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A first approach to Design through a hands-on 3D printing introductory course

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Abstract
A university orientation course, "Basics and Principles of Rapid Prototyping in 3D Printing", was conducted for 137 prospective students. The primary objective was to introduce them to the Design discipline by teaching them fundamental concepts and practical skills in 3D printing. This technology was ideal for combining technical constraints with creative stimulation, guiding students through their first design process. The course featured hands-on activities where students worked on redesigning objects while learning essential skills like object dimensioning, sketching, 3D modelling, printing, and post-production. A learning-by-doing approach was employed, blending interactive lectures with practical exercises, yielding positive student learning assessment results. Student progress was assessed using a Retrospective Pre-test methodology for a subset of available participants. By the end of the three-day course, all students demonstrated the ability to conceptualise and materialise design proposals, create 3D models, and operate 3D printers to produce tangible objects.

Keywords: *3D Printing; Design Education; Retrospective Learning Assessment; Introductory Course.*

1. Introduction

Over the last two years at Politecnico di Milano, an introductory course called "Designing with Basics and Principles of Rapid Prototyping in 3D Printing" was offered as part of the National Recovery and Resilience Plan (PNRR) orientation and tutoring activities for prospective students in preparation for university. The single course, comprising three lessons for a total of 15 hours per student group, aimed to give the students - without previous design knowledge - an overview of the Design discipline and a first encounter with its process through the application of basic principles of 3D printing, modelling and post-producing useful to manage a low-complexity level project. It included theoretical lectures and practical projects where students redesigned tangible everyday objects using 3D printing technology, letting them practice inside a hands-on design project while dealing with technical and technological requirements and constraints. The course also offered fundamental technical skills and a conceptual understanding of 3D printing technology, including printer structure, printable materials, and various applications. Most importantly, it fostered the development of additional methodological skills, including critical thinking, creativity, design thinking, and collaborative abilities. These skills have been identified among the learning outcomes associated with 3D printing teaching in educational programs (Trust et al., 2018). Ford and Minshall, when synthesising the current state of the integration of 3D printing technology within the educational system (Ford & Minshall, 2019), highlighted numerous advantages, such as the promotion of design creativity and student engagement, enhancing attitudes towards techno-practical subjects, and cultivating teachers' interest within the classroom setting. Thus, additional studies within the field have underscored the educational capacity associated with integrating 3D printing into classroom settings, benefiting both educators and students (Buehler et al., 2015; Pearson & Dubé, 2022; Schelly et al., 2015; Song, 2018).

2. Designing the course: a hands-on redesign approach

The "Basics and Principles of Rapid Prototyping in 3D Printing" course generally adopted a 'learning by doing' approach, where theoretical lectures were interspersed with hands-on activities. These practical activities delineated students' first "redesign project". Adopting a 'learning by doing' approach enhanced student engagement, enabling them to comprehend the process of creating a 3D model or how 3D printing operates through their actions. (Anzai & Simon, 1979; Macpherson, 1999; Thompson, 2010). For each class, the course was divided into three sessions of five hours each. Key topics covered in the course are listed above in the figure (Fig.1), including an overview of 3D printing technology, materials, structures, functionalities, and applications. Students engaged in hands-on activities like sketching, practising 3D modelling through the online software Tinkercad, and redesigning activities by guiding their design process following specific requirements and technical constraints. Due to temporal limits, tutors 3D printed students' redesigned objects before the final session, which focused on post-production techniques and common design errors for 3D printing. Specifics of the project are detailed in Section 3. Summarising, the course gave the students an overview of how different design strategies can be adopted inside the process based on a specific technology.

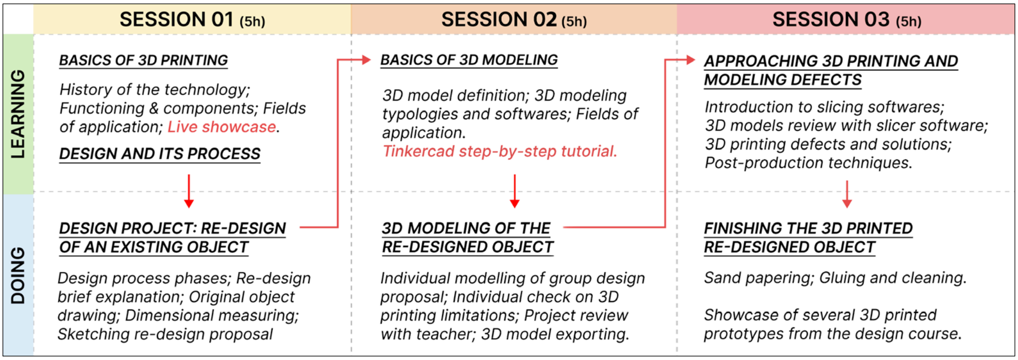

Figure 1. Schematic representation of the main activities (lectures, tutorials, design projects)

All teaching materials, including slides and step-by-step tutorials on printer functioning and 3D modeling, are available upon request by contacting the authors for educational purposes only.

2.1. Audience and Group Work Management

One hundred and thirty-seven students from five groups attended the course, while only sixty-six students completed the initial poll, due to temporary lack of internet connection. Students were between seventeen and nineteen years old and prospective university students with no significant gender or background differences among groups. Crucially, none had prior training in design or 3D modelling and printing technology, as verified by an initial exploratory survey conducted with the Wooclap platform, which was useful for assessing their prior knowledge of the topics and engaging them during the lessons. The results of the initial questions posed to the students - though to gauge their understanding of 3D printing themes before the lessons - indicate that most students (57 of 66 answerings) had 'zero' to 'a little' prior knowledge of the subjects. In contrast, five students claimed to have 'some' knowledge. If prompted, "How much do you think you know about 3D printing?" fifty-nine students answered "Zero" or "A little". Seven responded "Some", mentioning they gained previous knowledge from online videos related to technology fields. After the initial poll, students were grouped into three or four teams, depending on their class size. Each group selected an object to redesign, but each single student completed all the tasks, including measuring, sketching, modelling, and sandpaper finishing.

2.2. Course strategy: lectures alternating 3D learning and practical redesigning

2.2.1. Interactive presentation and initial design brief.

The course aimed to make theoretical sessions more interactive for student engagement. Tutors created presentation slides for visual support, with QR codes embedded to encourage student participation through smartphone responses, fostering engagement and attention by interacting with an online tool. The online platform Wooclap was employed as an open dialogue tool, as it has already been used in other educational case studies (Marin et al., 2021; Moreno-Medina et al., 2023). In session 01 (see Fig.1), an overview of the design discipline was given through the lens of 3D printing technology for a typical product design project, focusing on production constraints and prototyping opportunities while developing creative solutions. Thus, students had to select small everyday objects, measure them thanks to callipers, and redesign their shapes on paper for aesthetic or functional scopes according to their experience with the object and their related needs. This non-conventional activity, differing from the theoretical lessons students were used to, effectively captured students' attention and engaged them with the course.

2.2.2. Tutorial and modelling

The second session (see Fig.1) focused on "materialising" the design project from paper to 3D models using the Tinkercad app. Students, provided with individual workstations, received step-by-step tutorials from tutors. This activity was unusual for the students, but they quickly adapted and learned the software's basic functions and logic in about two hours. Visualising and constructing their redesign proposal in 3D was captivating and encouraging work, but most importantly, it clarified the product design process. By the end of the lesson, each student successfully modelled their project, detailing it based on the software possibilities and the 3D printing technology constraints. At this stage, the tutor transforms into a mediator, guiding students in their methods to execute their projects (Granjeiro, 2019).

2.2.3. Review-presentation and finishing

In last sessions 03 (see Fig.1), students received their 3D printed projects and participated in a guided observation of the pieces led by tutors. Tutors delivered a lesson on common 3D printing mistakes, with slides showcasing errors and solutions using students' prints and explaining how design choices impacted them. This action allowed students to analyse case studies and understand common mistakes visually and collectively. After receiving their objects, tutors explained the theory behind the post-processing operations needed to complete the 3D printed parts. Ultimately, an overview of other case studies in several design fields (e.g., fashion, interior, interaction, etc…) was provided to help students translate the acquired knowledge of the process into practice using examples from the university design courses. Theoretical lectures were tailored to students' interests, and observed mistakes, allowing tutors to adapt content lesson by lesson to meet evolving class needs: the customised content has enhanced learning engagement among student groups. (Huang et al., 2023)

3. Development of the Project

In the initial stages, student groups selected everyday little-sized objects, including items like glass jars, clothes pegs, and keys. They practised observational skills by sketching the objects' basic shapes on paper. Tutors introduced callipers and their use for dimensioning so that each group could measure their sketches, emphasising the importance of accurate observation and recording measurements. After the drawing activity, students had to redesign their objects' shapes and functions by modifying, adding or removing elements. They creatively 'hacked' the objects as desired, starting with a group brainstorming session to generate ideas. Based on previous sketches, students redrawn the objects, incorporating proposed changes while considering recorded measurements. The first day's output was the representation on paper of the newly redesigned and measured project (Frame '1' in Fig. 2).

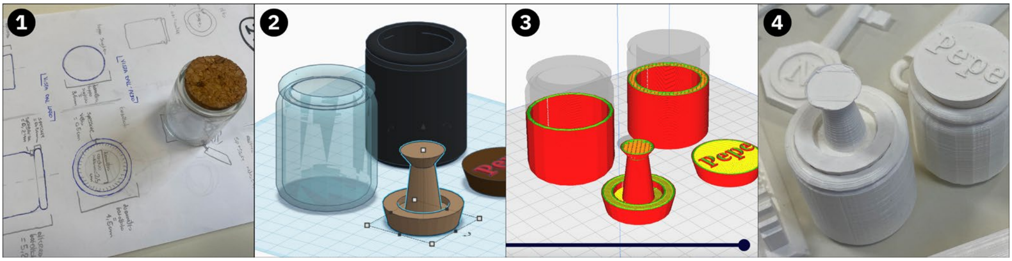

Figure 2. Example of outputs from the steps of the design project completed by the students.

The project's next stage involved transitioning from 2D paper to 3D space: following a frontal tutorial in the classroom, each student - provided with a computer - was tasked with modelling their redesigned object using a 3D modelling web app (Tinkercad). The role of tutors was to individually assist students at their workstations, providing guidance, refreshing tutorial steps as needed, and reviewing the shape elements of the redesign object to ensure the 3D model was printable to the highest standard possible. This part of the exercise has been functional in teaching how technical and production requirements should be considered in the design process and idea development while trying to define the functions and aesthetics of objects. Despite being their first experience with 3D modelling software and concepts, every student successfully produced a 3D model without substantial errors (Frame '2' in Fig. 2). Before the third and final lesson, tutors conducted final slicing operations of the 3D models using the Ultimaker Cura slicing software and subsequently 3D printed the objects to ensure timely delivery to the group. Although tutors conducted this activity separately, students could review their objects with them. Supporting slides displayed the main design mistakes encountered during the slicing activity and provided students with common errors to avoid in the future. Students could perform post-production operations on the parts at the end of the process by sandpapering the surfaces. Many students expressed interest in further steps, such as painting or cleaning their objects at home, indicating a desire to pursue additional activities driven by personal curiosity and interest. Frames '3' and '4' of Fig. 2 show the slicing operation and final 3D printed object. The ultimate goal of the course was to introduce students to the redesign process of an everyday life object through the application of 3D printing technology possibilities: this was their first experience in a design process that challenged them to think out of the box, produce solutions and practice new skills while respecting the technical constraints.

3.1. Students' project outputs

Despite their first disclosure of design process logic and 3D printing and modelling concepts, each student group successfully redesigned a 3D printable object, transitioning from theory to personalisation. Post-production engaged and motivated students to excel. They received their 3D printed objects at the project's end (Fig.3), taking home their design creations. Tutors highlighted mistakes to their students for future reference. Projects varied from basic redesigns (e.g., adding animal shapes to combs) to "innovative" solutions (e.g., adding hooks to improve clothes pegs or transforming keys into multifunctional cutlery). Many students explored tolerances between different parts, notably in redesigning jars, where they had to model both the body and the cap. Several students personalised object shapes by adding names or parts inspired by animals or fantasy characters. Everyone seemed to have understood the process, and most groups successfully integrated the technical requirements and opportunities in their product design definition and development.

Figure 3. Overview of the 3D printed projects of the redesign activity.

4. Students learning assessment

To assess learning before and after the implementation of the lessons, a Retrospective Pre-test was completed by students. As suggested in the literature, this questionnaire was selected as an effective approach for measuring learning outcomes (Levinson et al., 1990). The questionnaire comprised two sections: the first section focused on evaluating how the lessons were conducted, emphasising the management of content and interaction with the class by the tutors. The second section pertains to learning assessment and involves comparing students' knowledge and understanding of skills and theoretical concepts before and after. All questions and assessment requests were designed to understand the impact of the overall strategy employed in delivering the lessons - encompassing the redesign project, personalised and interactive slides, frontal tutorials, and theoretical lectures. A group of students didn't conduct the final survey due to the lack of internet connection in one classroom for the time being. The total number of respondents to the final stage questionnaire is 66, and nobody reported having ever approached a design project activity or a 3D modelling or 3D printing one. Evaluation points divided as follows in Table 2 (Poor = 1; Fair = 2; Good = 3; Very Good = 4; Excellent = 5).

Table 1. Distribution of answers to final Retrospective Pre-test

Section: 1 / Presenters (Ps)	1	2	3	4	5	Avg.
The Ps covered the important topics of the content area.	0	0	1	19	46	4.68
The Ps covered the topic in sufficient detail.	0	0	0	22	44	4.67
The Ps kept the discussion focused on the topic.	0	1	3	20	42	4.56
The Ps refocused the discussion when it began to wander.	0	1	3	31	25	4.21
The Ps created an atmosphere in which most learners participated.	0	1	16	28	21	4.05
The Ps created an atmosphere in which learners felt free to ask questions.	0	1	2	23	40	4.55
The Ps responded to questions with appropriate/relevant answers.	0	0	2	9	55	4.80
The Ps asked questions which led to lively and relevant discussion.	0	1	19	27	19	3.97
The Ps asked questions which were relevant to the topic objectives.	0	2	7	28	29	4.27
Section: 2 / Learning (Prior / After the session)	**1**	**2**	**3**	**4**	**5**	**Avg.**
PRIOR: My understanding of the subject	36	22	4	2	2	1.67
AFTER: My understanding of the subject	0	0	17	39	10	3.89
PRIOR: My ability to demonstrate comprehension of this subject	41	16	5	2	2	1.61
AFTER: My ability to demonstrate comprehension of this subject	0	0	23	34	9	3.79
PRIOR: My ability to apply concepts to an actual situation in this subject	35	19	8	2	2	1.74
AFTER: My ability to apply concepts to an actual situation in this subject	0	1	24	32	9	3.74

5. Discussion

Most students initially didn't possess previous knowledge and understanding of Design and 3D printing, and - even though not everyone has conducted the questionnaire - tutors have observed that all students successfully achieved the learning objectives, navigating through the steps of redesigning objects and preparing them for 3D printing. They also gained skills in measuring objects, using 3D modelling and slicer software, and materialising their design idea. Referring to the group that successfully conducted the retrospective pre-test, responses showed a significant increase in comprehension after the lectures, with students actively participating in design project exercises. By the end of the course, most of the sample reported a greater understanding of the topics covered than their initial comprehension. In addition, the unusual displacement of the theoretical parts of the course, rich in interactive questions through Wooclap and contemporary meme language, played an important role in catching students' attention and engagement, as enthusiastically reported by students through the lessons.

References

Anzai, Y., & Simon, H. A. (1979). The theory of learning by doing. Psychological Review, 86(2), 124–140. https://doi.org/10.1037/0033-295X.86.2.124

Buehler, E., Easley, W., McDonald, S., Comrie, N., & Hurst, A. (2015). Inclusion and Education: 3D Printing for Integrated Classrooms. Proceedings of the 17th International

ACM SIGACCESS Conference on Computers & Accessibility, 281–290. https://doi.org/10.1145/2700648.2809844

Ford, S., & Minshall, T. (2019). Invited review article: Where and how 3D printing is used in teaching and education. Additive Manufacturing, 25, 131–150. https://doi.org/10.1016/j.addma.2018.10.028

Granjeiro, É. M. (2019). Research-based teaching-learning method: A strategy to motivate and engage students in human physiology classes. Advances in Physiology Education, 43(4), 553–556. https://doi.org/10.1152/advan.00034.2019

Huang, A. Y. Q., Lu, O. H. T., & Yang, S. J. H. (2023). Effects of artificial Intelligence–Enabled personalized recommendations on learners' learning engagement, motivation, and outcomes in a flipped classroom. Computers & Education, 194, 104684. https://doi.org/10.1016/j.compedu.2022.104684

Levinson, W., Gordon, G., & Skeff, K. (1990). Retrospective Versus Actual Pre-Course Self-Assessments. Evaluation & the Health Professions, 13(4), 445–452. https://doi.org/10.1177/016327879001300406

Macpherson, R. C. S., Tamara R. Berman, Kimberli A. (1999). Learning by Doing. In Instructional-design Theories and Models. Routledge.

Marin, J., Brichler, S., Lecuyer, H., Carbonnelle, E., & Lescat, M. (2021). Feedback From Medical and Biology Students on Distance Learning: Focus on a Useful Interactive Software, Wooclap®. Journal of Educational Technology Systems, 50(2), 188–200. https://doi.org/10.1177/00472395211023383

Moreno-Medina, I., Peñas-Garzón, M., Belver, C., & Bedia, J. (2023). Wooclap for improving student achievement and motivation in the Chemical Engineering Degree. Education for Chemical Engineers, 45, 11–18. https://doi.org/10.1016/j.ece.2023.07.003

Pearson, H. A., & Dubé, A. K. (2022). 3D printing as an educational technology: Theoretical perspectives, learning outcomes, and recommendations for practice. Education and Information Technologies, 27(3), 3037–3064. https://doi.org/10.1007/s10639-021-10733-7

Schelly, C., Anzalone, G., Wijnen, B., & Pearce, J. M. (2015). Open-source 3-D printing technologies for education: Bringing additive manufacturing to the classroom. Journal of Visual Languages & Computing, 28, 226–237. https://doi.org/10.1016/j.jvlc.2015.01.004

Song, M. J. (2018). Learning to teach 3D printing in schools: How do teachers in Korea prepare to integrate 3D printing technology into classrooms? Educational Media International, 55(3), 183–198. https://doi.org/10.1080/09523987.2018.1512448

Thompson, P. (2010). Chapter 10—Learning by Doing. In B. H. Hall & N. Rosenberg (A c. Di), Handbook of the Economics of Innovation (Vol. 1, pp. 429–476). North-Holland. https://doi.org/10.1016/S0169-7218(10)01010-5

Trust, T., Maloy, R. W., & Edwards, S. (2018). Learning through Making: Emerging and Expanding Designs for College Classes. TechTrends, 62(1), 19–28. https://doi.org/10.1007/s11528-017-0214-0