

# MACHINE PART EXHIBITION AND FUNCTIONAL MOCK-UPS TO ENRICH DESIGN EDUCATION

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## ABSTRACT

Mechanical engineering design education aims to provide students with the required knowledge and skills to develop state of the art products. Practical hands-on experience supports theoretical teaching of the basics. This paper presents a new approach to integrate hands-on elements into the design education curriculum, while being constrained by large class sizes. Therefore, the need for improvements in design education is analysed and the concept of an interactive machine part exhibition is derived from pre-existing methods. The exhibition is the corner stone of the concept and contains physical models of basic machine parts as well as sophisticated mechanical systems. It is used to create a link between lectures (theory) and real objects (practice). Functional mock-ups specially prepared to teach students design are used to improve an existing first year design and drawing project.

*Keywords: Interactive Exhibition, Hands-On Education, Machine Part Mock-Up, Drawing Exercises, Mechanical Engineering Design Education*

## 1 INTRODUCTION

The success of companies working in innovation-driven markets, such as the automotive and machine building industries, depends on the skills of their employees [1]. Thus, there is high demand for qualified technicians and engineers in Germany. According to the European Engineering Report [2], Germany employed over 1.2 million engineers of all professions in 2007, which is over 3 per cent of total employees. The economic recovery after the financial crisis and the age distribution of employed engineers will create even higher demand in the future. Unfortunately, universities have not produced enough qualified engineers to meet the demand. Even though the number of first year students in mechanical engineering programs has increased, the number of graduates remains low due to high dropout rates. This results in a yearly average of over 34,000 engineering positions that could not be filled [3]. Universities need to find ways to increase the number of graduated engineers to ensure economic prosperity.

Decreasing dropout rates of engineering studies is one way to meet this challenge. Surveys of reasons for withdrawal [4],[5] found that inadequate ability and organisational constraints cause students to abandon their studies. Universities can have an influence on some withdrawal reasons. Improving engineering education can help close the gap between required and provided graduates. As a result, design education can have an impact on society by educational improvements.

Mechanical Engineering programs usually contain fundamental lectures, such as mathematics, physics and mechanics, along with more application-oriented lectures, such as production engineering and mechanical engineering design. Although all of these elements are potential areas for improvement, this paper focuses on mechanical engineering design education, with the aim of finding a way to improve design education using hands-on elements. As design education is different in each country and university, the work focuses on Hamburg University of Technology (TUHH) as an example of a German university. Nevertheless, similarities exist between universities that have comparable challenges. Therefore, design education at TUHH is investigated and possible research fields for improvement are described. Based on the requirements identified for improving the design education concept, a literature review is used to identify existing educational approaches. The educational concepts found are expanded and combined to create a new approach that matches the requirements of the existing educational situation. Basic ideas and an early model of the concept were published in [6]. This paper gives a more detailed description of the further developed concept. It closes with a short

status report on integration of the concept into everyday teaching to evaluate the concept in educational practice.

## 2 STATE OF DESIGN EDUCATION AND NEED FOR IMPROVEMENT

The limited funding and staff must be taken into account to understand the current educational model at TUHH. They have led to class sizes of up to 750 first year students and about 200 in third year. As a result, conventional lectures are often used and mentoring can only be given in selected classes by student tutors. Due to these critical constraints, the existing educational concept (updated during the change from Diplom to the bachelor and master qualification system) must be retained and enhanced with additional measures.

### 2.1 Design Curriculum at TUHH

Design education in the mechanical engineering program at TUHH is structured into two modules (Figure 1). The basics of design and machine parts are taught in the first year module “Fundamentals of Mechanical Engineering Design”. Background theory is taught in two 6-month long lecture series. They are accompanied by auditorium exercises focussing on dimensioning calculations of machine parts. The module also contains a practical design project. In this first project, students learn how to design technical documentation of an existing assembly by disassembling machines and drawing them by hand. This design project also functions as a drawing exercise. In their second and third years, students deepen their design knowledge and skills in continuative lectures and auditorium exercises in the module “Mechanical Engineering Development and Design”. This module contains further practical design projects that take 1.5 years.

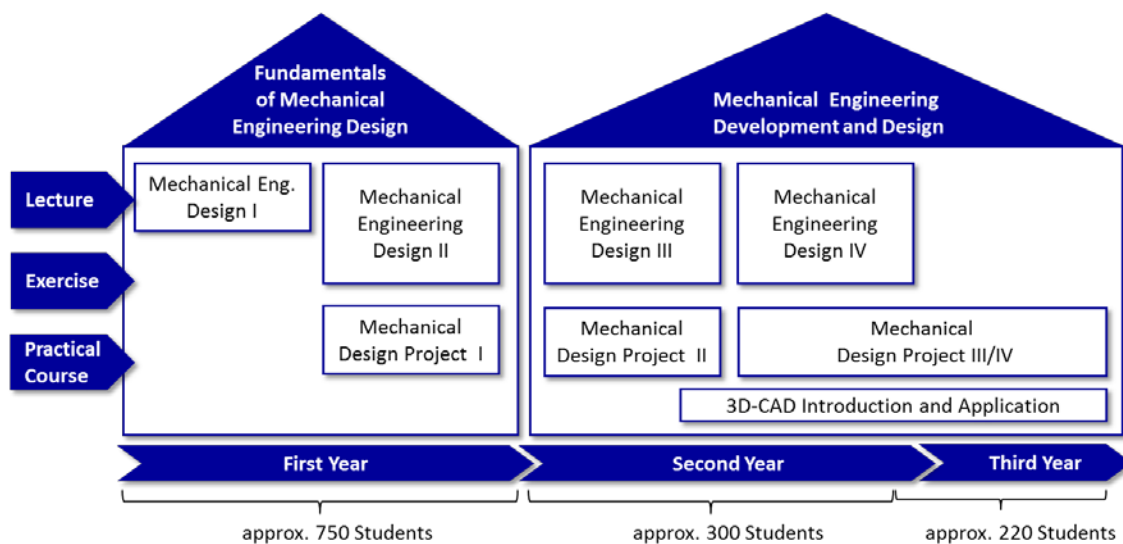


Figure 1. Design Education in the Mechanical Engineering Program at TUHH [7]

In Design Project II, students design a spindle driven apparatus. Design Project III/IV completes the basic design education. Students have to combine and apply their design abilities to set up a complex gearbox system and have to use design methodology in a teamwork activity to find principal solutions for the given problems. During these design exercises, student tutors guide the students in groups of six, supervised by one or two members of academic staff. Furthermore, the students are introduced to 3D-CAD, which they can use in the final design project.

### 2.2 Need for Improvements

In everyday application of the concept described, it became apparent that some students were not able to connect the design elements that they use in their design projects with real physical objects. They are showing a lack of understanding of working principles and three-dimensional representation of crucial machine parts. This major problem, which appears in design projects, lectures and examinations, may be a result of students not having contact with objects of mechanical engineering prior to their studies. Insufficient models are available for Design Project I (drawing exercises), due to

the increase in student numbers. In addition, the connection of this first design project with subsequent projects could be also improved.

The challenges observed will be complemented here with select results from the research of the Impuls-foundation [5] and Derboven and Winker [4]. They interviewed students of mechanical [5] and other engineering programs [4] about their reasons for withdrawal and highlight shortcomings in engineering education. A lack of motivation to study is a major problem [4], [5] that causes students to withdraw from their studies. Furthermore, students often lack an understanding of the industrial and practical relevance of their studies. Students are critical of facts being presented in isolation from the bigger picture and its relevance to these facts [4]. Finally, the rate of student dropout at the beginning of studies has increased since the change from Diplom to the bachelor and master qualification system [5].

From the identified shortcomings at TUHH and the findings of the surveys presented, the major problems are lack of motivation to study, insufficient practical relevance, and poor comprehension of machine parts. Measures that improve comprehension of machine parts, enhance the industrial and practical relevance of design education, and motivate the students to study mechanical engineering, need to be found (Figure 2). In addition, better integration of the first design project and didactic improvement of the drawing models used are desirable.

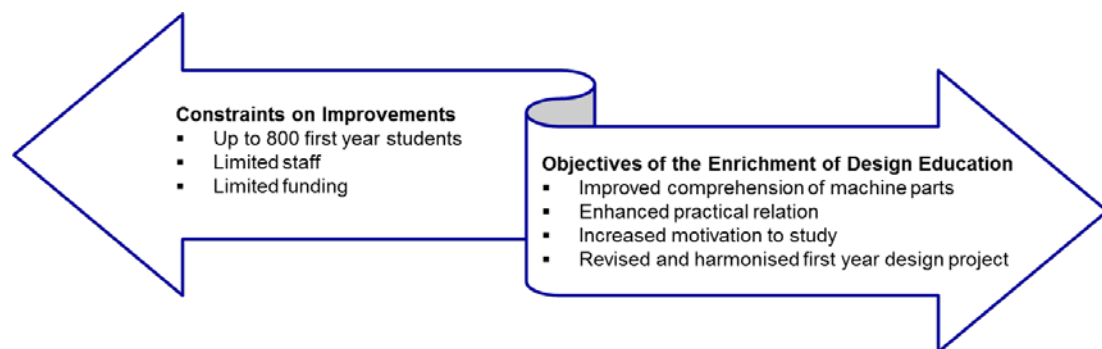


Figure 2. Objectives and Constraints of the Improvement Measures

To fulfil these objectives under the given constraints, the idea of advancing design education by using more hands-on elements with real machine parts arose. It resulted in two main questions:

1. *How can more hands-on education with machine parts be integrated into the existing curriculum?*
2. *Will hands-on education improve design education and fulfil the objectives?*

A literature review is performed to find existing ways of integrating hands-on education. The approaches found will be adapted to fit the objectives and constraints of TUHH. To answer the second question, future integration of the concept into everyday teaching and an analysis of its success is needed.

### 3 EXISTING HAND-ON APPROACHES IN DESIGN EDUCATION

In [6], an analysis of new approaches ([8]/[9], [10], [11]) of using hands-on elements in engineering design education was undertaken. The findings of this review will be summarized and complemented with additional approaches.

#### 3.1 3D-Models in Design Education

Field, Burvill, Weir and Alirezaee [8], [9] replaced two-dimensional with three-dimensional wooden teaching materials and observed the effects on student comprehension. They found that the ability to read and analyse drawings depends on student visualisation skills; students with strong visualisation skills performed better. The performance of students with weak skills can be improved by teaching with 3D wooden models. Thus, 3D models are a possible way to educate students with low visual skills more effectively, with the intention that they gain a deeper understanding of complex 3D machinery.

#### 3.2 Dissection Exercise and Reverse Engineering as an Educational Tool

Several variations on dissection exercises and reverse engineering can be found in the literature.

### ***First Year Reverse Engineering Course***

Barr et al [12] are using reverse engineering in an integrated teaching effort to introduce first year students to mechanical engineering. Student teams dissected household products, such as doorknobs, to set up an improved design using reverse engineering. They analysed the structure and the function of the overall system and its subsystems, gaining an understanding of the basic principles of machine setups, for example, the use of springs. Afterwards, the groups created hand drawings to document their products. The drawings are transferred to 3D CAD and can even be manufactured using rapid prototyping.

### ***Artefacts as an Engineering Design Education Tool***

Lilly, Fentiman and Merrill [10] employ single-use cameras in hands-on classes to improve design education. The students learn design by observing, dissecting and analysing highly engineered products. The objective of this educational concept is to train students to look at products through “engineers’ eyes” and to comprehend why the product was built in a specific way. The educators point out that contact with real objects in the first years of study provides a counterpoint to theoretical lectures. Classes focussed on various different design aspects of the cameras. The courses were rated highly by students.

### ***Dissection of a Car***

Rismoen and Mathisen [13] presented a way to increase student practical knowledge by disassembling a car. Students analyse the complex system and have to understand its function. The course was implemented due to the authors’ observation that students often have not seen technical systems and elements in real life. In the course evaluation, students declared their enthusiasm for dissection exercises and demanded similar courses with other technical systems for dismantling.

## **3.3 Improving Drawing Ability with Artefacts**

Robb, Childs and Flora [11] highlight the importance of hand sketching skills and observed decreasing ability in students. They used hands-on involvement, observation, and drawing of real objects to improve the students’ hand sketching skills.

## **3.4 Reflection on Existing Approaches**

The papers described agree on the success of hand-on education and high student enthusiasm for practical courses. Generally, use of hands-on education fulfils the objective of TUHH to motivate students in their studies. However, the approaches vary and have different focus areas (Figure 3). The observations of [8] / [9], that wooden 3D models are a superior way to teach students the working principals of complex systems, may be a worthwhile way to achieve the objective of improving student comprehension. There could be additional benefits if objects were made from their typical material, not wood. This would give students the chance to experience the material-specific characteristics of the models, such as weight and surface structure.

Furthermore, the improvement of hand sketching skills by drawing existing technical artefacts also fits TUHH’s demand to improve the first year drawing exercise (decreasing skills were observed at TUHH, too). Not least, the dissection and reverse engineering exercises are important because they underscore the importance of students gaining an understanding and image of real machinery to comprehend theoretical design lectures. Additionally, it was discussed by [10], how students could learn to design by analysing and understanding existing products, such as single-use cameras. Selecting appropriate products for dissection exercises is challenging [12]. In the case of TUHH, these objects (e.g. cameras, doorknobs, etc) should be replaced with products that are typical of the local industry, for example, components of a drive train.

Stronger integration of these ideas into the TUHH curriculum could generally help reach the objectives defined in Figure 2. As no fundamental contradiction exists between these concepts, a combination of these ideas may add additional benefits to design education and may be worth implementing. Nevertheless, TUHH’s constraints need to be considered, particularly big class sizes, as previously discussed. This is critical as the majority of the approaches described are designed for smaller class sizes. Therefore, adaption of the concepts is required. Consequently, it is appropriate to create a new approach that combines the benefits of the existing concepts and suits the specific needs of design education, as described in Chapter 2. The initial concept that combined existing concepts

with additional ideas was published in [6]. The further developed approach of the interactive machine part exhibition completed with the idea of functional mock-ups will be presented in detail in the following chapter.

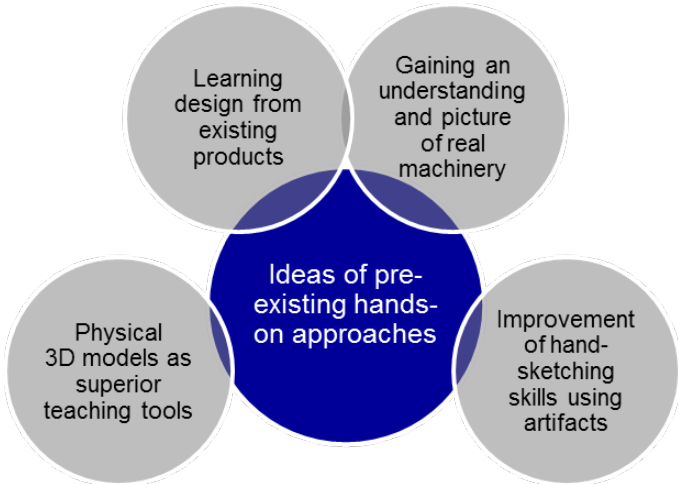


Figure 3. Ideas of Existing Hands-On Approaches

#### 4 CONCEPT OF FUNCTIONAL MOCK-UPS AND INTERACTIVE MACHINE PART EXHIBITION

The basic element of the new integrated approach is the interactive machine part exhibition. It will be used to provide students with real objects to supplement theoretical lectures with hands-on experience. Additionally, functional mock-ups that are part of the exhibition will be integrated into the revised first year design project to deepen practical experience. Figure 4 visualises the concept of the new integrated approach. This approach will be explained within this chapter, focusing on the concept of the exhibition in the first section and the mock-ups used in the design project in the second section.



Figure 4. Concept of the New Approach

##### 4.1 Machine Part Exhibition

The central hypothesis of the interactive machine part exhibition is that students need the opportunity to see and physically interact with all of the basic machine parts that are taught in lectures and used in design projects. The concept uses five pillars (Figure 5) to reach the defined goals (Figure 2). Each pillar represents a concept of how the students get hands-on experience. The Machine Part Exhibition provides students with the opportunity to increase their design knowledge with self-study of the objects and additional written explanations. The Machine Part Exhibition gives the student an open opportunity to use the required aid when needed. On the other hand, it became clear during development of the concept that further guided and tutored activities are needed to integrate the concept into the curriculum. The revised first year design project will be the first class to use the exhibition.

The first pillar of the exhibition “Touch and explore machine elements” enables students to get in touch with machine elements, which are a basic prerequisite to setup mechanical designs. The exhibition contains a collection of basic machine elements, such as fasteners, sealing, bearings, shafts,

along with more complex parts, such as clutches and gears. Compared to 3D CAD or wooden models, the real elements not only add the third dimension to the usually two-dimensional teaching materials, but additionally enabling a tangible experience. It is possible to feel the properties of the parts, such as the weight and the texture of the materials. In this way, students who have not had contact with real machinery prior to their studies can have a chance to build up basic practical experience.

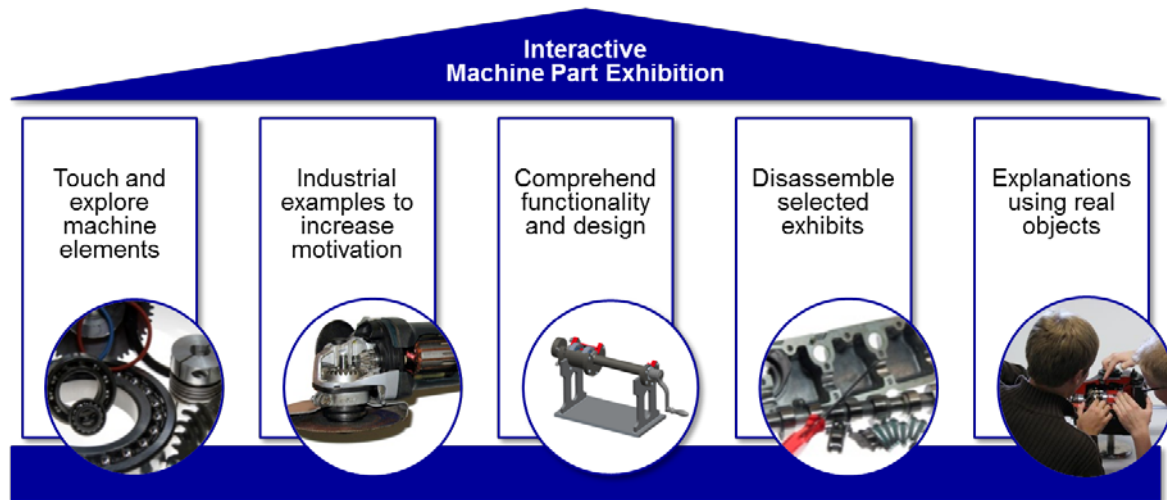


Figure 5. Basic Pillars of the Interactive Exhibition

This concept requires a broad collection that covers the basic elements discussed in lectures. Theoretical knowledge acquirement in lectures is supported by observation of real objects; using the exhibition. This could be seen as the link between the drawings and 3D models used in lectures and the real objects (Figure 6). The goal is to create a spatial 3D image in the students' minds to support the abstraction process from real object to technical drawing and vice versa. This abstraction process is essential to understanding the theoretical working principles of the machine elements presented in lectures, and is mandatory in setting up technical drawings.

The interaction with basic machine parts could be motivating for students. The potential to motivate students will be further increased with models representing typical products of the local industry. These models add to the collection and are part of the pillar "Industrial examples to increase motivation". Through early contact with highly engineered products, students get to know typical fields of application of mechanical engineering, as represented by these products. Knowing that theoretical and practical knowledge is needed to develop such products in their later professional life can be motivating during challenging studies.

The main aim of the pillar "Comprehend functionality and design" is increasing student comprehension of machine parts. Exhibits that represent typical machine element setups or typical part designs are supplied. Ways to examine the functional core of the systems are needed to teach students the functionality of sophisticated mechanical systems. Cross-sectional models are a possible solution. However, removing material to create cross-sectional models often makes the system inoperable. For this reason, functional mock-ups will be used to show the working principles of systems without disabling the functionality. Thus, the student should be able to see the function and explore it. For example, students can explore the function of a free-wheel clutch with a functional mock-up that allows the shaft to be turned clockwise by a crank handle, but is blocked by the clutch in counter-clockwise direction. The student must be able to see the working area of the clutch, which requires special design of the clutch. As well as presentation of function, the mock-ups can be used to show typical setups of machine elements, for example, bearing setups. If designed rigorously to standard, the mock-ups could be a physical "machine element design textbook". Thus, a collection of the most important setups will be developed and provided to students as part of the collection. Such specially prepared functional and design mock-ups will be used in the redesigned First Design Project, as described in Section 3.2. Students also have the opportunity to analyse other parts to derive design for x guidelines. For example, a shaft manufactured by turning can be used to teach students how to design their own parts for the turning process.



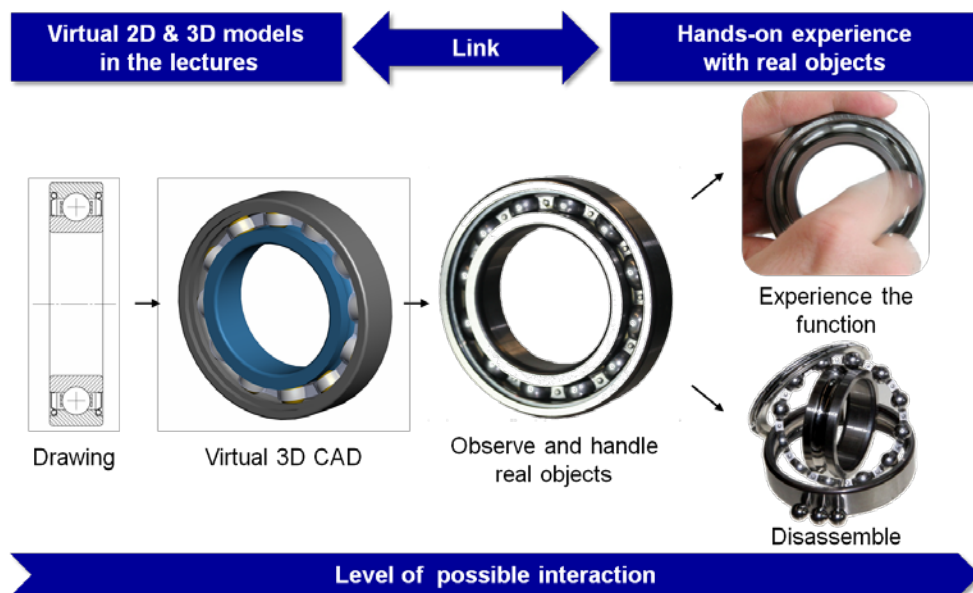


Figure 6. Linking Virtual and Real Objects cf. [6]

The first concepts described support the self-study learning process without the need for intense tutoring. Nevertheless, the teaching tools will also be integrated into lectures and design projects as mentioned before. However, the last two principles require more support from lectures. The pillar “Disassemble selected exhibits” provides another practical way to understand the system design and the working principle of technical systems. Students also experience the importance of design suitable for disassembly and assembly. Supervision is needed to ensure integrity of the models and can be provided by a student tutor in doors open hours or within the design project (see 4.2).

Finally, a broad collection of the physical teaching tools could give answers to students’ questions that arise during self-study or preparation for examinations. Thus, question sessions can be held using the exhibition. The last pillar, “Explanations using real objects”, captures the idea of bringing selected models to lectures and exercises to integrate hands-on explanations into large classes.

#### 4.2 Functional Mock-ups in First Year Drawing Classes

Possible ways to integrate the machine part exhibition into everyday teaching and make it public to the majority of the students needed to be found. On the other hand, a revision of the existing first year design project and the objects used for the drawing exercise was needed (Section 2.2). The idea of utilising functional and design mock-ups in this class arose. The basic idea of creating the first drawing skills in students by hand-sketching objects will not be changed. Nevertheless, by using the specially prepared mock-ups, students gain an initial understanding of typical machine element setups by producing technical documentation.

In the revised Design Project I, students get their first practical design experience in four steps (Figure 7). In the first step, the students will be guided through the exhibition by a student tutor in groups of less than ten people. In this way, they get to know the collection and the self-study aid provided by the exhibits. The tutor also gets the chance to present motivating industrial products and explain the function of systems using the mock-ups. In the next step, each student group analyses a mock-up to understand its function and design. For example, the free-wheel clutch mock-up mentioned previously is investigated. Students experience the coupling process by turning the handle counter-clockwise and observing the movement of the rollers, which connect the parts of the clutch and block the rotation in this turning direction. If turned clockwise, the rollers are slipping and a rotation is possible. The clutch mock-up also contains a standard bearing setup, which is a design example. Thus, students gain design knowledge of basic setups which they will need in the subsequent design projects and their future careers as mechanical designers. In the third step, the students disassemble the mock-up to create hand drawings of the parts of the fragmented assembly. This not only improves drawing skills, but provides hands-on experience and teaches the use of the measurement equipment, e.g. callipers. In the final step, the students use the hand sketches and set up technical documentation using hand drawings. They

also describe the function of their mock-up and have to explain it to other groups to deepen their understanding.

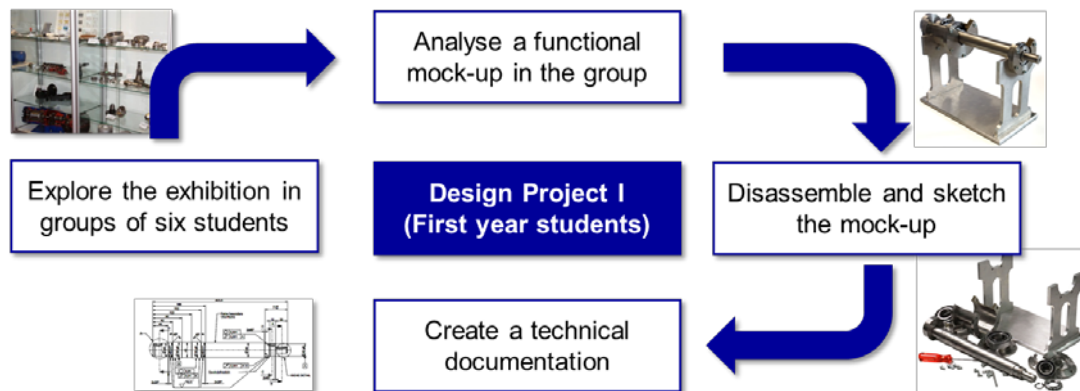


Figure 7. Concept of the New First Year Drawing Course

As a start, twenty mock-ups are designed to replace the existing conventional drawing examples. The models are specially designed to introduce the students to design and the use of machine elements. The models are selected to cover the most important parts of the design lectures to give students the opportunity to understand these elements practically before analysing them theoretically in the lectures and exercises. Furthermore, the mock-ups are designed to cover frequently used elements of the next two design projects (e.g. gearbox design; Section 2). In this way, the students have a pool of practical design knowledge to rely on when they switch from sketching existing products to designing their own systems.

#### 4.3 Linking the Exhibition, Drawing Classes and Lectures

The revised design project is going to be an integral part of the new hands-on educational framework (Figure 8).

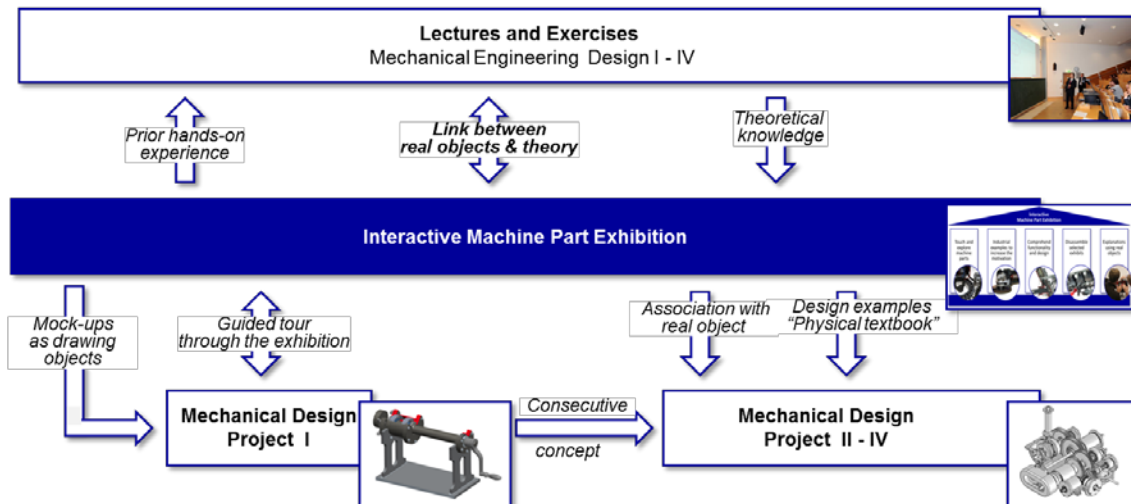


Figure 8. Educational Framework of the Exhibition

Mechanical design will be taught in lectures that present the fundamentals and with complementary practical hands-on experience, provided by the interactive machine part exhibition. Finally, the first year design project using didactically arranged mock-ups fits the overall approach, as it prepares the first year students for later design projects and enhances the understanding of mechanical systems.

## 5 STATUS OF THE INTEGRATION INTO EVERYDAY TEACHING

The theoretically developed educational framework needs to be tested in everyday teaching for evaluation. Consequently, an exhibition containing fundamental machine elements, complex systems, industrial examples and functional mock-ups is presently being built at TUHH. Because the



integration of the concept is currently in progress, reliable evaluation is not available yet. Nevertheless, progress has been made in the design of the functional mock-ups. At least 40 mock-ups are needed for the course size of the first year design project. A product family of 20 different variants of mock-ups has been developed. Some examples of these mock-ups visualised by 3D CAD models are shown in Figure 9. These models are currently being manufactured in the university workshop to introduce the first physical demonstrators to the design project this spring. Finally, a basic collection of machine elements is already available and used in lectures, but it will still be supplemented.

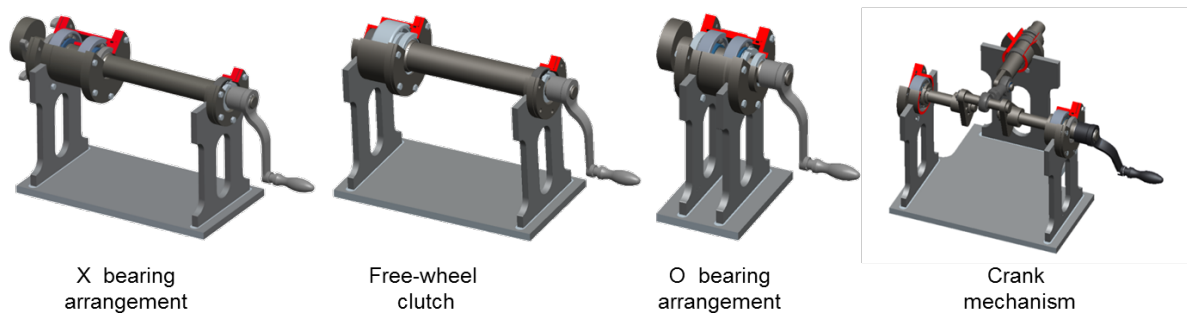


Figure 9. CAD Models of Functional Mock-Ups

## 6 CONCLUSION

Analysis of the current educational situation and a literature review were undertaken to derive a new educational concept that improves design education at TUHH. The concept developed provides a possible answer to the question “How can more hands-on education with machine parts be integrated into the existing curriculum?” It uses an interactive machine part exhibition to enrich the existing design education and to create a strong link between theoretical and hands-on learning. Functional mock-ups are employed to enlarge the scope of the first year design project. The drawing exercise was changed to a drawing and analysis hands-on project to increase student experience and comprehension of machine element setups and design in the beginning of their studies prior to being taught the theory. Although basic educational approaches from the literature are reused to improve the design education concept, a future evaluation of the concept in everyday teaching is needed. Only thorough evaluation can prove the assumptions made about the potential for improvement and answer the second question “Will hands-on education improve design education and fulfil the objectives?” This evaluation will be carried out in the future.

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