq x < 50$ points, 7% of the participants received points and 2% achieved less. 51 people did not use the opportunity to participate. The results of the three recorded periods are briefly shown in the following table 2.

Table 2. Amount and percentage distribution of the points achieved

achieved credits	semester 15/16		semester 16/17		semester 17/18	
	Amount	**Percent.**	**Amount**	**Percent.**	**Amount**	**Percent.**
x = 100	5	3%	23	16%	4	3%
90 ≥ x < 100	30	17%	46	33%	21	16%
75 ≥ x < 90	74	43%	35	25%	41	32%
50 ≥ x < 75	47	27%	6	4%	37	29%
25 ≥ x < 50	12	7%	22	16%	16	12%
0 > x < 25	4	2%	8	6%	10	8%
x = 0	51		113		143	

In summary, it can be stated that the number of students registering for the event is increasing over the evaluated period. The number of students deciding to spend time on bonus credits is around 50%. It is gratifying to see that more than 50% of the students receive more than half of the overall credits available. Thus, in the semester 15/16, 63% students achieved at least 50% of the credits. This can be seen at the three upper bars in the diagram, in Figure 3. In semester 16/17 about 74% of the students and in semester 17/18 already 80% of the students achieved more than 50% of the credits.

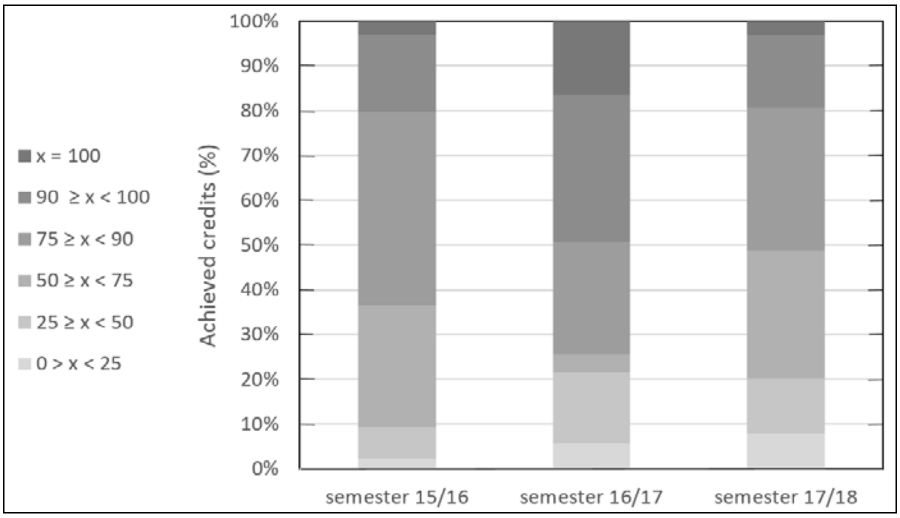


Figure 3. Bonus results of the participating students

The number of students who have achieved more than 90% of the credits is 35 (20% of students) for 15/16, 69 (49% of students) for 16/17 and 25 (19% of students) for 17/18. It is reasonable to assume, that 20% is a reliable value for students who deliver excellent performance. For the deviations, minor differences in the general procedure have to be determined. In semester 15/16 and semester 16/17 two different products (a hand-held blender and a window cleaner in 15/16; a hand-held circular saw and a hand vacuum cleaner in 16/17) were analysed. Furthermore, the optimisation task was the students' own choice, meaning that students could freely decide for the optimisation goal of a self-selected component or assembly. In semester 17/18, for the first time, a specific task for a product detail was the same for all groups. This uniform and concrete task seems to increase the level of difficulty and eliminates the possibility of a potentially simpler topic for students.
After reviewing the success rate of the bonus tasks, the next paragraph shows the analysis of the relationship between bonus credits and the final exam grades.

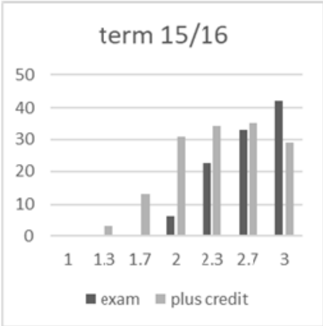
4.2 Relationship between bonus credits and final exam grade

In this paragraph, the students' score in the bonus credit tasks as well as the final exam is evaluated. Therefore, an extract of the achieved points and their grades will be discussed. To ensure the international comparison of the following grades, Table 3 should give an overview of the individual grades and their gradation.

Table 3. Grades at University level (app.)

<table>
<tr><th>Percentage</th><th>German System</th><th>UK System</th><th>US System</th><th>US Grade Points</th></tr>
<tr><td>≥ 95</td><td>1,0</td><td>A+</td><td>A+</td><td>4.0</td></tr>
<tr><td>≥ 90</td><td>1,3</td><td rowspan="3">A</td><td>A</td><td>3.7</td></tr>
<tr><td rowspan="2">≥ 85</td><td rowspan="2">1,7</td><td rowspan="5">A-</td><td>3.3</td></tr>
<tr><td>3.0</td></tr>
<tr><td>≥ 80</td><td>2,0</td><td rowspan="3">A/B</td><td>2.7</td></tr>
<tr><td rowspan="2">≥ 75</td><td rowspan="2">2,3</td><td>2.3</td></tr>
<tr><td>2.0</td></tr>
<tr><td>≥ 70</td><td>2,7</td><td>B</td><td>B+</td><td>1.7</td></tr>
<tr><td>≥ 65</td><td>3,0</td><td>B/C</td><td>B</td><td>1.3</td></tr>
<tr><td>≥ 60</td><td>3,3</td><td rowspan="2">C</td><td>B-</td><td>1.0</td></tr>
<tr><td>≥ 55</td><td>3,7</td><td>C+</td><td rowspan="2"></td></tr>
<tr><td>≥ 50</td><td>4,0</td><td>D</td><td>C</td></tr>
</table>

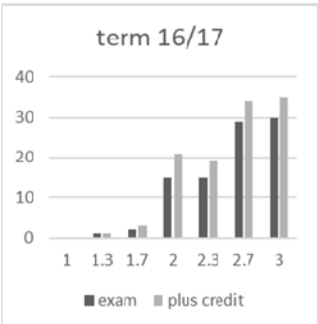
Looking at the students' examinations, there are no better grades than 2.0 for semester 15/16, and most students received a grade of 3.0. However, no bonus points are included here.
Considering the grades including the bonus points, the distribution of grades changes, as shown in Figure 4. The result is a bell curve, which starts at 1.3. The bonus point assignments allowed three students to get this better grade, which would otherwise have been 2.0. The grade 1.7 is now reached by 13 students (previously 0) and a 2.0 even by 31, instead of 6.



Exam Grade	Amount exam	Amount plus credit	X >10 points	X <10 points	0 points
1,0	0	0	0	0	0
1,3	0	3	3	0	0
1,7	0	13	11	2	0
2,0	6	31	30	1	0
2,3	23	34	31	1	2
2,7	33	35	26	5	4
3,0	42	29	17	3	9

Figure 4. Exam results term 15/16

The right side of Figure 4 shows the distribution of grades in relation to the test results and the bonus points. The exact number supplements are in the right columns. Thus, the three students with a grade of 1.3 also received more than 10 bonus points. Of the students who received a 1.7, 11 have achieved a bonus score greater than ten, two of them less than ten points.
Interesting results of this evaluation are that 12 students resigned from the exam, with six of them receiving bonus points. Three of them received more than ten points, three less than ten points. Four students have not written this exam until today, although they have received bonus points of 13 points, two of them 11 points and one two points.
Regarding semester 16/17, the best exam score here is 1.3, followed by two students with a grade of 1.7 and 15 with a grade of 2.0. However, the distribution with bonus credits shall also be done here.
Looking at the bonus credits, the score distribution shown in Figure 5 is flatter, compared to Figure 4. The number of students with the highest grade of 1.3 has not changed, although this student has received more than 10 points in the bonus point tasks. The grade 1.7 was achieved by three students, with two having worked more than ten points, one got none. By inclusion of the extra points, 21 received a 2.0 instead of 15 students without bonus points.



Exam Grade	Amount exam	Amount plus credit	X >10 points	X <10 points	0 points
1,0	0	0	0	0	0
1,3	1	1	1	0	0
1,7	2	3	2	0	1
2,0	15	21	12	0	9
2,3	15	19	6	6	7
2,7	29	34	20	6	8
3,0	30	35	16	7	12

Figure 5. Exam results term 16/17

In semester 16/17, noticeable side results are apparent, too. In this semester, 23 students have resigned from the exam. Eight of them had earned bonus points with more than ten points.
To make a resume, in semester 17/18 the students participated for a longer time and did not break up after a short term. The interest in the product was unexpectedly high this semester and noticed for the first time in this year's term. The balance about the electrical, electronic, and mechatronic components as well as their interaction in the hand circular saw seems to perfectly match for this course.

5 CONCLUSION AND OUTLOOK

In this paper it is shown, how students of the fifth semester of a mechanical engineering programme at university level can implement the mediated theory directly in practice by means of a closed learning cycle. The theoretical knowledge of the design methodology presented in the lectures could be used directly in a concurrent engineering product development project.

The product data management system (PDMS) Windchill from PTC was used. A complete digital submission and review by the interim results by the advisors prepared the students for their future work environment. Worldwide locations and the associated digital editing, administration, and delegation of the documents in a data management system will thus become indispensable.

The PDMS was used for the delivery of bonus credit tasks. Students can carry out these bonus credits as written paperwork for the exam preparation and as a creditable exam performance during the semester.

This paper shows that students who deal with the tasks and carry out a processing of the bonus credit tasks receive most of these credits. Furthermore, it was shown that these extra credits could achieve up to two jumps in the overall score of the final exams. This is presumably the biggest incentive for students to participate in the bonus credit programme.

As an outlook, it is to mention that the exam for semester 17/18 has not yet been carried out right now. A subsequent evaluation of the determined characteristic values is still pending. From the mentioned evaluations of the students it is known that the formulations of the tasks are perceived as "spongy". Therefore, we aim for a revision of the documents for semester 18/19.

ACKNOWLEDGEMENT

We thank the companies BSH, Braun, AEG, Vorwerk and Hilti for their kind support of various products for our lectures and exercises.

REFERENCES

[1] Zwicky, F. *Discovery, Invention, Research: Trough the Morphological Approach*. The Macmillian Company, Toronto, 1969.

[2] Pahl, G., Beitz, W., Feldhusen, J. and Grote, K.-H. *Engineering Design, A Systematic Approach*, 2007 (Springer, London).

[3] Zhang, W., Fan, Y. *Information Technology for Balanced Manufacturing Systems*. In *IFIP International Federation for Information Processing, Volume 220*, 2006, pp. 183-192, (Springer, Boston).

[4] Siemens PLM Software. *Teamcenter integration for NX, Best-in-class engineering design and collaboration solution for any size team using NX*. Available: https://www.geoplm.com/knowledge-base-resources/GEOPLM-Siemens-PLM-teamcenter-integration-nx-14046-tcm1023-62630.pdf [Accessed on 2018, 19th February].

[5] PTC Inc. *Windchill Users Quick Start Guide, Maximize your user experience.* Available: http://support.ptc.com/WCMS/files/117580/en/7158_Windchill_QSG_EN.pdf [Accessed on 2018, 19th February].

[6] Tomiyama, T., Gu, P., Jin, Y., Lutters, D., Kind, C. and Kimura, F. Design methodologies: Industrial and educational applications. In *CIRP annals: manufacturing technology,* Vol. 58, No. 2, 2009, p. 543-565.

[7] Suh, N. P. *Axiomatic Design: Advances and Applications*, 2001 (Oxford University Press, New York).

[8] RWTH, *Comprehensive examination regulations for all Bachelor's and Master's programs of RWTH Aachen with the exception of teacher training Courses*. Available: https://www.rwth-aachen.de/global/show_document.asp?id=aaaaaaaaaanmogl [Accessed on 2018, 19th February], (2015).