

LINKING A LAB ON PROTOTYPING FOR ENGINEERING STUDENTS WITH ITS “DIGITAL LEARNING ENVIRONMENT TWIN”

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ABSTRACT

The restricted timeslots for the use of labs and the availability of resources are often the cause of delayed student projects. This paper describes the transition of an existing lab on prototyping for engineering students from the analogue world into a digitized learning environment that can be used 24/7. This includes all aspects starting from general safety instructions and ending with detailed information and examples on how to use the machinery. Through this transition, the students gain more flexibility in their planning and work in a more agile manner. In addition, with the digitization of the “creative prototyping” lab, the quality of instructions given to the students and the documentation have changed in a positive way. The framework for the digital learning environment twin is provided through the Moodle platform. It is complemented by the e-portfolio software Mahara for the project documentation needed for the test course on project-based product design used to evaluate its digitization. The “digital learning environment twin” combined with Mahara provides a fully digital assessment of the course and provides a positive experience for students and lecturers.

Keywords: Product design, prototyping, digital twin, digital lab, Moodle

1 INTRODUCTION

The transition from an analogue to a digital learning experience is more complex in certain fields of study (e.g., engineering) than in others. This paper deals with the digitization of a laboratory for creative prototyping used in engineering education at the University of Applied Sciences Ansbach, Germany. The lab is used in a course on project management where students are required to develop and build a wooden product from the idea to the prototype.

In recent years, it has become apparent that the manufacture of a prototype is time-critical in many cases and contingent upon the availability of staff, machine capacity, and time allocated for working in the lab. The solution we developed to these problems involves a digital twin of the “creative prototyping” lab. It is available around the clock to students, thus reducing the need to be on-site and keeping fixed deadlines to a minimum. The digital twin allows for greater project flexibility, enabling professors and lab staff to provide higher-quality and individualized support for students (who in turn improve their tool and machinery skills) [1]. In this paper, we describe the changes that are needed to digitize the lab and link it to the analogue world and evaluate the suitability of our framework for engineering education. First, we present the steps involved in digitizing the lab. This is followed by a section on the challenges posed by the analogue-to-digital conversion. The paper concludes with some feedback from the staff, the lab’s incorporation into the project management course, and a discussion on whether the digital lab might increase the agility of engineering education.

2 THE METHODOLOGICAL APPROACH TO THE DIGITIZATION OF THE LAB

The digitization of the lab takes place in several steps and on several levels. The main framework comprises a project management course on the learning platform Moodle, a widely known and well-established environment that enables the individual elements needed for lab usage and the course itself to be connected and digitized.

The digital learning environment twin of the creative prototyping lab can be separated into two principal sections. The first maps the product development cycle of the product management course from the initial idea to the production of the prototype (Figure 1). The second maps the lab itself with all the machines, tools, and documents that are needed as well as the safety training.

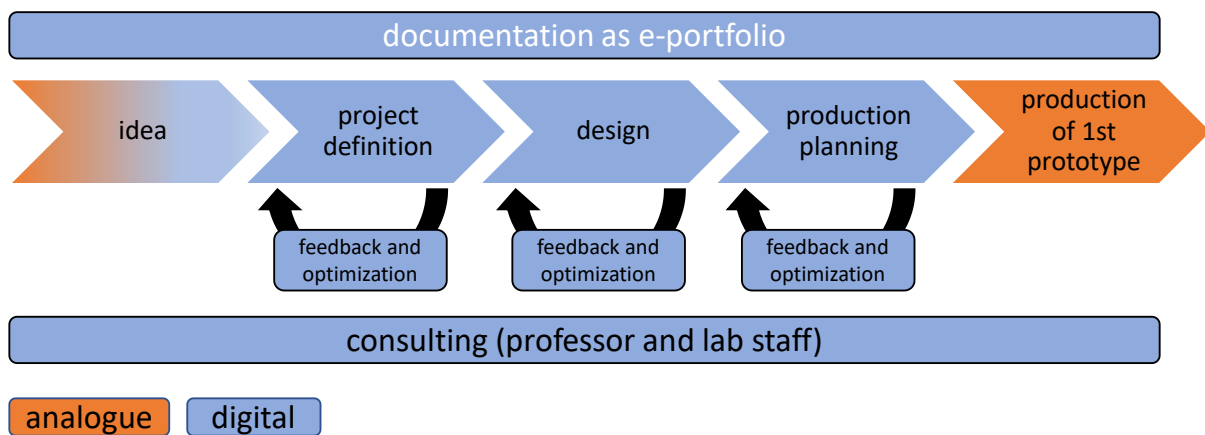


Figure 1. Flowchart of the workflow during the course “project management”

The course on project-based product design, which was used to test our prototype’s digitization and usability during the summer semester of 2022, is a mandatory course in the sustainable engineering bachelor’s programme at the university of applied sciences. We merged product design and project management and designed a course that satisfies the demand for product design education and provides a satisfying initial experience of project management for the students [2]. The students are required to plan, design, and build a prototype for a wooden product (for children aged 3+ or teenagers up to 16 years) [3+4]. They are free to decide on the target group for their projects. Currently, the course is conducted and coordinated face-to-face within the creative prototyping lab during scheduled hours. The procedure is therefore analogue and non-agile.

The individual intermediate steps of the course have been digitized, and progress is subject to feedback loops and checks by the professor and staff. The students have to complete each step of the product development cycle before advancing. The completion of each step must be synchronized with the project schedule of the students, which cultivates their time management skills. Their work is documented throughout the course in an e-portfolio, and their completed (digitized) project [5] is submitted using the portfolio software system Mahara [6]. Only the manufacturing and the physical prototype of the product idea take place/exist in the analogue world.

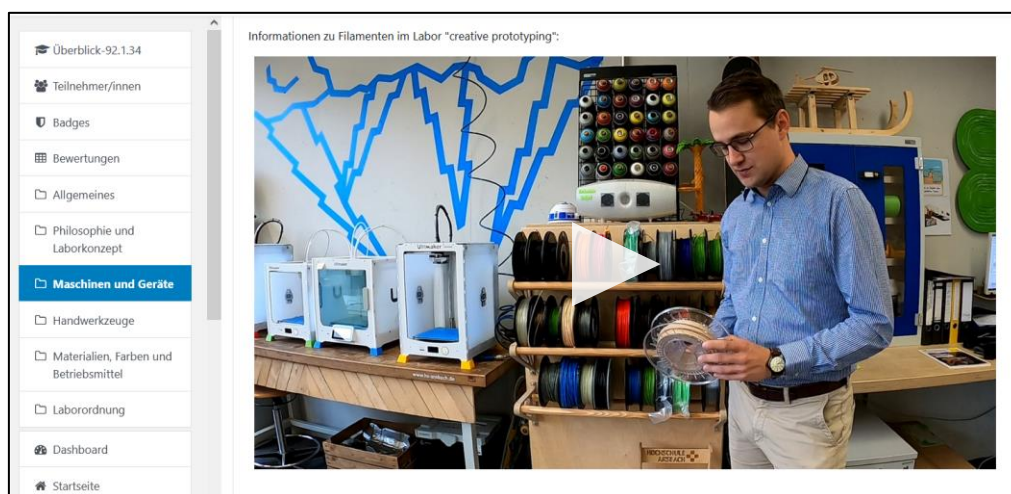


Figure 2. Video frame of a staff member describing the attributes of filament spools for 3D printers using the fused deposition modelling technology embedded in Moodle

The second part of the Moodle course maps the lab digitally. The process begins with mandatory general safety instructions, including the machine manual and specific safety data sheets. This section of the course is divided into subgroups: an overview, operating instructions, safety instructions, safety data sheets for the different machine types (e.g., 3D printer, laser cutter, and milling machine), and links to the required software. The level of detail increases the deeper the students go into each topic. For each machine, a short data sheet with the technical data, the most important safety instructions, and possible applications can be found at the first level. The next level offers access to video material (Figure 2) that maps all the instructions for the individual machines and devices, independent of the time of day or the lab staff's consultation hours.

The general safety instructions for the creative prototyping lab and the instructions for the individual machines and devices (including hand tools such as saws, pliers, and knives) were previously carried out in person, noted on a sheet, and filed in a folder for each student or small groups of students. This was a very important but time-consuming task. As part of the digitization, we mapped the general safety instructions as an e-learning unit for which the students receive a certificate upon completion. This is then digitally archived, so the previous paper-based form of documentation has been supplanted. The safety instructions for the individual machines and devices are carried out through e-learning and a final test, and the students receive a certificate of completion. A result of 100% must be achieved in all safety instruction tests. Figure 3 shows a screenshot of the general safety instructions test.

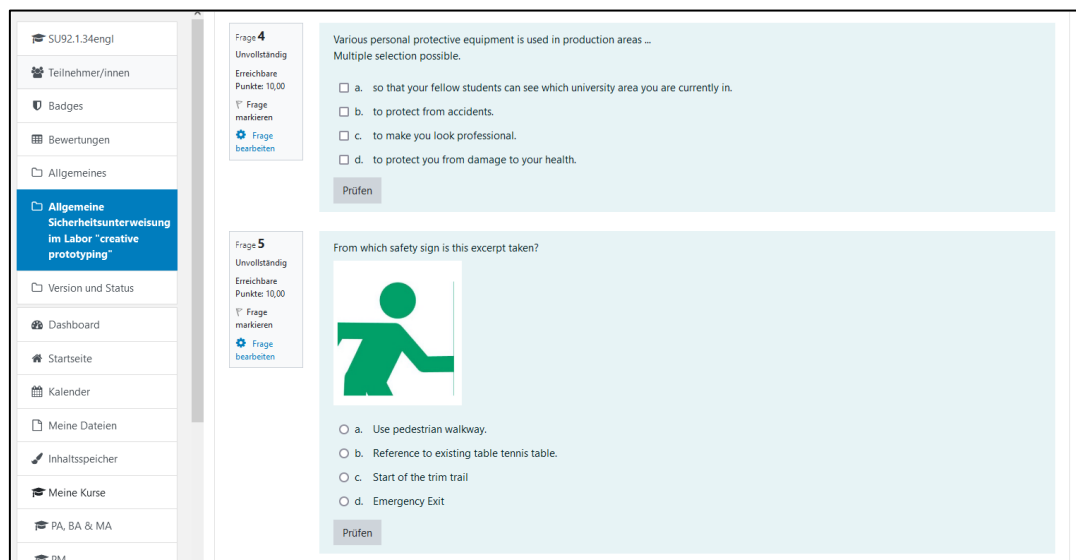


Figure 3. Part of the test on general safety instructions

The digital approach to the safety instructions part of the course is superior to the previous analogue route in virtually all respects. The flexibility it affords (as with the machine instructions) in terms of time is the biggest advantage. The understanding of hazards and processes is also improved through the combination of self-study and a mandatory final test. The digitized lab is rounded off by an appointment calendar (on Moodle) that can be used to book machines and consultations with the professor or the lab staff, during which general questions or issues raised during feedback loops can then be addressed.

3 THE CHALLENGE OF TRANSFERRING THE LAB TO THE DIGITAL WORLD

Various difficulties and obstacles were encountered during the implementation of the project. First and foremost, the professor and staff had to invest a great deal of time in preparing it. The digitization of a lab that ordinarily functions solely in the analogue world necessitated discrete solutions for a multitude of small problems, and the effort required to produce the videos, images, and audio recordings for synchronization with Moodle was substantial. The time involved far exceeded the time needed to prepare an analogue course and indeed the length of the semester itself. However, the effort was a one-time effort, and subsequent maintenance and updates to the course will be less time-consuming than the analogue version.

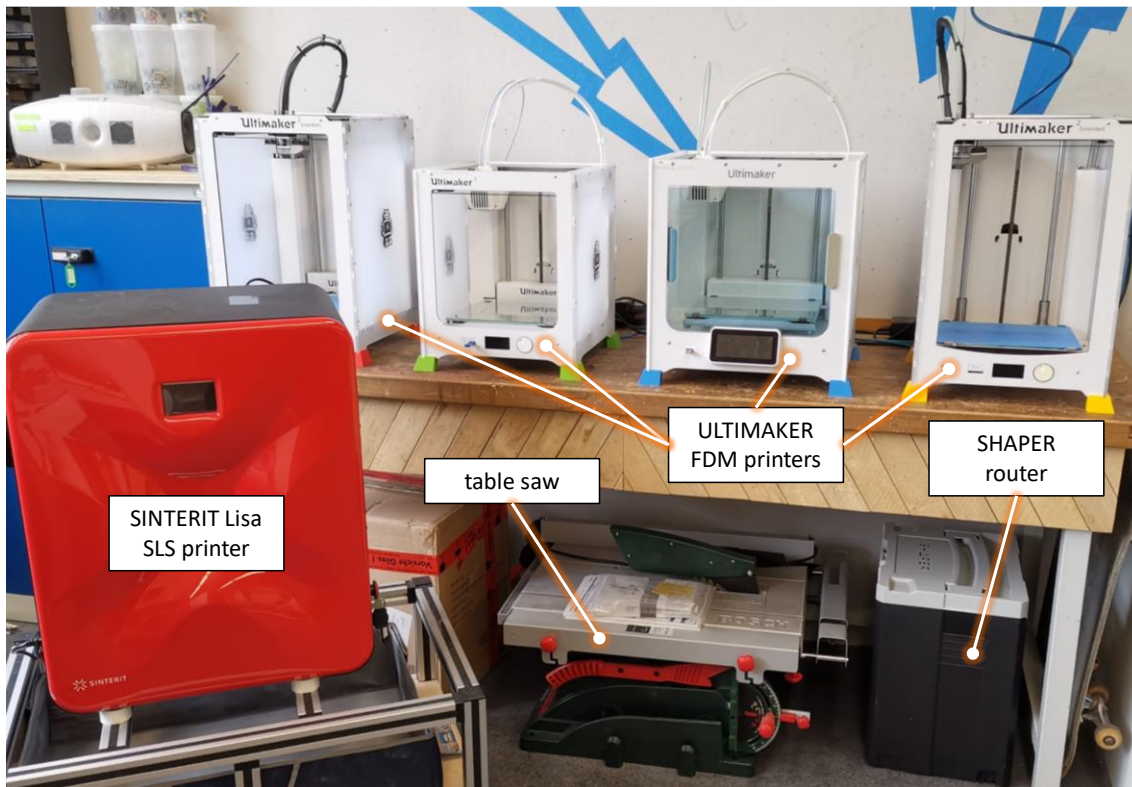


Figure 4. Resources and machinery in the “creative prototyping” lab (3D printing corner)

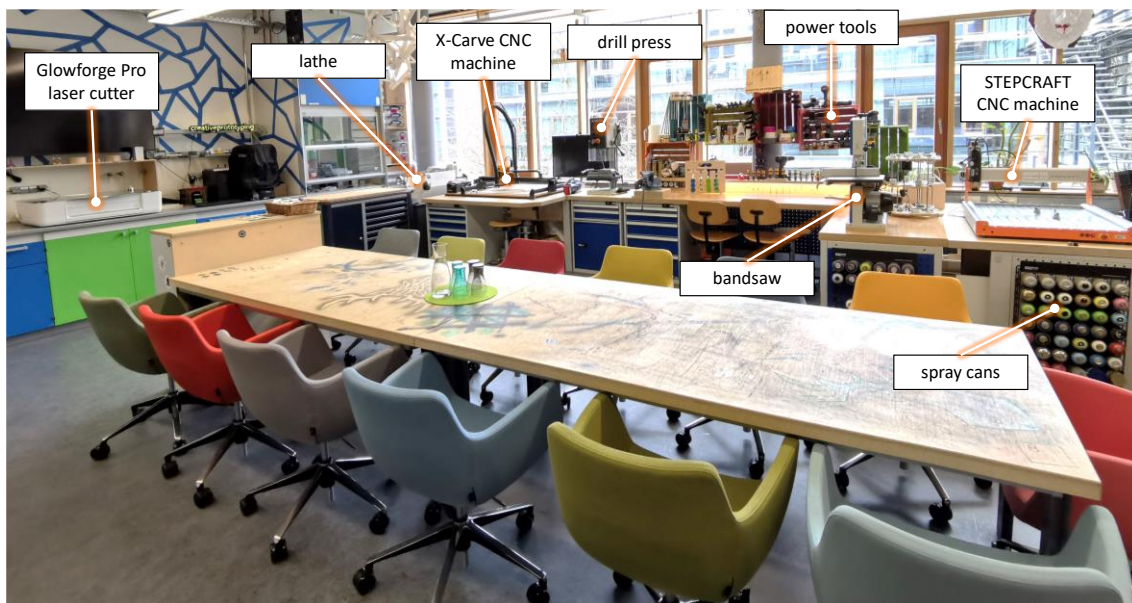


Figure 5. Resources and machinery in the “creative prototyping” lab (view from right corner)

Another problem was presented by the different interfaces between the lab machines and devices (Figures 4 and 5). Since the latter tend to be designed for the hobby sector and enthusiasts, and there are no common interfaces for devices and machinery for industrial use, direct communication is virtually impossible. Though every fabrication machine works with g-code-based controls, and some come with browser-based software, each type of device had to be prepared separately, and this applies even when a 3D printer is changed in favour of another model from the same manufacturer. Acquiring a uniform system to manage, control, and supply all the devices with data or devices with industry-standard interfaces was not an option, for financial reasons.

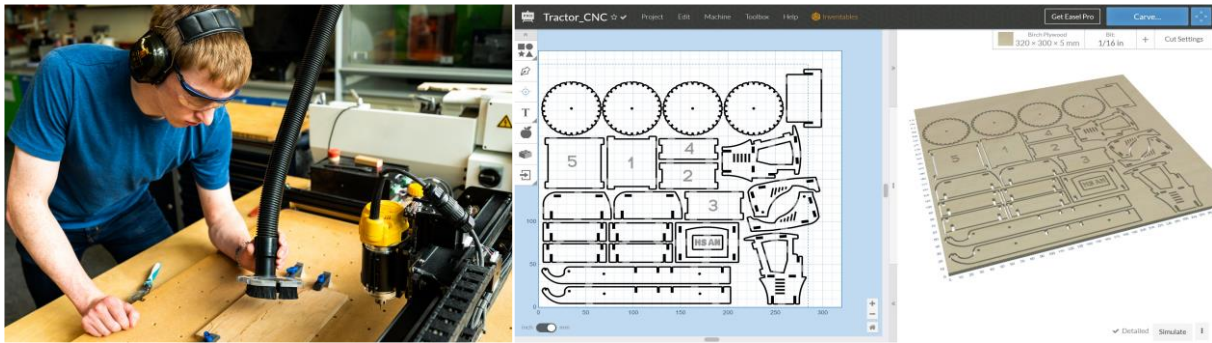


Figure 6. Student working with the CNC carving machine (left) and view of the browser-based software for the milling machine (right)

To solve these issues, we first created a network to control the 3D printers and the laser cutter. These devices have either built-in Wi-Fi capabilities (e.g., the Glowforge laser cutter) or can be connected using an ethernet interface (e.g., the series 3 Ultimaker 3D printers and later). Students working in the lab can connect to the network and access the devices virtually. The browser-based milling machine software (Figure 6) [7] and the laser cutter can be prepared independently of location; only the final manufacturing has to be done in person. The software is linked within the Moodle course and is readily accessible. The course is supplemented with links to online CAD [8] and slicing software for the FDM 3D printers, which gives the students even more flexibility. Unfortunately, these browser-based tools cannot be embedded as plugins into Moodle. The current version of the digital twin of the creative prototyping lab jumps from digital solutions within the infrastructure of the lab and the university to external infrastructure. This will be the subject of further research.

Similarly, external access to the devices or the lab itself is not entirely straightforward. Although an internal lab network exists, it is not connected to the public Internet and cannot be accessed remotely (for security reasons). A completely automated and globally accessible solution is therefore necessary. Unfortunately, this is not financially feasible for the university; what is more, since the solution would have to be bespoke, time is a limiting factor. At present, the submission feature of the Moodle platform is being used as a compromise. After the student submits their doublechecked production data, a member of staff transfers them to the lab's ecosystem and conducts a last check before the prototype parts are manufactured. A centralized means of exchanging and storing production data from outside the lab's ecosystem that bypasses the need for manual work on the part of the staff is in progress.

4 FEEDBACK AND CONCLUSIONS

The feedback given by the students on the 2022 summer semester led to the conclusion that access to the lab (e.g., in terms of timeslots) and the overall experience of it had to be improved upon. Following the next round of the course on project-based product design (to take place this year), the evaluation of the changes made to the creative prototyping lab and the students' interaction with this new digital learning environment twin will be evaluated. The evaluation will include an assessment of the project documentation using the e-portfolio software Mahara and a section for the presentation of new ideas. Based on the results of the evaluation, changes to the digital learning environment twin and the overall process will be carried out iteratively over each new semester. The course lecturers have observed a decreased and more flexible workload because the students do not have to consult with them in temporally constraining conditions. The high initial investment of time and work in setting up the digital learning environment twin has already begun to pay off.

In conclusion, the digitization of the creative prototyping lab and its use in teaching has proven to be a viable concept. For instance, the increased understanding of hazards and processes within the lab has improved through the combination of self-study and mandatory testing. Our concept can, however, be improved upon. Without the consistent use of digital offerings, the course will fall back into traditional – that is, more analogue – patterns. Thus, all those involved must maintain discipline. We intend to transform the creative prototyping lab into a digitized and open-access production space for students from all faculties; for example, it will be extended and equipped with technology to design, build, and program electronic devices and systems. The lessons learnt from creating a digital learning environment twin and the different rounds of evaluation will provide the basis of a production space that offers new levels of usability and 24/7 access for all.

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REFERENCES

- [1] Mostert-van der Sar M., Mulder I., Remijn L. and Troxler P. FabLabs in design education. In *DS 76: Proceedings of E&PDE 2013, the 15th International Conference on Engineering and Product Design Education*, Dublin, September 2013. Available: <https://www.designsociety.org/publication/34781/Fablabs+in+design+education> [Accessed on 2023, 3 March].
- [2] Mills J. E. and Treagust D. F. Engineering Education – Is Problem-Based or Project-Based Learning the Answer? *Australian Journal of Engineering Education*, 3, 2003, pp. 2-16.
- [3] Riess C., Walter M. S. J., Tyroller M., Gomolka L., Augustin J. and Altieri M. Having a real prototype of your own product design – small effort but big eureka moment for students. In *4th International Conference. Business Meets Technology, BMT22*, Ansbach, July 2022, pp. 266-279. Available: <http://ocs.editorial.upv.es/index.php/BMT/BMT2022/paper/view/15624> [Accessed on 2023, 3 March].
- [4] Berglund A. and Grimheden M. The importance of prototyping for education in product innovation engineering. In *Proceedings of the 3rd International Conference on Research into Design Engineering, ICORD 11, Bangalore, January 2011*, pp.737-745 (Research Publishing and Indian Institute of Science, Bangalore).
- [5] Riess C., Walter M. S. J. and Tyroller M. Digital documentation and planning of student projects in engineering and product design using e-portfolios. In *50th Annual Conference of The European Society for Engineering Education*. Barcelona, September 2022, pp. 2161-2165. Available: <https://www.sefi.be/wp-content/uploads/2022/12/ebook-sefi-2022-1.pdf> [Accessed on 2023, 3 March].
- [6] Tyroller M., Walter M. S. J., Kaetzel C. and Riess C. A didactic look on the introduction of e-portfolios in a product design course, In *DS 117: Proceedings of the 24th International Conference on Engineering and Product Design Education (E&PDE 2022)*, London, September 2022. Available: <https://www.designsociety.org/publication/45829/A+DIDACTIC+LOOK+ON+THE+INTRODUCTION+OF+E+PORTFOLIOS+IN+A+PRODUCT+DESIGN+COURSE> [Accessed on 2023, 3 March].
- [7] Inventables Inc. *EASEL World's Easiest CAD/CAM Software*. Available: <https://www.inventables.com/technologies/easel> [Accessed on 2023, 3 March].
- [8] Eigner M., Eiden A. and Apostolov H. Crowd Engineering – Bringing full cloud CAD into the lab. In *DS 88: Proceedings of the 19th International Conference on Engineering and Product Design Education (E&PDE17)*, Oslo, September 2017. Available: <https://www.designsociety.org/publication/40308/CROWD+ENGINEERING+-+BRINGING+FULL+CLOUD+CAD+INTO+THE+LAB> [Accessed on 2023, 3 March].