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DEVELOPMENT OF FUNCTIONAL MOCK-UPS FOR ENGINEERING DESIGN EDUCATION

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ABSTRACT
Hands-on interaction with machinery is a possibility to enhance engineering design education. Based on the existing approach of an interactive machine part exhibition [1], a concept has been created to improve a first year drawing course by the use of functional mock-ups. These mock-ups are didactically prepared to teach students typical machine element setups. The machine part exhibition and mock-ups are used to create a framework that integrates hands-on education with the traditional teaching approaches. A preview of the currently performed evaluation by integrating the new concept into the design teaching is given.

Keywords: Machine element mock-up, drawing exercises, hands-on experience, mechanical engineering design education

1 INTRODUCTION

In order to fulfil the high demand for engineers in Germany as reported by the European Engineering Report [2], efficient ways of teaching mechanical engineering design are needed. On the other hand, high dropout rates are reducing the number of graduates and are creating a gap between the supply of, and demand for, engineers [3]. Engineering design courses are an essential part of the curricula for Mechanical Engineering and therefore a possible field for improvement. The objective is the introduction of students to design, dimensioning and application of machine elements. Traditionally this is done by theoretical lectures and accompanying exercises. In order to improve this existing concept, an approach was presented at the E&PDE10 conference [1] expanding design education by hands-on experience with machine parts. The cornerstone of this approach is the interactive machine part exhibition, which enables students to familiarise themselves with a broad collection of physical objects.
This work will advance the approach of the interactive machine part exhibition by demonstrating a way to enrich first year design exercises (disassembly and technical drawing) by the use of functional machine element mock-ups. The article points out educational constraints, gives a brief retrospect of the interactive machine part exhibition and presents a literature review of existing disassembly exercises. The developed concept of using functional mock-ups in design education is discussed and a preview of the evaluation of the current experimental integration of this concept into teaching is given.

2 DESIGN CURRICULUM AT TUHH AND AREAS OF IMPROVEMENT

The concept of the interactive machine part exhibition and functional mock-ups were created to improve the existing design curriculum at Hamburg University of Technology (TUHH), structured into the first year module “Fundamentals of Mechanical Engineering Design” and the second and third year module “Mechanical Engineering Development and Design” (Figure 1). Educational constraints are the limitations in staffing and costs as well as class sizes of up to 700 students.
Theoretical background is provided by lectures supported by auditorium exercises. The first year module contains a practical course in technical drawing (Design Project I). The students disassemble technical products, measure their components and create production drawings. The existing objects are not entirely suited to teaching students an understanding of design. Furthermore, there is no strong connection between these objects and the following design projects, in which students design a spindle-driven apparatus as well as a complex gearbox. Some students also show a lack of understanding of the function of machine elements and are not able to read or understand technical drawings, most likely caused by lack of contact with these elements prior to their studies [1].

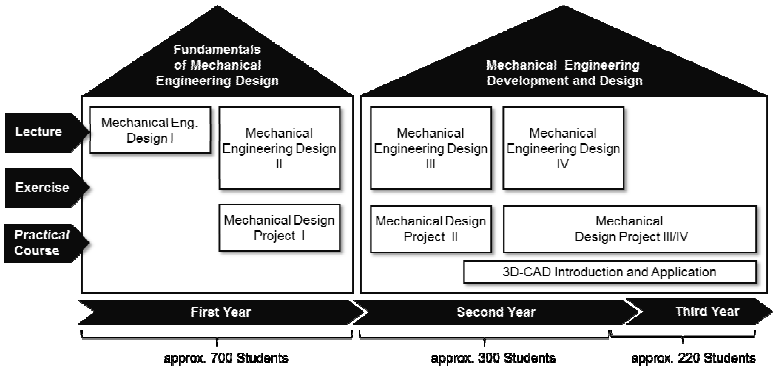

Figure 1. Design Education Curriculum at TUHH [4]

One objective of the interactive machine part exhibition is to overcome these issues. Additionally, surveys by the Impuls-foundation [5] and Derboven and Winker [6] regarding drop-out reasons were used to setup general objectives for improvements [1]. Thus, the existing concept could be extended in order to create a more efficient way of teaching first year students technical drawing skills and to align the design projects with the existing lectures to form a consistent educational approach (Figure 2).

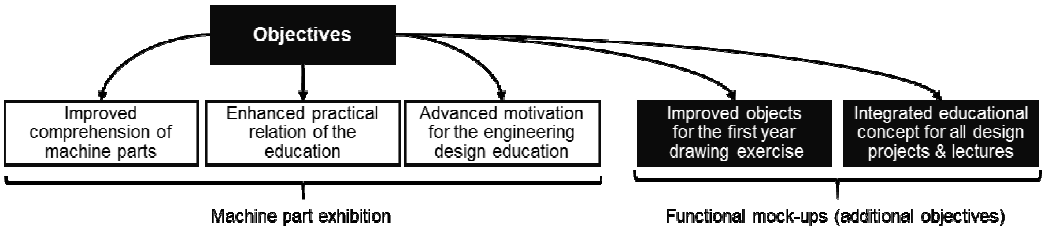

Figure 2. Expanded Objectives of the Improvements cf. [1]

3 INTERACTIVE MACHINE PART EXHIBITION

The concept of the interactive machine part exhibition [1] was derived from papers of [7], [8] and [9] describing different concepts for use of hands-on activities in design education. These ideas are combined and extended in the machine part exhibition approach suited for TUHH. The exhibition offers mechanical design students the opportunity to investigate, handle and interact with real machine parts during open door hours. This interaction is used to create a link between the real parts and teaching materials that can be used in lectures. The exhibition is described by five 'pillars' (Figure 3).
The first three pillars are used to build a pool of practical knowledge, which the students can rely on, when setting up their own designs. Therefore, the first pillar offers students the opportunity to get in touch with a broad collection of fundamental machine elements, such as bearings, that can be experienced tangibly prior to the lectures. The second pillar contains complex systems as examples of goods of the local industry. For example, a car gear-box is used to teach the students the function of this complex system and motivate them via contact with objects that could be part of their future professional life. To give students practical design guidelines, the pillar "Comprehend functionality and design" is used. Hence, the students observe systems that represent typical machine element setups or investigate parts designed under specific constraints (e.g. parts designed for turning). So far the exhibition works as a library of physical teaching objects and supports the students' self-study. The fourth and fifth pillars require tutoring. Disassembling activities are described by the fourth pillar and can also provide students a better knowledge about design for assembly. Furthermore, the exhibition offers the opportunity to answer students' questions about machinery using the real objects.
From the described concept and the shortcomings of the models used in the first year drawing exercise the idea arose to use the interactive machine part exhibition as a pool for drawing objects. The pillar "Comprehend functionality and design" is in particular relevant for giving students the chance to comprehend design and function of basic mechanical systems in an early stage of the studies. The possibility to design special prepared mock-ups of machine element setups provides educators with the chance to use the drawing exercise as a preparation for the later design projects and improves the way of teaching students technical drawing abilities.

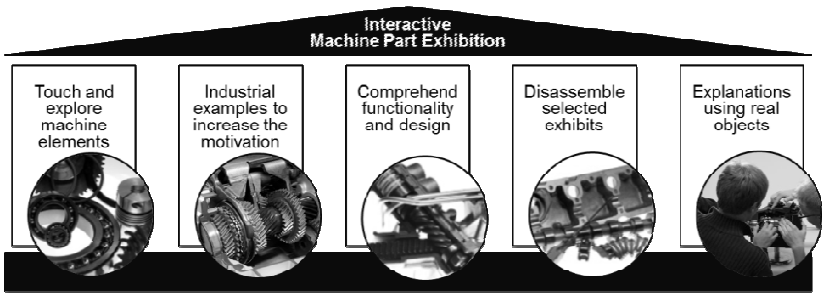

Figure 3. Basic Pillars of the Interactive Exhibition cf. [1]

4 EXISTING DISSECTION EXERCISES IN DESIGN EDUCATION

In order to substantiate the idea of using mock-ups in drawing classes, certain literature has been reviewed, expanding on the general review performed earlier [1].

4.1 Reverse Engineering in the First Year of the Studies

Barr et al [10] introduce students to mechanical engineering by a reverse engineering project. Within this integral concept, student teams dismantle household products, for example a doorknob, and analyse the function as well as the composition of the overall system into subsystems. The students are required to gain an understanding of the design and function of the product because they are then instructed to improve the system. After the performed analysis, the groups create hand drawings of their investigated product and transfer these drawings into a CAD-System. Barr et al demonstrate that students also gain an understanding of basic working principals of machine parts and of how these basic elements are used in the system.

4.2 Car Dissection Project

In a student project presented by Rismoen and Mathisen [11] students, divided into groups, dissect a car. Each student group disassembles and analyses a different subassembly of the car. The different groups present their gained knowledge to the other groups. This approach was integrated into the curriculum to enhance the students' practical knowledge using a typical industrial good.

The reviewed literature demonstrates the general success of dissection exercises, supporting the idea of improving the existing dissection and drawing exercise at TUHH rather than replacing this course. Therefore, a new approach using mock-ups has been devised to fit into the TUHH curriculum under the existing constraints.

5 USING FUNCTIONAL MOCK-UPS IN DESIGN EDUCATION

The idea of designing functional mock-ups was derived from the exhibitions pillar "Comprehend functionally and design". A functional mock-up is a system didactically prepared to teach students machine design. Its task is to visualise typical machine element setups and to give students the possibility to understand their function hands-on. This way, the students gain valuable hands-on experience with machine elements and assemblies, the like of which they will have to design in the following projects.

5.1 Development of Functional Mock-Ups

For the development of the functional mock-ups, a general methodical approach based on Pahl et al [12] was used. Challenges result from the requirement that the whole mock-up must fully comply with the standards and design guidelines taught in the lectures. On the other hand, a conflict between the objective of teaching students the functionality, and the objective of creating standard, unadulterated arrangements exists, because the demonstration of function usually requires some additional elements that would not be used in standard arrangements. The main challenge is to visualise the function and the arrangement of the part while the system is still operable. To solve this, the models material may be removed to create a full cross-sectional cut or to form an observation window. Transparent materials, for example plastics, as an alternative solution are more expensive to machine (grinding and

polishing are required to keep the transparency) and the transparency can be reduced over time by scratches. Thus, cross-sectional cuts along the axis of the mock-ups are often used.
The first mock-up prototype visualises an X arrangement of angular ball bearings in combination with a grooved ball bearing (Figure 4). As a force is inducted on the shaft by imbalance, the fit of the bearings and the shaft is of importance. Thus, by observing this mock-up with the imbalance on the shaft, and analysing the bearing arrangement including the fixing and fit of the bearings, the students can define design guidelines based on hands-on experience.

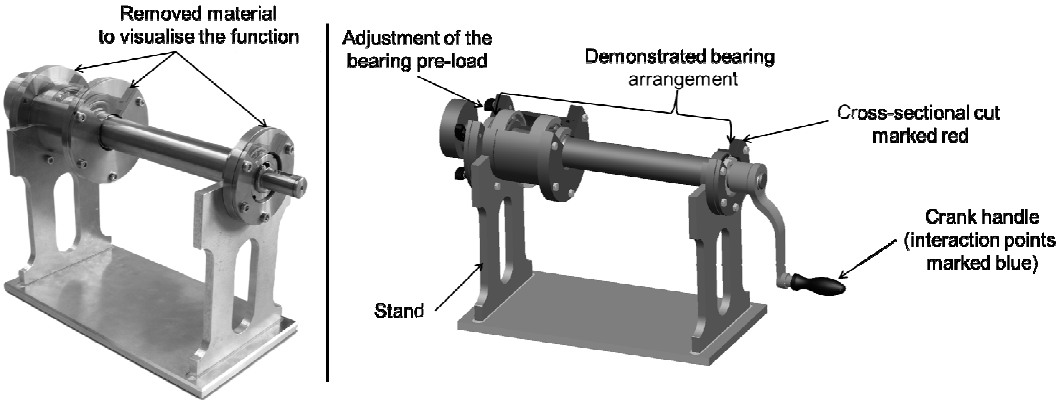

Figure 4. First Prototype (l.) and CAD-Model (r.) of the X Bearing Arrangement Mock-Up

As shown in the CAD-model of Figure 4, different colours are used to guide the students. Red represents the areas were material has been removed to visualise the function; blue objects are handling points for experiencing the function. In this case, the crank handle is used to turn the shaft and screws to adjust the preload on the bearings, allowing students to observe that high preload reduces the bearing clearance but in the same time increases the friction and the needed torque to turn the shaft. In this way, students learn hands-on that engineering often means finding a compromise between two conflicting objectives (low friction vs. small clearance).
To educate about 700 students in the first year drawing exercise at least 40 mock-ups will be needed. The designed mock-ups represent 20 (Figure 5) different setups and each will be produced twice by the university work shop.

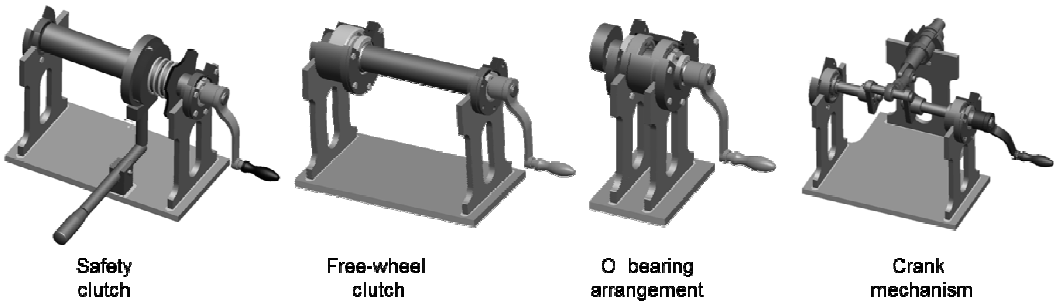

Figure 5. Examples of Different Functional Mock-Ups

5.2 Integration of the Mock-Ups into the Drawing Exercise

To integrate the interactive machine part exhibition into the early stage of the studies, they will be used as drawing objects in the first year drawing course in four steps (Figure 6). In the first steps, the students will be guided through the exhibition to get in contact with standard machine elements, examples from industry and the mock-ups, prior to lectures and to inform themselves regarding the additional resources supplied by the exhibition. In the next step, each student group analyses one of the 40 mock-ups in order to understand the working principles of the machinery. In the third step, they disassemble the mock-ups and document dimensions in sketches of the parts. In the final step, the students create production drawings of the mock-up parts and prepare a description of the function. These descriptions can be exchanged with other groups to make sure each student gains an understanding of all mock-ups.

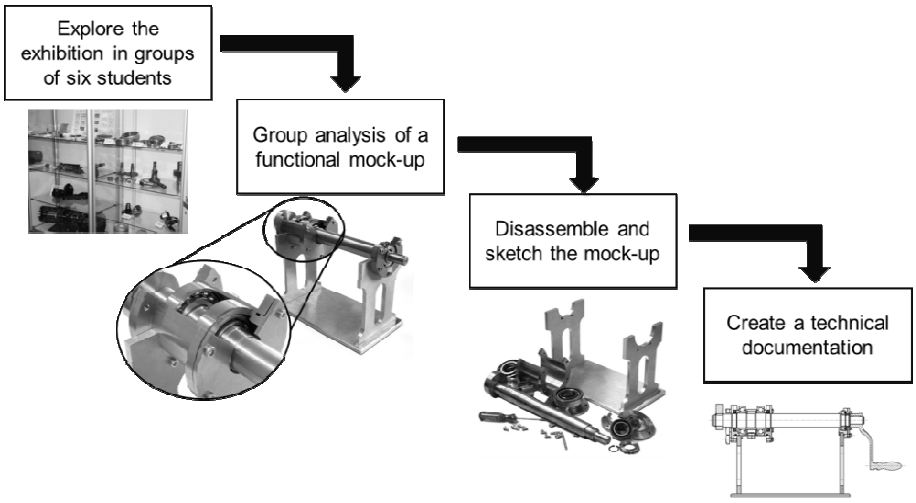

Figure 6. Concept of the New First Year Drawing Course

5.3 Exhibition and Mock-Ups in an Hands-On Educational Framework

The use of the interactive machine part exhibition and the mock-ups in mechanical design teaching makes it possible to create an educational framework where hands-on experience is linked to the theoretical lectures (Figure 7). Students have contact with the physical objects early in their studies prior to lectures. The lectures can be enriched by exhibits taken from the exhibition. On the other hand, in lectures students gain the theoretical knowledge required to fully understand the complex examples from industry presented in the exhibition. The integrated first year drawing exercise prepares students for the future design projects. Furthermore, the students can gain a deeper understanding from hands-on experience and can use the mock-ups as "physical machine element textbook" during lectures and design projects.

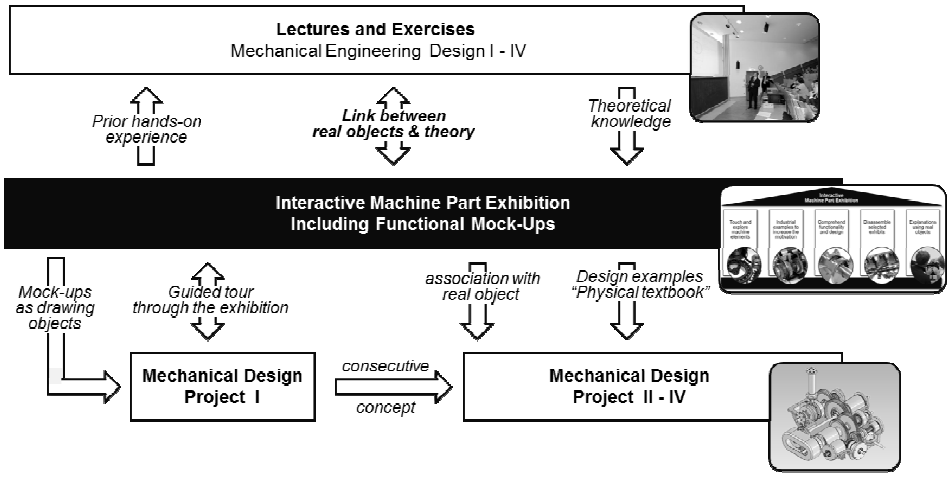

Figure 7. Hands-On Educational Framework

6 INTEGRATION INTO TEACHING AND EVALUATION

In order to evaluate the potential of the developed concept, two prototypes (Figure 4) have been built and are included in the Design Project I, taking place this spring. While the majority of the students are still educated in the old way, a test sample of four student groups (24 students) is taught using two mock-up prototypes. A survey at the end of the course (July 2011) will investigate the students' opinion and allow a comparison between the old and the new concepts to be made. As yet, the first student groups have analysed the mock-ups, disassembled them, created sketches including the measured dimensions and are beginning to create technical drawings. Observations of these students, as well as feedback from the student tutor who attended and interviewed them, are giving a first insight of the application of the concept. The students have worked with the new teaching tools with

high interest and motivation. The analysis of the functioning of the mock-ups, supported by the tutor, appeared to significantly improve the students' comprehension of the basic working principles of the models. Students which were able to link practical experience with theoretical knowledge seemed to benefit especially. This demonstrates the need for an integrated teaching effort containing parallel hands-on and theoretical lessons as described in Section 5.3. The parts of the mock-ups, specially-designed to be simple and to fulfil design-guidelines for this exercise, were shown to help the inexperienced students create their first technical hand-sketches and measure the needed dimensions.
Although first promising findings have been made during the observation of the first part of the course, a long-term monitoring of the development of the students within this test sample will be undertaken. It is to be observed, whether the students in the test sample perform better during the following design project and the mechanical design examinations.

7 CONCLUSION

The use of functional mock-ups offers the possibility to broaden the hands-on education provided by the interactive machine part exhibition and to form a hands-on mechanical engineering framework. It provides first year students with a better introduction to technical drawing. Therefore, different functional mock-ups have been designed and an example was presented in this paper. Two prototypes of the mock-ups have been made so far. These have been used in spring of this year to test the mock-up concept in educational practice. Based on this application of the concept, a first insight into the evaluation of the concept was given, however a long-term monitoring will be performed to evaluate the assumptions about possible improvements that have been made in this contribution.

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