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# HAVING A REAL PROTOTYPE OF YOUR OWN PRODUCT DESIGN – SMALL EFFORT; BUT BIG EUREKA MOMENT FOR STUDENTS

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**ABSTRACT:** This paper presents a project-based product design course, which is the only course on product design in our curriculum. We noticed that the building of a prototype is often omitted in academic teaching. However, students benefit from building a prototype of their design. Hence, we reduced the theoretical content to give students time to design and build a prototype. To illustrate the course two student projects are shown. We want to motivate lecturers to introduce prototyping to courses, since our experience is that the benefits of building a prototype outweigh the decrease in theoretical knowledge.

***Keywords:*** *Design education; Project management; Project-based learning; Sustainable design*

## 1. PURPOSE OF THE PAPER

Product development comprises all the steps and activities in the computer-aided development of a technical product, starting with the initial idea and ending with the first virtual prototype as a 3-dimensional computer-aided-design model (CAD model).

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Actually, a holistic approach to teaching would go one step further by realizing the virtual prototype through manufacturing and assembling its individual parts. This **w**ould allow the students to experience and test the real prototype as well as to identify design modifications to finally optimize the virtual CAD model (Berglund and Grimheden, 2011).

Unfortunately, it is precisely this last step - the first realization of a prototype - that is often skipped in established courses in academic teaching at universities. The reasons are manifold and obvious. We see the following three most significant reasons as our challenges to overcome:

- Teaching students to design and develop products is extremely time-consuming. Since only limited courses on product development and product design are available in the (already packed) curricula of universities, the real prototype - as the last step - is omitted due to time constraints.
- The building of a prototype requires further demanding competences (Jensen et al., 2016), which are hardly taught within established product development education. These include a well-founded use of software interfaces, knowledge on interrelations between product and process, reflection on and evaluation of change requirements, and responsibility in terms of safety.
- Prototypes are always unique. Hence, the required supervision of students during manufacture and assembly goes hand in hand with high teaching expenses (lab time, teaching load, etc.). Intensive bilateral coordination between lecturers and students (often 1:1) is essential.

It is becoming obvious that there is an undeniable gap between the importance of a real prototype and the actual implementation of this significant step in academic teaching.

In this paper, we detail a project-based product design course, which is a mandatory course in the 6th term of the bachelor program on Sustainable Engineering at the University of Applied Sciences Ansbach (Germany). The course allows students to design a product and to gain individual experience in design. However, this is the only course focusing on product design in the curriculum of the bachelor program. As a consequence, our students have only had a quick and superficial taste of product design in the past and not had the chance to build prototypes of their designs. We decided to reduce the scope of theoretical content (and thus the number of lectures) to give the students time and resources to really do an individual product design project by themselves - starting with the first idea, including manufacture, assembly and finally the testing of a real prototype. The response of the students revealed that the realization of a prototype helps them to strengthen the acquired competences and to gain a better and more holistic view of product design. With our work we want to motivate colleagues and lecturers to introduce the building of a prototype into product design courses. Obviously, this goes hand in hand with a decrease of time to teach theoretical knowledge. However, we found that the benefits of building a prototype (Lande and Leifer, 2009) outweigh the decrease in theoretical knowledge on product design.

The paper is structured as follows: First, we present the structure and implementation of the course (Section 2.1). Afterwards, the design challenge is stated and explained (Section 2.2) and in Section 2.3 the available resources and machinery in the "creative prototyping" lab are detailed. Section 3 then presents two product design projects carried out by students in the summer of 2020. The students designed and finally built a wooden toy tractor (student #1, Section 3.1) with its garage (student #2, Section 3.2). Furthermore, each student developed and prepared a 90-minute workshop, in which the designed product can then actually be designed and/or manufactured and/or built by children from different age groups (Section 3.3). The paper closes with a conclusion and an outlook on further improvements to the course (Section 4).

## 2. THE COURSE ON "PROJECT-BASED PRODUCT DESIGN"

The course on project-based product design for bachelor students is a mandatory course in the 6th term of the bachelor program on Sustainable Engineering at the University of Applied Sciences Ansbach, Germany. This is the only course focusing on product design in the curriculum of the bachelor program. Hence, our aim is to provide a comprehensive experience of relevant aspects of product design in just one course with five credit points (ECTS). In addition, there is no separate course in the students' curriculum that focuses on the fundamentals of project management. Therefore, we merged those two topics and designed a course that both satisfies the demands on product design education and provides an adequate first experience of project management for the students (Mills and Treagust, 2003).

This section details the basic structure and the content of the course on project-based product design (Section 2.1). In Section 2.2 the project challenge is presented and the general conditions for all projects are defined. Additionally, relevant information on the available tools and machines (Kriesi et al., 2014) in the "creative prototyping" laboratory are presented in Section 2.3.

### *2.1 Structure and implementation of the course*

The course includes two 90-minute slots in the weekly curriculum over 14 weeks during each summer semester. The course is structured in two main parts, each spanning the entire semester (Figure 1):

- The **theoretical part** is assigned to the first 90-minute slot each week. It includes seven lectures and five workshops that provide the content on relevant aspects of project management and product design, which are seen to be essential for the students and the success of their design projects. A listing of the topics and content of these lectures and workshops is given in Figure 1.
- The **practical part** is assigned to the second 90-minute slot each week. During these time slots, the lab (Section 2.3) is open to all students to discuss their projects and designs with colleagues, the lecturer as well as the lab engineer. Furthermore, the students can get to know the available manufacturing machines and tools in the lab, take part in safety training and (usually rather later in the project) manufacture and assemble their prototypes.

Once the students have achieved some progress in their projects, a short pitch is given by a student at the beginning of each 90-minute slot. No requirements are set for these pitches other than recommending a duration of seven minutes. Finally, the evaluation of the projects and the course is based on i) a presentation by each student at the end of the semester and ii) a short report that documents the project and provides reflection on the project, the individual progress and the lessons learned.

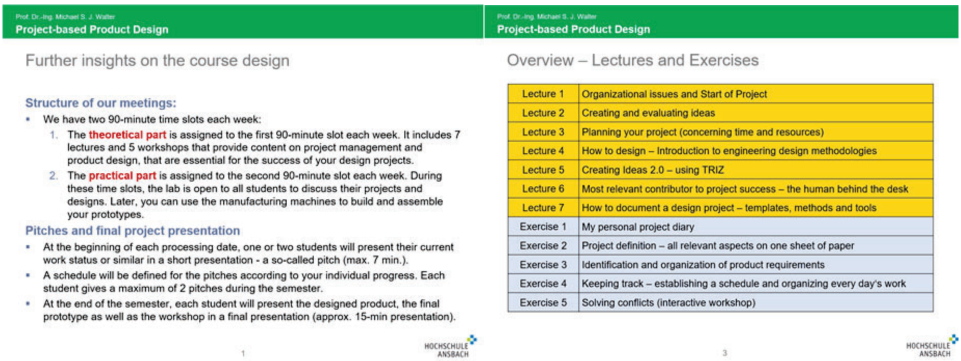


**Figure 1.** Slides with organizational issues (left) and topics of lectures and workshops (right)

### *2.2 Defining the project challenge*

The students face a challenge to **design** and **build a first prototype of** a wooden product for children (age: 3+) or a useful wooden product for teenagers (up to 16 years). They are free to decide on the target group for their product. To give a first orientation for the students, they are motivated to get inspiration from agriculture, agricultural technology, farm life and work, etc. However, the scope of designs is not limited to these fields. A wooden toy tractor (made by the lecturer, Figure 2) is shown to the students to illustrate a sustainable product design (Soomro et al., 2021) and to stimulate the creative flow of project ideas. In addition, each student must develop and prepare a 90-minute workshop, in which the product can actually be designed and/or manufactured and/or built by the children (of the previously defined target group) themselves in the laboratory. This additional assignment achieves student reflection on their products, the projects' process, as well as communicating their lessons learned to others (Balve and Albert, 2015). The final project challenge, however, is stated very simply:

*Plan and perform your product design project!*

Figure 2 shows the slide presenting relevant information on the design project as well as the available CNC carving machine in the lab.

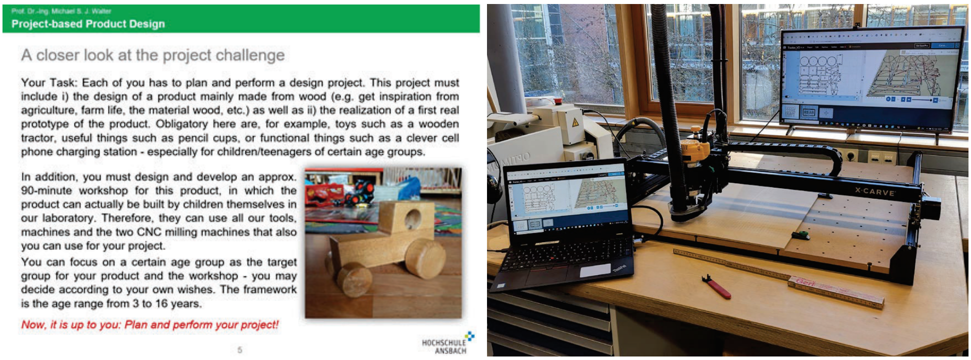


**Figure 2.** Presentation slide with the definition of the project challenge (left) and available open-source CNC Carving machine X-Carve (right).

## 2.3 AVAILABLE RESOURCES AND MACHINERY IN THE “CREATIVE PROTOTYPING” LAB

As many meetings and lectures as possible are taking place in the lab, to allow the students easy and low-threshold access to the machinery and thus to counter hesitant approaches of the students during their projects. The first meeting of the course always takes place in the lab. It includes an introduction to all the required organizational information as well as the project challenge (as detailed in Section 2.2). Furthermore, the students are also introduced to the main manufacturing machines (in particular, the CNC carving machines) and the available tools in the lab (from the workbench and screwdriver, to the hand planer and palm sander, surface finishes, etc.). Figures 3 and 4 show the lab and highlight the resources and machinery.

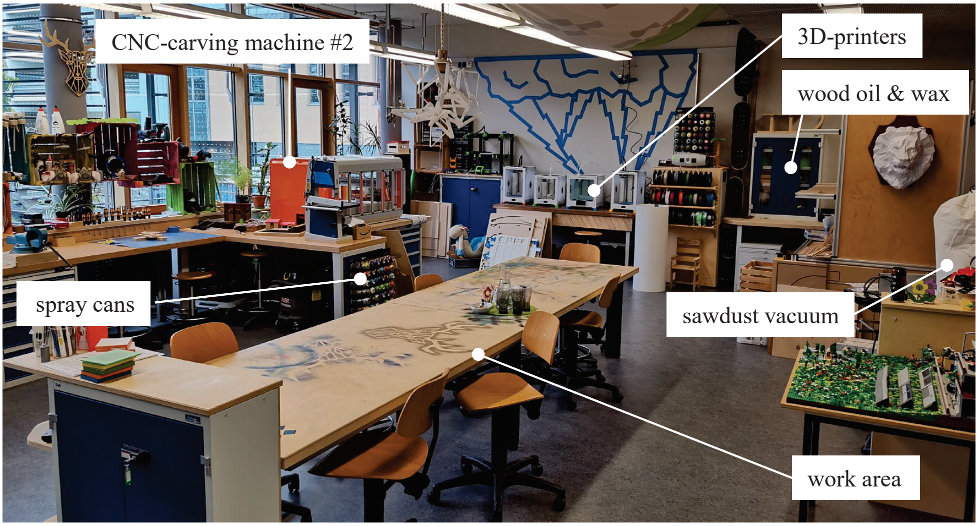


**Figure 3.** Resources and machinery in the "creative prototyping" lab (view from left corner).

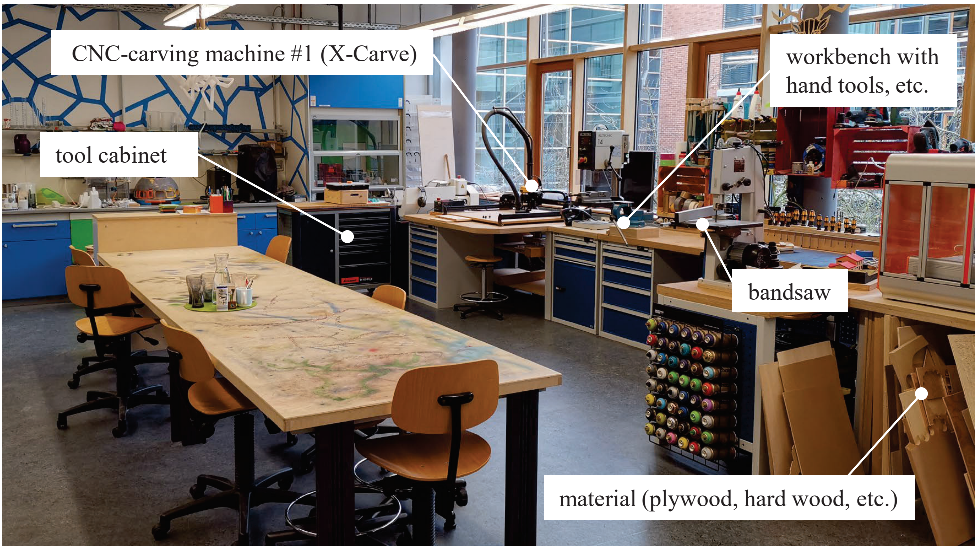


**Figure 4.** Resources and machinery in the "creative prototyping" lab (view from right corner).

## 3. BEST PRACTICE – TWO DESIGN PROJECTS BY STUDENTS

This section details the design projects of two students carried out in the course from April 2020 to July 2020. Both students attended the course in their sixth semester and had no experience or knowledge of product design aside from the basic application of 3D-CAD (from the lecture on engineering design in their second semester). Both students collaborated and came up with the idea of designing two individual products that were "connected" in a certain way to force both students to adjust and synchronize their own projects. The students decided to design a wooden toy barn (project #1) and a wooden toy tractor (project #2). Furthermore, they defined the connecting requirement that the tractor must be able to drive into the barn and that the barn door can be completely closed when the tractor is parked inside. The final prototypes of the tractor and the barn are shown in Figure 5.


**Figure 5.** Final prototypes of the toy barn (project #1) and the toy tractor (project #2).

### *3.1 Design project #1 – The barn*

The student aimed for the toy barn to be a design made of single wooden parts that are assembled only by stacking, thus being suitable for children of younger ages. Furthermore, the barn must have an opening to allow the tractor to enter and leave. Therefore, movable doors were required to open/close the barn entrance. Finally, a nice spot to attach a wooden sign (for a logo or the children's name) was an essential requirement set by the student. To gain information about alternatives for the joint design, the student studied existing 3D wooden puzzles for children by measuring the dimensions of the single parts and evaluating the effects on the assemblability and the resulting stability of the finalized puzzle.

The student then focused on defining her project, prepared her project definition and progressed to the development of the time schedule. The eight work packages (WP) and three milestones (MS) are shown in the Gantt diagram in Figure 6. To document her project and her progress, she kept a project diary, developing a one-page template for each day to document her work, working times and to structure and organize achievements and "To Do" list. Overall, she spent ~58.5 hours on her project - starting with the first thoughts about the project until the first prototype of her barn design was completed.

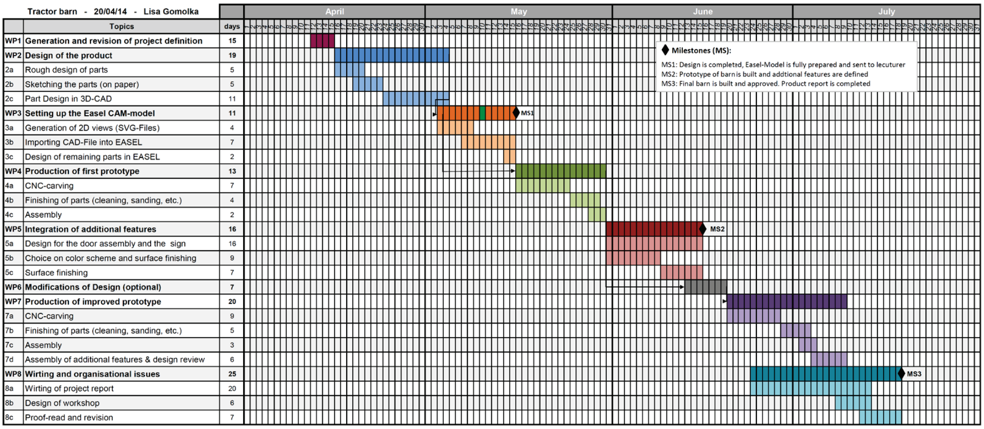


**Figure 6.** Gantt diagram of the design project #1.

The Gantt diagram already provides plenty of time (several weeks) to plan, set up and finally do the manufacturing of the single parts of the wooden barn. Therefore, the student designed the barn assembly using the CAD system SolidWorks and exported two dimensional, vector-based SVG files for all single parts. Then the SVG files were imported into the browser-based CAM freeware EASEL (Inventables, Inc., 2021) that is used to set up the carving process and to control the CNC carving machine in the laboratory. After setting the parameters of the carving process (such as feed rates, bit dimensions, material properties, plywood dimensions, etc.), the parts were carved from sheets of plywood. All these steps were done by the student, supported and supervised by the lecturer and the lab engineer to ensure safety. Figure 7 shows two pictures that were taken during the carving of the parts of the barn wall (made from 8 mm plywood) and the roof (made from 10 mm plywood). Finally, the barn walls and the roof were assembled, and the doors were mounted to the barn.

Furthermore, the student attached a small wooden plate engraved with the abbreviation *HS Ansbach* of the University of Applied Sciences Ansbach. To visually upgrade the final barn assembly, the student decided to paint the roof parts with a red acrylic color (that is also approved for use by children). After a final presentation of the barn to the lecturer, the prototype got the status "approved".

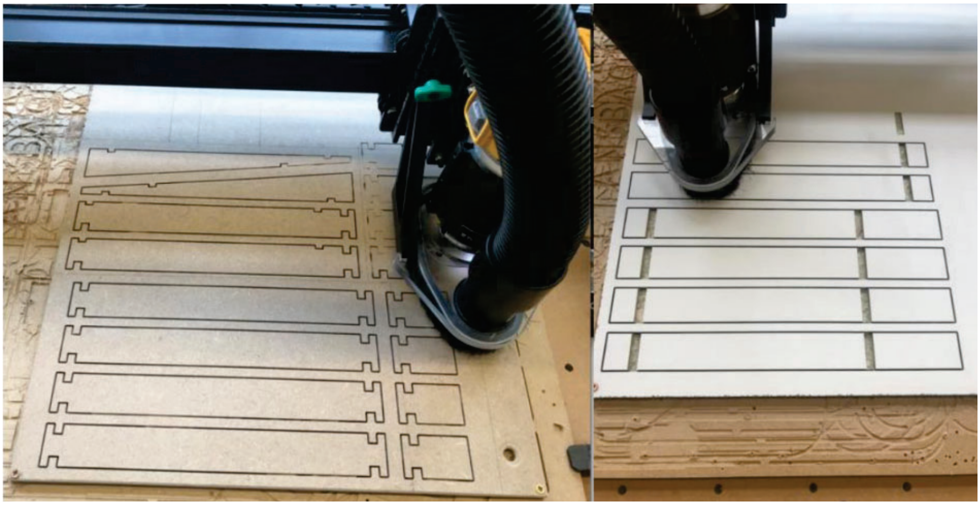

**Figure 7.** CNC carving the parts of the barn walls (left) and the roof (right) out of plywood.


**Figure 8.** Front and rear view of the completely assembled toy barn.

### 3.2 Design project #2 – The Tractor

The second student's design project focuses on the design and building of a wooden tractor, a scale model of a real tractor. Therefore, he had to face a different variety of challenges from the first student. One major aspect is the reduction of the original tractor's complex shapes for a wooden model without losing the unique visual features and elements. After writing the project definition, the student developed a Gantt diagram to organize and structure the available time for each task. At this stage, he was already aware that the design of the joints would be a major challenge for his project. Therefore, he focused immediately on the analysis and evaluation of different approaches on "joining the individual wooden parts". While low-cost wooden puzzles are often assembled by key/slot connections (see Figure 9), the student finally decided on the assembly technique of "rectangular pin/hole" joints, which can be precisely carved with the available X-Carve (Inventables, Inc., 2021).

**Figure 9.** Comparison of three different approaches on assembly joints.

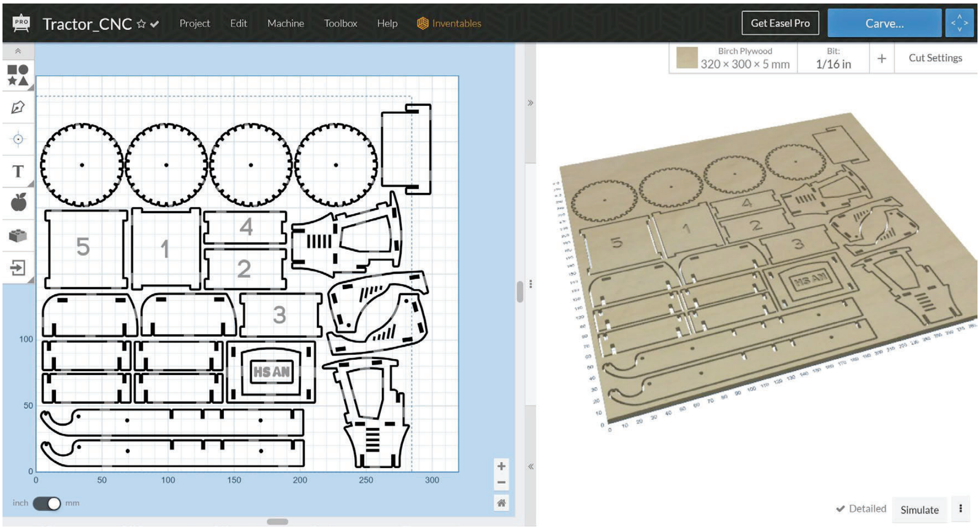


**Figure 10.** Screenshot of the tractor model in the CAM software EASEL (left: working area; right: preview of final carving).

The student's next step included the CAD design of the parts using SolidWorks. Therefore, he took several photos of a real CLAAS tractor and imported these into the software's sketch environment to trace the main shapes as well as relevant geometrical features (such as the ventilation grille of the hood). After the final assembly of the parts in a 3D CAD assembly, the quantities and positions of all the required pin/hole-joints were defined. Based on the 3D model, the 2D sketches of all parts were saved to vector-based SVG files, which were later imported into the EASEL software. Figure 11 shows the screenshot of the final EASEL model. All the tractor parts were carved with the X-

Carve using birch plywood (thickness: 5 mm) and a router bit (diameter: 1/16 inch). Finally, the parts were sanded and painted, the prototype was assembled and driven into the barn to test the students' requirements on their products. The tractor got the status "approved".

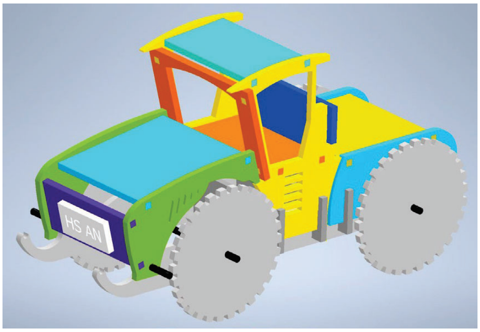


**Figure 11.** Screenshots taken from the design process in SolidWorks: final virtual assembly of the tractor.

### *3.3 Development of workshops for children*

The project challenged the students with two main tasks: on the one hand, the design and its realization as a first real prototype (as shown by the example of both students); on the other hand, each student must develop and prepare a 90-minute workshop, in which the product can be designed and/or manufactured and/or built by children in the "creative prototyping" laboratory. This additional challenge prompts the students to reflect on their products, the development processes, and the communication of the lessons learned. Furthermore, the students had to switch perspectives (from learner to teacher). This leads to a different view of things and uncovers misunderstandings in the simplicity of the design and/or the complexity of carrying out a project and/or an adequate presentation and documentation of the project. In addition, didactic skills are acquired by the students. The students developed their workshops for children aged 5+ (barn) and 10+ (tractor). Both students took into account that the preparation of workshops would be time-consuming, including the manufacture of individual parts in sufficient quantities, as well as setting up the workspace. As part of the preparation, selected parts and sub-assemblies (whose manufacturing and/or assembly were too time-consuming and/or too complex and/or required patience and thus might cause frustration) had to be done in advance. For instance, the barn door sub-assembly had to be pre-assembled. Moreover, small parts such as nameplates were prepared in their basic form and finished during the workshop (such as carving a child's name into the plate).

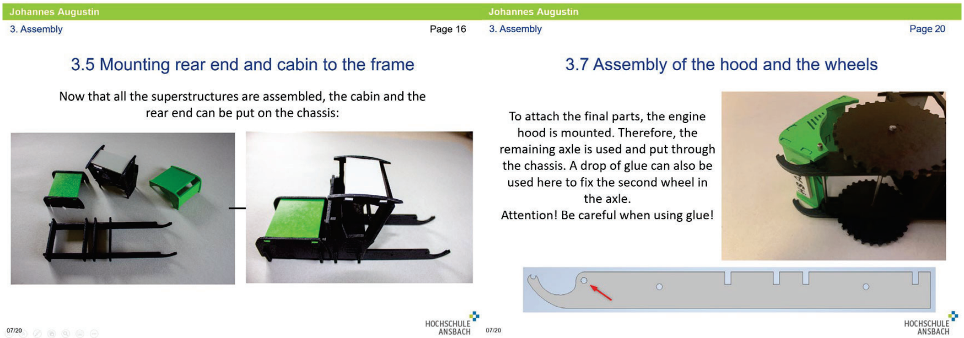


**Figure 12.** Presentation slides providing instructions on the tractor assembly.

| Nr | Name | Bauteil | Stückzahl |
|---|---|---|---|
| 1 | Bodenplatte | | 1 x |
| 2 | Seitenteil lang (26 cm) | | 4 x |
| 3 | Seitenteil lang oben | | 2 x |
| 4 | Seitenteil schräg | | 2 x |
| 5 | Bogen | | 1 x |
| 6 | Hinten (20 cm) | | 4 x |
| 7 | Hinten / Mitte oben | | 2 x |
| 8 | Mittelteil Dach | | 1 x |
| 9 | Seitenteil kurz (5 cm) | | 4 x |
| 10 | Vorne (4 cm) | | 8 x |
| 11 | Dach (30 cm) | | 7 x |
| 12 | Tor | | 2 x |
| 13 | Namensschild | HS ANSBACH | 1 x |
| 14 | Farbe + Pinsel | | Rot 1x Blau 1x Grün 1x |
| 15 | Magnete | | Magnet-band Magnet 1x |
| 16 | Passstifte | | 4 x |

**Figure 13.** Bill of materials for the "barn" workshop (in German)

The younger the participants, the greater the additional focus on occupational safety. The nature of edges, chemicals (such as paint) and tools must be adapted accordingly, which makes the complexity vary. Furthermore, the number of supervisors also depends on the participants and their ages. Each student prepared a presentation (visualising step-by-step), a bill of materials and a guideline and checklist to allow a thorough preparation of the workshop. The presentation slides in Figure 12 give instructions on the assembly of the tractor's cabin, rear end, front axle and hood. Figure 13 details the bill of materials for the "barn" workshop of student #1.

## 4. CONCLUSION AND OUTLOOK

Our aim is to motivate colleagues and lecturers to introduce the building of real prototypes to product design courses and to increase active elements such as setting up individual projects. At first sight, this may raise concern that the loss of time for teaching theoretical knowledge will have negative effects on the students' competencies. However, we found that the benefits of carrying out a design project and building a prototype outweigh the decrease in theoretical knowledge on product design. Furthermore, the students' feedback on the course was very positive, stating that it is "*fun*" to do a product design project, and

> *"It was the first time in my studies that I had to use and apply all the stuff I learned".*

However, problems also became obvious during the course. The holistic documentation of the product design process (from the idea to the real prototype) is always unique. Moreover, this includes digital content (CAD models, manufacturing data, etc.) and non-digital content (sketches, the product itself, haptic feedback, etc.) in valid versions. Students currently struggle to document the project and acquired competencies and skills in a holistic, consistent, and traceable manner. From a didactic point of view, "analog" documentation hardly reflects the competencies and skills acquired by the students and is therefore not suitable for a well-founded assessment of the acquisition of competencies and the contents of the course. In consequence, we emphasize the future use of e-portfolios for documenting and evaluating product design projects. This can be a possible next step to provide the students with a significant improvement in the quality, transparency and traceability of their activities, decisions, results (e.g. digital CAD models), etc. when documenting them as part of their project.

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