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A Digital Learning Environment Twin Of A Lab On Prototyping To Give Engineering Students Digital Access 24/7

Christian RIESS
University of Applied Sciences Ansbach, Germany, christian.riess@hs-ansbach.de

Michael S. J. WALTER
University of Applied Sciences Ansbach, Germany, michael.walter@hs-ansbach.de

Maria TYROLLER
University of Applied Sciences Ansbach, Germany, maria.tyroller@hs-ansbach.de

See next page for additional authors

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Authors

Christian RIESS, Michael S. J. WALTER, Maria TYROLLER, and Robert NIERLICH

A DIGITAL LEARNING ENVIRONMENT TWIN OF A LAB ON PROTOTYPING TO GIVE ENGINEERING STUDENTS DIGITAL ACCESS 24/7

C. Riess[1], Michael S. J. Walter, M. Tyroller, R. Nierlich
University of Applied Sciences Ansbach
Ansbach, Germany

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ABSTRACT

Students do not always enjoy an in-depth practical learning experience with adequate hands-on activities during their academic education. In many fields, traditional laboratories are common learning spaces that are, however, not accessible 24/7 and the students' task is mostly pre-defined, resulting in a short and very "passive" active learning. To overcome this limitation and to provide a broader availability and to foster individual learning experience, we transformed a lab from this analog world into a digital learning and teaching environment twin. The laboratory on product design with an extensive machine park (3D-printers, CNC-carving machines, laser cutter, hand tools, etc.) is digitized and finally linked with the real-world lab. All student activities arising in the lab are transferred to the digital environment and accessible 24/7. This digitalization is implemented in Moodle incorporating mostly open-source and browser-based software to control the various machines. This results in a digital copy of the lab, its equipment, that follows the underlying product development processes and includes feedback loops and

[1] Corresponding Author

C. Riess

Christian.riess@hs-ansbach.de

assessment levels for the individual progress of students – the “digital learning environment twin”.

In this paper, we illustrate the methodological approach on the established digital learning environment twin of the lab. Furthermore, we detail the transfer of analog manufacturing process to the digital world and their combination to provide a continuous digital workflow. The paper closes with an analysis of feedback (by both students and lecturers) as well as on the usability of the new digital twin.

1 INTRODUCTION

The transition from an analog to a digital learning experience is more complex in certain fields of study (e.g., engineering) than in others. This paper looks at the digitization of a laboratory used for the subject of creative prototyping in engineering education at Ansbach University of Applied Sciences, Germany. The lab is mainly used in a course on project management, where students have to design and build a wooden product of their own choice from the idea to the finished first prototype.

In recent years, it has become apparent that in many cases the production of a prototype is time-critical and depends on the availability of personnel, machine capacity and the time allocated to work in the lab. To solve these problems we developed a digital twin of the “creative prototyping” lab. This digital twin is available to students 24/7, reducing the need to be on site and minimizing fixed deadlines. The digital twin allows for greater project flexibility, allowing professors and lab staff to provide a higher-quality and more individualized support to students (who in turn improve their skills with tools and machines) [1]. In this paper, we describe the changes required to digitize the lab and connect it to the analog world and evaluate the suitability of our framework for engineering education.

First, we present the steps required to digitize the lab. This is followed by a section on the challenges posed by the analog-to-digital conversion. The paper concludes with some feedback from staff, the inclusion of the lab in the project management course, and a discussion of whether the digital lab could 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 consists of a project management course on the Moodle learning platform of the university, a widely known and well-established environment that makes it possible to connect and digitize the individual elements needed to use the lab and the course itself.

The Creative Prototyping lab's digital learning environment can be divided into two main areas. The first area maps the product development cycle of the product management course from the initial idea to the production of the prototype (Fig. 1). The second area maps the lab itself with all the required machines, tools and documents as well as the mandatory safety training for the lab and it’s machines.

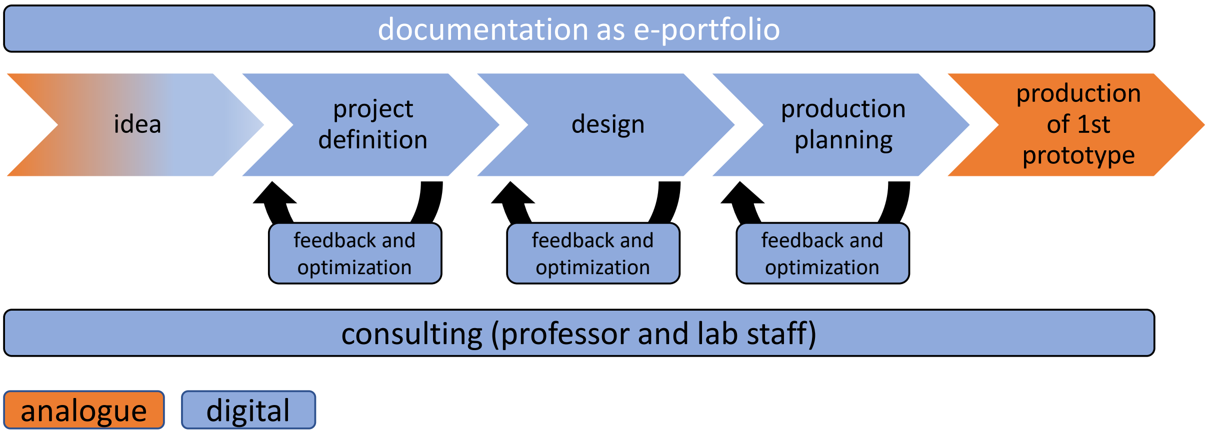

Fig. 1. Flowchart of the workflow during the course "project management"

The course on project-based product design [2], in which we tested the digitalization and usability of our prototype in the summer semester of 2022, is a required course in the bachelor's degree program in sustainable engineering at the University of Applied Sciences. We merged product design and project management to design one course that meets the demand for product design education and provides students with a satisfying first experience on project management. Students are tasked with planning, designing, and building a prototype for a wooden product (for children ages 3 and up or youths ages 16 and up) [3+4]. They are free to choose the target audience for their projects. Currently, the course is conducted and coordinated in person at set times inside the creative prototyping lab. The process is therefore completely analog and not agile.

Each intermediate step of the course has been digitized, and progress is subject to feedback loops and checks by the professor and staff. Students must complete each step of the product development cycle before moving forward. Completion of each step must be synchronized with the student's project schedule, which trains their time management skills. Their work is documented in an e-portfolio throughout the course, and their completed (digitized) project [5] is submitted using the portfolio software system Mahara [6]. Only the fabrication and physical prototype of the product idea will take place/exist in the analog world.

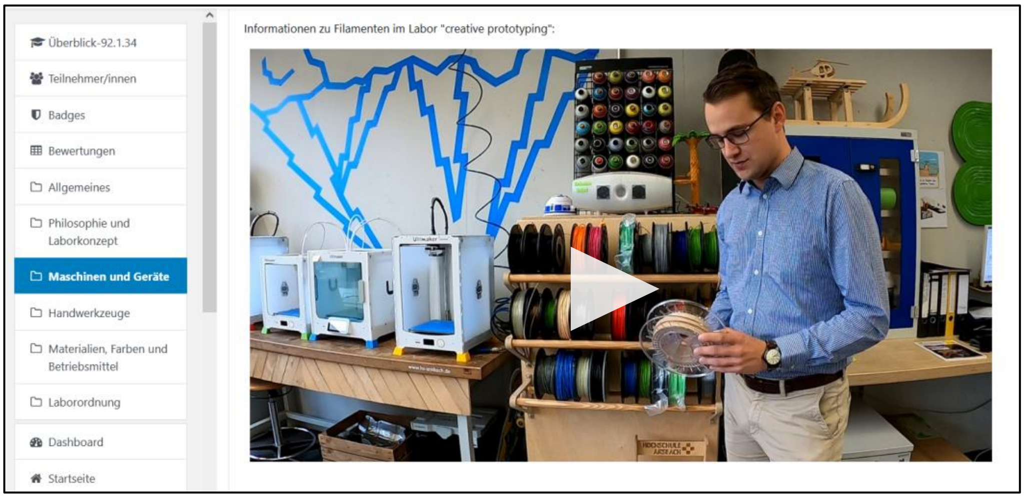

Fig. 2. Video frame of a staff member describing the attributes of filament spools for 3D printers using the fused deposition modelling technology embedded in Moodle

The second part of the Moodle course digitally maps the laboratory. The process starts with the mandatory general safety instructions, including the machine manuals and the specific safety data sheets. This part of the course is divided into subgroups: a general overview, operating instructions, safety instructions, safety data sheets for the different types of machines (e.g., 3D printer, laser cutter, and milling machine), and links to the required software. The level of detail increases as students dive deeper into each topic. For each machine, the first level provides a short data sheet with technical data, the most important safety instructions and possible applications. The next level provides access to video material (Fig. 2), which depicts all the instructions for the individual machines and devices, regardless of the time of day or the laboratory staff's office hours.

The general safety instructions for the creative prototyping lab and the instructions for each machine and piece of equipment (including hand tools such as saws, pliers, and knives) were previously done in person, written down on a sheet, and placed in a binder for each student or small group of students. This was a very important but time-consuming task. As part of the digitization process, we mapped the general safety instruction as an e-learning unit, for which students receive a certificate upon completion. This is then archived digitally, so that the previous paper-based form of documentation has been replaced. The safety instructions for the individual machines and devices are carried out via e-learning and a final test, for which the students receive a certificate. A score of 100% must be achieved on all safety instruction tests to ensure a high level of understanding. Figure 3 shows a screenshot of the general safety instruction test.

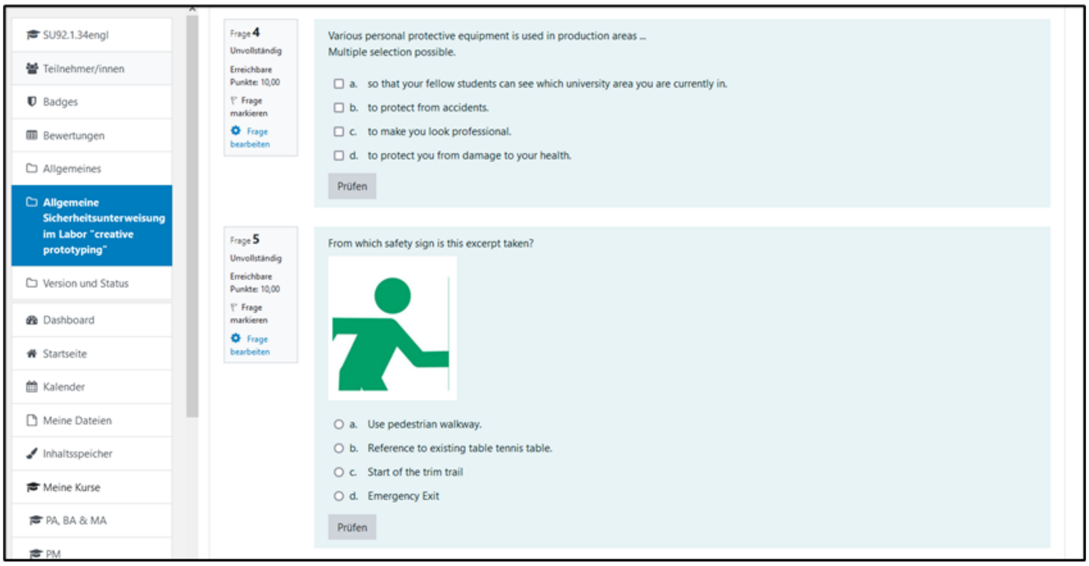

Fig. 3. Part of the test on general safety instructions

The digital approach for the safety instruction part is superior to the previous analog way in virtually all respects. The time flexibility (as with machine instruction) is the biggest advantage. Understanding of hazards and processes is also improved by the combination of self-study and mandatory final test. The digitized lab is rounded out by an appointment calendar (on Moodle) that can be used to book machines and office hours with the professor or lab staff, where general questions or problems from feedback loops can then be addressed. When a face to face meeting is not necessary the students can contact the staff via vide call and gain additional flexibility within their time schedule.

3 THE CHALLENGE OF TRANSFERRING THE LAB TO THE DIGITAL WORLD

Various difficulties and obstacles arose during the implementation of the project. First and foremost, the professor and staff had to invest a great deal of time in preparing for the project. Digitizing a lab that normally operates exclusively in the analog world and only with staff present required discrete solutions to a variety of small problems. The effort required to create the videos, images, and audio for synchronization with Moodle was significant. The time required exceeded the preparation time for an analog course by far. However, it was a one-time effort, and subsequent maintenance and updating of the course will be less time-consuming than for the analog version.

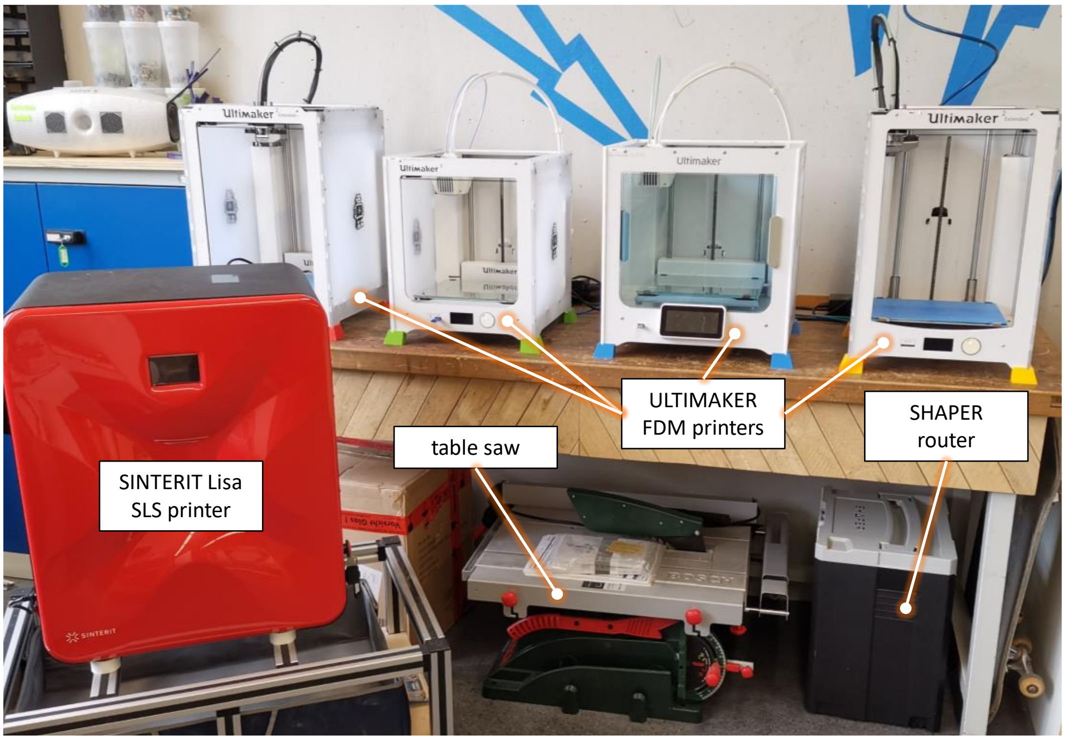

Fig. 4. Resources and machinery in the "creative prototyping" lab (3D printing corner)

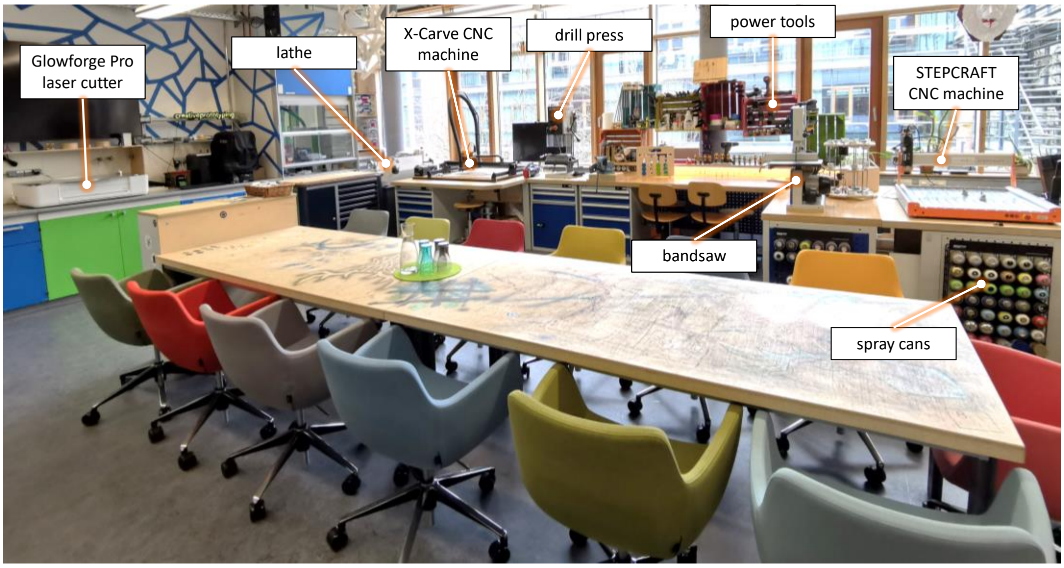

Fig. 5. Resources and machinery in the "creative prototyping" lab (view from right corner)

Another problem was presented by the different interfaces between the laboratory machines and devices (Fig. 4 and Fig. 5). Since the latter are designed more for hobbyists and enthusiasts and there are no common interfaces for devices and machines for industrial use, direct communication is hardly possible. Although each fabrication machine uses a g-code-based controller and some are equipped with browser-based software, each type of device has to be prepared separately, and this also applies even when a 3D printer is replaced with another model from the same manufacturer. The acquisition of a uniform system for managing, controlling and supplying all devices with data or devices with industry-standard interfaces was out of question for financial reasons.

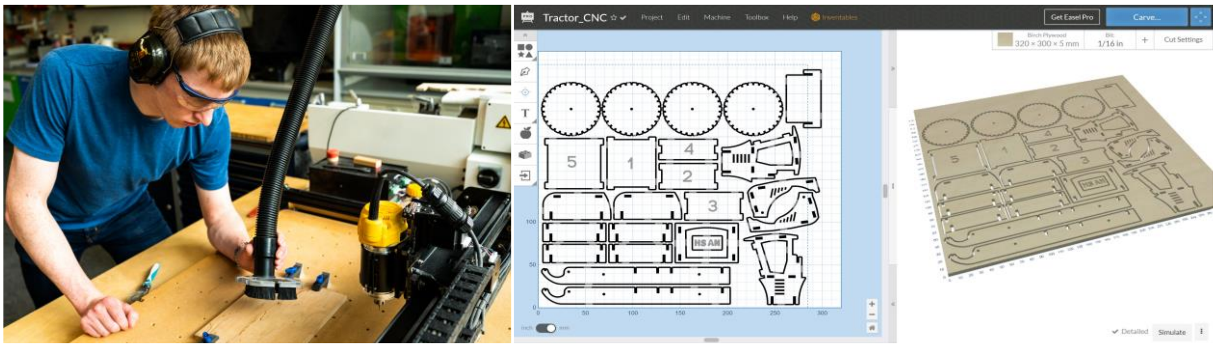

Fig. 6. Student working with the CNC carving machine (left) and view of the browser-based software for the milling machine (right)

To solve these problems, we first set up a network to control the 3D printers and the laser cutter. These devices either have built-in Wi-Fi capabilities (e.g., the Glowforge laser cutter) or can be connected via an Ethernet interface (e.g., the Ultimaker 3D printers series 3 and higher). Students working in the lab can connect to the network and access the devices virtually from their own computers wich reduces necessary data transfers to the computers of the staff and the network of the university. The browser-based milling software (Fig. 6) [7] and laser cutter can be prepared regardless of location; only the final fabrication must be done in person. The software is linked and easily accessible within the Moodle course. The course is supplemented by links to online CAD [8] and slicing software for the FDM 3D printers, giving students even more flexibility. Unfortunately, these browser-based tools cannot be embedded as plugins in Moodle. The current version of the creative prototyping lab's digital twin jumps from digital solutions within the lab and university infrastructure to external infrastructure. This will be the subject of further research.

External access to the devices or the lab itself is also not entirely straightforward. Although there is an internal laboratory network, it is not connected to the public Internet and cannot be accessed from outside for security reasons. Therefore, a fully automated and globally accessible solution is needed. Unfortunately, this is not financially feasible for the university; in addition, time is a limiting factor, as the solution would have to be customized. As a compromise, the submission feature of the Moodle platform is currently being used. After the student submits their double-checked production data, a staff member transfers it to the lab's ecosystem and performs a final check before prototype parts are produced. A centralized means of sharing and storing production data outside of the lab's ecosystem that eliminates the need for manual work by the lab staff is in the works.

4 STUDENT AND STAFF FEEDBACK

The students feedback on the summer semester 2022 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. In 2023 with the next round of the course on project-based product design, the evaluation of the changes to the lab ‘creative prototyping’ and the students’ interaction with the new digital learning environment twin will be evaluated. The results of the evaluation are the base for iterative changes to the digital learning environment twin and the lab. This cycle of feedback and modifications to the course will be used for at least the 4 following years to refine the students' learning experience.

The lab staff and course lecturers mention a decreased and more flexible workload. This is a direct result of the temporally non constraining conditions provided by the digital lab twin. The initial investment of time and work to set up the digital lab twin is already paying off.

5 CONCLUSIONS AND OUTLOOK

The digitization of the lab and the use of the digital lab twin in teaching have proven to be a viable concept with a high potential. In conclusion, the future use of the new setup with iterative improvements promises a great learning experience for students. It helps to gather agility within the engineering education. The increased understanding of hazards and processes within the lab has improved through the combination of self-study and mandatory testing. To prevent a fallback into old (more analogue) patterns, the new digital offerings must be used consistently. This involves all parties to maintain discipline.

In the future the lab 'creative prototyping' shall be linked analogue and digitally with an also digitized neighbouring lab to create an open-access maker space for students from all faculties and people from the public, to realize their project ideas. With the lessons learned from the evaluation of multiple rounds of the course on project-based product design, this new maker space shall offer new levels of accessibility and usability 24/7. However, the focus of usability stays on the students.

For the future the question on interaction between students has to be asked. How differs the student interaction within the digital environment from the high level of peer interaction in physical maker spaces? Does the digital twin reduce the peer interaction by significant means?

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