CERN IdeaSquare Journal of Experimental Innovation, 2024; 8(2): 23-27
DOI: https://doi.org/10.23726/cij.2024.1463

ORIGINAL ARTICLE

Making skills: how courses on digital fabrication enhance 21st-century skills

Clara Dieing[1*], Kirstin Kohler[1], Christian Müller[1], Manuel Walter[1], Damian Wrobel[1]

[1]inno.space Design Factory Mannheim, University of Applied Sciences Mannheim, Paul-Wittsack Straße 10 68163 Mannheim Germany
*Corresponding author: c.dieing@hs-mannheim.de

ABSTRACT

The paper elaborates on critical "design decisions" of a series of digital fabrication micro-courses offered as an optional addition to the full one- or two-semester programs on engineering design. It presents the results of an evaluation regarding the learning outcomes and 21st-century skills acquired by the students. The evaluation indicates that the courses convey practical making skills and contribute to 21st-century skills like self-efficacy, self-initiative and learning competence. The result of the work can inspire other universities and design factories to set up their device training courses similarly to gain this additional benefit.

Keywords: 21st-century skills; course design; making; prototyping; digital fabrication; challenge-based learning; makerspace.

Received: July 2023. Accepted: October 2024.

INTRODUCTION

With inno.space, an innovative learning space was created at the University of Applied Sciences Mannheim which promotes the students' action competence through its learning offers, design, and furnishing. Students can develop into so-called "change agents" through innovative learning formats such as ME310 (Wiesche et al., 2018; Kohler et al., 2022) and CBI A3 (Thong et al., 2021). In transdisciplinary project teams, they develop concrete solutions for complex challenges. All courses follow the pedagogical concept of "Challenge Based Learning" (Charosky et al., 2018) and teach 21st-century skills (OECD, 2019) such as self-efficacy, learning competence, and ambiguity competence. Physical prototyping plays a crucial role in concept exploration and active learning (Camburn et al., 2017). It allows students to transform their ideas into tangible and graspable demonstrators. It highlights the significance of space, specifically the availability of "access to raw material for prototyping" (Weinberg et al., 2014). Besides that, access to digital fabrication devices (e.g., 3D printers) is an essential part of the space to enable students to realize these demonstrators (Wilczynski, 2015). Students acquire the ability to operate digital fabrication devices through micro-courses.

Initially, these micro-courses on digital fabrication were conducted exclusively in presence. We realized it took much work to consider the different levels of prior knowledge and the associated learning speeds.

For this reason, a series of micro-courses was designed for students to acquire basic skills in operating a device through blended learning. These micro-courses are optional and can be chosen by the students, depending on the status and focus of the project as well as their individual experience, which varies depending on their progress in studies and professional background. The micro-courses thus take up the "challenge and affordance character" of the room architecture and self-directed learning paradigm, which is spatially supported by group worktables and a makerspace and thus already call for prototyping through its design and promotes initiative and performance competence (Galaleldin et al., 2016; Thoring et al., 2018).

Based on our challenge-based courses, the question arose of how to empower students in prototyping while using learning methods that can promote 21st-century skills.

THEORETICAL BACKGROUND

21st-century skills are abilities that enable students to collectively drive societal change towards a more sustainable future. In other words, we define 21st-century skills as competencies that empower individuals to solve complex problems independently and act successfully in highly emergent contexts. These skills are based on cognitive, motivational, volitional, and social resources, are value-driven, and can be acquired through a learning process (Ehlers, 2019). Modern education is challenged to enrich the next generation of engineers with 21st-century skills in addition to their technical knowledge (OECD, 2019; Kirchner et al., 2017). These include creativity, resilience, and flexibility (Byers et al., 2013). It is widely accepted that university makerspaces encourage engineering students' creativity, digital and fabrication skills that they can later apply in their work environments

(Wilczynski, 2015; Forest et al., 2014). As such, makerspaces contribute to the encouragement of dedicated 21st-century skills with this skill transfer. It has been shown that students who engage in 3D modeling for 3D printing have better creative and spatial skills due to the influence of the educational design process (Tomc & Kočevar, 2020). In addition, teaching formats such as design thinking (Koh et al., 2015; Luka, 2019), challenge-based learning (Papageorgiou et al., 2021), and project-based learning (Rajendra & Patil, 2020; Ravitz et al., 2012; Shaw, 2018) have proven to promote 21st-century skills.

While there is no longer any dispute about the effectiveness of makerspaces and course formats in terms of 21st-century skills in general, there are still no results on whether smaller course formats for mastering digital fabrication devices are also able to promote self-efficacy, self-initiative, and learning competence through their course structure and design.

We were seeking an opportunity to change our micro-courses to a blended concept. In contrast to classical classroom training, blended learning concepts offer the advantages that everyone can learn at their own pace and therefore build up a better understanding. In addition, tasks can be repeated as often as desired, thus ensuring that the learning objective is achieved (Trapp, 2006; Rao, 2019).

While investigating the influence of our changed micro-course design on 21st-century skills, we focus on four goals (G):

- G1) acquiring basic skills in digital fabrication while promoting,
- G2) self-efficacy,
- G3) self-initiative, and
- G4) learning competence.

Self-efficacy describes the inner conviction of successfully coping with challenging situations out of personal strength. In comparison, self-initiative is defined as the ability to motivate yourself to work on goals and tasks. Learning competence is the ability and willingness to self-directed learning and supervise learning progress. (Bacigalupo et al., 2016; Ehlers, 2019)

COURSE DESIGN

Our solution describes a blended learning approach to learn the handling of digital fabrication devices (3D printer, laser cutter, and vinyl cutter) through micro-courses in the context of challenge-based courses. The micro-courses are divided into three parts: Self-study, video tutorials and face-to-face appointment. The first two are accessible via the learning platform and can be worked on independently.

For the third part, students appear in presence to finish and "produce" their workpiece as represented in the digital model on the device. They receive support from course coaches and can clarify any questions.

Structuring of the three-part micro-course content in the learning platform [processing time from the student's point of view]:

(i) Self-study: Basic information on the subject areas is given through written material, pictures, and fact sheets. [~1h]

(ii) Video tutorials: Three short videos introduce students to digital fabrication software. They are guided to create a digital model for a given design independently. Completing the digital model is a prerequisite to taking the third part of the micro-course. Students submit their digital model through the learning platform and choose an in-class date. [~2h]

(iii) Face-to-face appointment: On-site, students can discuss their digital model with a learning coach, clarify questions, and put the device into operation. As a result, students can take home their personalized fabricated objects. [~1h]

Students learn about the device and create digital models as a requirement for the third part. Students can choose between:

- Personalizing a model: Students create and personalize the given model from the tutorial,
- Creative design: Students create their own models. Therefore, they have to transfer the tutorial instructions to their own model.

The duration of the micro courses is between two and four hours, depending on the level of knowledge. The students are supervised by skilled coaches. One coach supervises a maximum of four students per face-to-face part (third part of the training). The micro courses are open to engineering, computer science and communication design students from the first semester onwards.

We assume the following course design details (DD) meet the objectives (G1-G4) mentioned above.

- DD1: Learning content can be worked autonomously and independent of the location at one's own pace and depending on the level of knowledge (G2, G4).
- DD2: Digital model can be personalized, which has a motivating effect (G3).
- DD3: Students decide which devices to learn and when (G2, G3, G4).
- DD4: The micro-course's short duration lowers the participation hurdle (G3).
- DD5: Submission of the created digital design (G1).

METHOD AND DATA

28 students who participated in the 3D printing micro course were interviewed as part of a lager study. The data for this study were collected through semistructured interviews conducted in both semesters of the academic

year 2022/2023. Those participating students are 7 master's students and 21 bachleor's students. The students voluntarily participated in the interviews at the end of the third part of the course design. All interviews were conducted and recorded in person. The interview included questions about the general flow of the course and qualitative open-ended questions. Questions were asked about the individual parts of the microcourse. How did the students perceive the course structure? What opportunities have arisen and what problems have emerged? Furthermore, the question was asked to what extent the students feel able to work independently on the devices in the future.

All interviews were transcribed verbatim, and all information that could be traced back to an interviewee was anonymized. The answers to the interview questions underwent a content-structured content analysis, according to Kuckartz (Kuckartz, 2012). Qualitative content analysis, according to Kuckartz, is an iterative method. For this reason, the analysis runs three times to refine and improve the results. The first step is the initiated text work. In this process, text passages are highlighted. Passages were marked that, when first read, suggested interesting answers related to all 21st century skills. In addition, the first special features and evaluation ideas are recorded. Subsequently, the thematic main categories are formed. The goal of this step is to create categories based on the content structure of the text. In the third step, the coding of the material with the previously formed main categories takes place. Finally, the text passages are then compiled according to the main category. Two persons performed all these steps to increase the validity of the results. These two people went through each of the three steps independently and met after each step to compare the results.

Additionally, observations were made. These related to the question of what type of workpiece the students submitted. It was noted whether they submitted a personalized workpiece or a creative design. Data was collected through digital submissions of students' work. The completion rates of the courses and micro-courses were recorded, along with the quality and content of the digital designs submitted by the students.

RESULTS

Our current results show that all students who have completed the micro-courses have demonstrated during the face-to-face portion that they can operate the appropriate device by fabricating their digital models using the device (DD5, G1). Some students submitted personalized digital models; many even had creative designs (DD2, G3). 92 out of 113 students submitted their own creative design (shown in Table 1).

Table 1. Percentages of students' personalized and own creative designed model submissions divided into the three micro-courses.

	3D Printer	Laser cutter	Vinyl cutter
Total number of submissions	58	31	24
Percentage of students handed in a personalized model	19 %	19 %	17 %
Percentage of students handed in their creative digital design	81 %	81 %	83 %

In addition, we observe that self-management is working (DD3, G2, G3, G4). In the summer semester of 2022, 19 students took one of our challenge-based courses while all completed at least one of the micro-courses. In the winter semester of 2022/23, 8 out of 11 completed a micro-course (G3). All participating students submitted a digital design. We conclude that students took the courses and understood the content (G4).

Furthermore, to the quantitative analysis, a qualitative analysis was carried out as already mentioned under Method and Data. Here, the interviews of the participants of the 3D printing courses were analyzed according to Kuckartz. The coding and evaluation of these interviews provided evidence of teaching 21st-century skills, as seen in Figure 1. Self-efficacy was identified in interviews with 26 out of 28 (approx. 94%). In 24 interviews, the second most frequent learning competence could be demonstrated. Self-initiative, in turn, was evidenced in 22 interviews. Basic digital fabrication skills were acquired in less than half of all interviews.

Several text segments were found in the 3D printing interviews indicating 21st-century skills (G1-G4). One per skill is listed here as a representative example (Table 2). Each text segment has been translated analogously from German.

Table 2. Representative literal citations from the analyzed 3D printing interviews for each code.

Code	Representative Citations
Acquiring basic skills in digital fabrication (G1)	• We know how to make shapes. We know how to do construction lines; we have a standard on how to do circles. • I first modeled it this way, I drew it the way I wanted it, or rather, I drew it once, then rotated it around the axis, then extruded it down, then connected it in three-dimensional lines, that is, just at the tips in front of the curves, and then rotated it.
Self-efficacy (G2)	• I say, if, I would fail, then at Fusion, but that would be then probably also a training thing. So, let's say the basic understanding is there now and if I then wanted to do a special rounding off or whatever, then you would just have to look at it again. But I mean, that's not what an introductory course is for, that you can design perfectly. • So, I would say now for simple things yes, for more difficult things not so yet, but I think that is a bit of learning by doing.
Self-initiative (G3)	• And then you can just try it more pleasant and even if there is a problem: On YouTube

	you can actually find something for everything and then you can just try it out often and then just, if you have questions, you can just write to you. • If I didn't know something, I just googled it.
Learning competence (G4)	• I think I actually liked online better, especially because it is, let's say, interdisciplinary here. The probability is quite high that we have different previous knowledge. And I would say that someone always gets bored, either those for whom it is too fast or those for whom it is too slow. The way it is now, you can divide it up a bit more freely so that you do sometimes more of one thing and sometimes another. • Yes, I also think it's very good, I'm also a fan of working things out for yourself at home and dividing up your time when you want to do it.

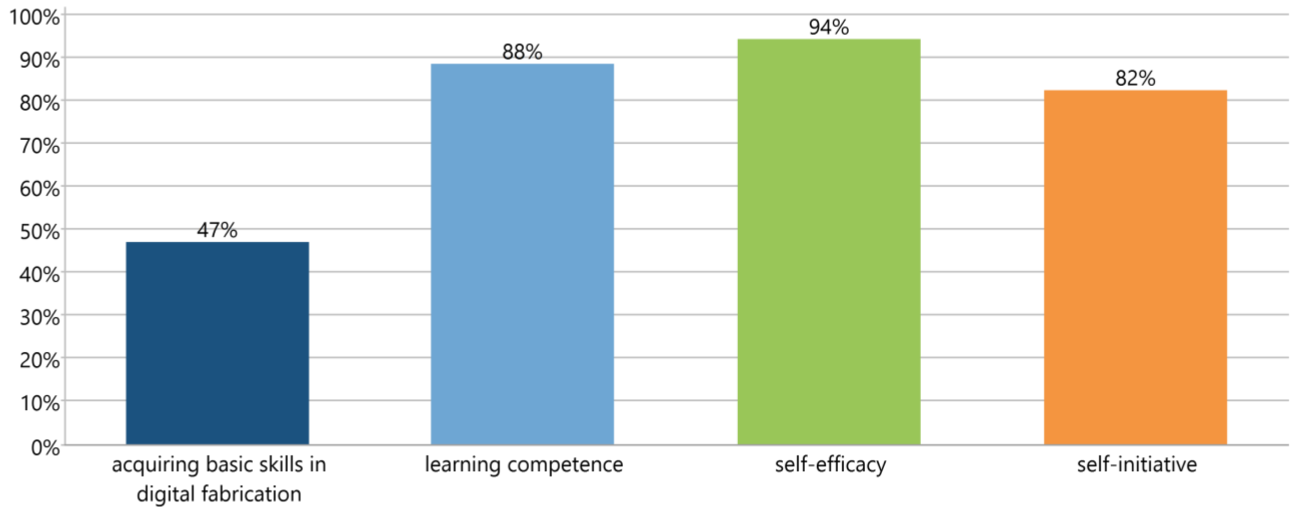

Fig. 1. Percentages of 21st century skills demonstrated in 3D printing interviews.

DISCUSSION AND CONCLUSIONS

The analysis showed that the course teaches students how to operate digital fabrication equipment (G1). However, the qualitative content analysis showed that only 47% of the interviewees unveiled this ability. One possible explanation is that students may not feel self-confident yet to verbalize this skill after a micro-course. Also, the quantitative number of own creative digital designs shows us that the course design promotes self-initiative (G3) and learning competence (G4). The qualitative content analysis strengthened this finding. Circumstantial evidence supporting self-efficacy emerged in the qualitative content analysis (G2).

It also became apparent during the interviews that the initial motivations for converting the micro-courses to a blended learning format proved to be justified. The course participants appreciate the advantages, such as free time management, that this format provides.

Having focused on the interviews on a subset of the courses in this research, the following would now include an analysis of the other interviews. Specifically, this means that in addition to the interviews on the 3D printing courses, the interviews on the laser cutter and vinyl cutter courses should also be evaluated qualitatively.

Furthermore, the interviews were coded using predefined main categories according to the set design decisions. It cannot be ruled out that the micro-courses also convey other 21st-century skills. This could be investigated accordingly in subsequent research.

This research aims to inspire other universities and design factories to set up device training courses so that 21st-century skills such as self-efficacy, self-initiative, and learning competence can be promoted in addition to the skills to operate the devices. In doing so, educators can act as a catalyst beyond their field of expertise, equipping today's generation with essential skills they need for their professional and personal lives.

ACKNOWLEDGEMENTS

We acknowledge the financial support through the project fund SHELLS 4.0 from the Stiftung Innovation in der Hochschullehre.

REFERENCES

Bacigalupo, M., Kampylis, P., Punie, Y., & Van den Brande, G. (2016). EntreComp: The entrepreneurship competence framework. Luxembourg: Publication Office of the European Union, 10, 593884.

Byers, T., Seelig, T., Sheppard, S., & Weilerstein, P. (2013). Its role in engineering education. The Bridge, 43(2), 35-40.

Camburn, B., Viswanathan, V., Linsey, J., Anderson, D., Jensen, D., Crawford, R., ... & Wood, K. (2017). Design prototyping methods: state of the art in strategies, techniques, and guidelines. Design Science, 3, e13.

Charosky, Guido, et al. "Challenge based education: an approach to innovation through multidisciplinary teams of students using Design Thinking." 2018 XIII Technologies Applied to Electronics Teaching Conference (TAEE). IEEE, 2018.

Ehlers, Ulf. -D., Kellermann, Sarah A. (2019): Future Skills - The Future of Learning and Higher education. Results of the International Future Skills Delphi Survey. Karlsruhe

Forest, C. R., Moore, R. A., Jariwala, A. S., Fasse, B. B., Linsey, J., Newstetter, W., ... & Quintero, C. (2014). The Invention Studio: A University Maker Space and Culture. Advances in Engineering Education, 4(2), n2.

Galaleldin, M., Bouchard, F., Anis, H., & Lague, C. (2016). The impact of makerspaces on engineering education. Proceedings of the Canadian Engineering Education Association (CEEA).

Kirchner, J., Klier, J., Lehmann-Brauns, C., Winde, M. (2017). Future Skills: Which skills are lacking in Germany. Stifterverband für die Dt. Wissenschaft.

Koh, J. H. L., Chai, C. S., Wong, B., & Hong, H. Y. (2015). Design thinking for education: Conceptions and applications in teaching and learning. Springer.

Kohler, K., Kaiser, P., Dieing, C., Walter, M., Wrobel, D. (2022) „The smaller siblings of ME310 – Commonalities and differences between three courses on interdisciplinary and international user-centric innovation“. 1st Design Factory Global Network Research Conference: Designing the Future. Designing the Future.

Kuckartz, U. (2012). Qualitative Inhaltsanalyse. Methoden. Praxis, Computerunterstützung, 3, 166-169. ISO 690.

Luka, I. (2019). Design thinking in pedagogy: Frameworks and uses. European Journal of Education, 54(4), 499-512.

Organisation for Economic Co-operation and Development (OECD). (2019). OECD future of education and skills 2030: OECD learning compass 2030.

Papageorgiou, K., Hassi, L., Bragós Bardia, R., Charosky Larrieu-Let, G., Leveratto, L., & Ramos Castro, J. J. (2021). Prototyping the future of learning: reflections after seven iterations of Challenge-Based Innovation (2014-2020). CERN IdeaSquare Journal of Experimental Innovation, 5(1), 5-10.

Rajendra, S., & Patil, S. P. K. (2020). Project based learning: an innovative approach for integrating 21st century skills. Journal of Engineering Education Transformations, 33(4).

Rao, V. (2019). Blended Learning: A New Hybrid Teaching Methodology. Online Submission, 3(13).

Ravitz, J., Hixson, N., English, M., & Mergendoller, J. (2012, April). Using project based learning to teach 21st century skills: Findings from a statewide initiative. In American educational research association conference, Vancouver, Canada (Vol. 16).

Shaw, R. L. (2018). Using project-based learning to cultivate 21st century skills in STEM education. ProQuest Dissertations And Theses; Thesis (Ed.D.). Lamar University - Beaumont, 2018.; Publication Number: AAT 13422541; ISBN: 9780438806887 Dissertation Abstracts International, Volume: 80-06(E), Section: A.; 79 p.

Thong, C., Cotoranu, A., Down, A., Kohler, K., & Batista, C. (2021). Design innovation integrating deep technology, societal needs, radical innovation, and future thinking: a case study of the CBI A3 program. CERN IdeaSquare Journal of Experimental Innovation, 5(1), 32-39.

Thoring, K., Mueller, R. M., Luippold, C., Desmet, P., & Badke-Schaub, P. (2018). Co-creating an idea lab: lessons learned from a longitudinal case study. CERN IdeaSquare Journal of Experimental Innovation, 2(1), 30-37.

Tomc, H. G., & Kočevar, T. N. (2020). Observation on creativity and spatial visualisation skills of graphic arts' students. In Proceedings of the 10th International Symposium on Graphic Engineering and Design.

Trapp, S. (2006). Blended learning concepts-A short overview. In CEUR Workshop Proceedings (Vol. 213, pp. 28-35).

Weinberg, U., Nicolai, C., Hüsam, D., Panayotova, D., & Klooker, M. (2014). The impact of space on innovation teams. In Proceedings of the 19th Academic Design Management Conference (pp. 902-923).

Wiesche, M., Uebernickel, F., Byler, E., Garcia-Cifuentes, J. P., Suzuki, S., Vignoli, M., ... & Krcmar, H. (2018). Teaching innovation in interdisciplinary environments: Toward a design thinking syllabus.

Wilczynski, V. (2015). Academic maker spaces and engineering design. In 2015 ASEE Annual Conference & Exposition (pp. 26-138).