Research Article

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Opportunities for 3D printing in Hybrid Education

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Abstract: In this paper, we present 3D printing examples that we developed and unitized for hybrid teaching during the global pandemic. We highlight the benefits of 3D printing in classrooms and opportunities for developing different knowledge and skills, starting from mathematical and technological knowledge to communication and collaboration skills. During our activities, we used GeoGebra for 3D printing preparations, it was also utilized for online students' activities, while supporting theoretical background students gained in real classrooms. Since 3D printing technology in the classroom is at its beginnings, the presented observations are highlighting teaching new kinds of strategies supported by 3D printing.

Keywords: 3D printing; Geogebra; mathematical and technological knowledge.

1 Introduction

3D printing creates objects from digital designs by overlapping thin layers of a particular substance in a precisely desired shape. Once a futuristic technology, 3D printing has become realistic, available, and affordable to use in different activities. This opens new opportunities to create various objects, from toys to medical implants. Numerous companies and manufacturers are finding different ways to use 3D technology in production. Its application ranges from tooling parts of objects to end-use products. Research and predictions show that the development of 3D printing will contribute to the quality of our lives (Candi & Beltagui, 2018). Danit Peleg (https://danitpeleg.com/), the author of a 3D printing clothing collection expressed that we should forget shopping since we will be able to download our clothes. Also, the car factory Audi tool maker Hubert Waltl states that one of the aims of his company is to use 3D printed metal parts for regular car production (https://www.audi.com/en/career/working-world/3d-printing.html).

Besides the use in different industries, 3D printing is gradually finding its way into education and modeling. The final 3D printed object is representing a learning path where students travel from an abstract idea to a realistic, useful, and applicable product.

In this paper, as a concept, we present our observations of the use of 3D printing in hybrid classroom environment trialed during the pandemic, where students have lessons in a hybrid format, both online and in person. The new educational settings that were established due to the pandemic, opened many possibilities for the different approaches in teaching mathematical content. In a short period of time there were many challenges, and we decided to observe the use of 3D printing in the hybrid classroom to take a clear picture of the benefits of this innovative approach. We have collected notes, students' comments and results that were informative in constructing a clear picture of 3D printing applications for hybrid classrooms, where activities connected to 3D printing were helpful for students to transfer from theoretical to practical knowledge, as well from online to real classroom settings. Using 3D printing technology students had an opportunity to observe the products of their knowledge and work.

2 Aim of the study

Following the research literature, we found the motivation to describe our experience and contribute this to the classroom practice. We considered that it would be helpful to the teachers to learn from our experience how to use 3D printing in the classroom. This paper presents initial ideas and resources and the basis for applying this tool in classrooms, and it can be a good starting point in researching the learning of mathematical concepts through 3D modeling. Our idea was to listen to the voice of students to observe if the application of 3D printing in learning mathematical concepts would be motivating and worth applying in classrooms. In this paper, we are describing the concept of the use of 3D printers in our

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practice which was based within the framework of the first of six categories of 3D printing in education and we are analyzing an example of how to teach students about 3D printing by combining active multidisciplinary methods and experimental learning. Collected materials and observations are based on the classroom observation in the specific condition of pandemic and hybrid education process, where part of the activities was online, and part of the activities was in the real classroom. The steps for 3D printing application in the classroom are described, as well as students' reflections on 3D printing tasks. Because we have applied this activity in the specific conditions of the pandemic, which was a time of many challenges, we have not applied any statistical collections of data. Our idea was to listen to the voice of students to see if the application of 3D printing in learning mathematical concepts was motivating and worth applying in the classroom.

3 3D printing in education

If 3D printing in learning environments started to become applied in various classrooms, this tool could also enable active learning at all school levels (Eisenberg, 2013, Fernandes & Simoes, 2016, Pence, 2020). Moreover, it is recognized as a beneficial tool in different fields of education, from STEM education to social studies, and special education, in project based or individual learning settings (Isaakidis et al., 2017). Recent research and observations about 3D printing highlight that implementation of 3D printing in education is mostly connected to STEM subjects since engineering design projects could contribute to understanding mathematics and science (Bull et al., 2014).

Ford and Minshal (2018) stated that there are six categories in which the application of 3D printing in education can be covered: teaching students about 3D printing in general, teaching educators about 3D printing, teaching design and creative skills and methodologies, producing aid for learning, creating assistive technologies, and supporting outreach activities. Using 3D printing in education would contribute to more and wider 3D printing applications in everyday life and during that process, students could gain useful knowledge and skills not only in areas such as data synthesis, creative, analytical, and critical thinking, but also in productivity. Additionally, during the use of 3D printing in classrooms, students have the possibility to work together and improve communication, collaboration, teamwork, and other soft skills. 3D printing is also recognized as an important technology for developing 21st-century skills such as curiosity and creativity (Cano, 2015). In the process of application of 3D printing, the learning process becomes deeper and more meaningful by obtaining different information. The whole process contributes to the improvement of problem-solving, decision making and computer literacy (Karaduman, 2017, Trust & Malay, 2017, Novak & Wisdom, 2018). Products and outcomes which resulted in 3D printing help in complete and permanent learning.

It is evident that during the application process of 3D printing in the classroom students develop different kinds of skills besides gaining useful knowledge. They learn how to create models using different software and they also improve their digital skills and connect their theoretical knowledge learned in the different subjects. Through 3D printing, besides being users, students are becoming the creators of technology. By identifying problems around them and finding 3D printed solutions they are learning how to become responsible citizens ready to live and work in the digital age.

3D printed models provide real-world experience to the learners, by the physical tactility of the models (Radniecki, 2017). Introducing 3D printing in the classroom contributes positively to pedagogical perspectives and diversity of learning styles, especially to learning by doing and experimenting. Usually, producing a final 3D model requires several attempts, so students can learn by analyzing failure trials (Blikstein, 2013). Many activities during 3D printing are usually based on solving real-life problems where solutions require cross analyses of design activities in general (Cross, 2001). Integration of 3D printing should be meaningful and connect science, mathematics, and technology in both creative and constructive ways to achieve educational goals (Novak & Wisdom, 2018).

This educational example contributes to the first of the six categories of the Ford and Minshal (2018) application of 3D printing in education. It contributes to teaching students about 3D printing in general and a lesson consisted of following steps: providing students with written instructions, modeling mathematical objects and preparing files for 3D printing, 3D printing, analyzing both correct or incorrect solutions, and the acquisition of formal knowledge at the end of the lesson.

The specific objectives on which we based our study were: to communicate innovative approach with students in the hybrid classroom, to teach students to understand the 3D printing process, to connect geometrical content with the real-world settings, and to learn from the mistakes.

In this study, we utilized a qualitative research approach to collect information about the implementation of 3D printing in the hybrid classroom, with online and real-world instruction. The collected data helped us to examine 3D printing application practice and its contribution to the educational process on a more profound level through analyzing data obtained from fieldwork notes. The study was conducted at Petro Kuzmjak School in Ruski Krstur in Serbia.

The main point of our analysis was to understand students' experiences in using 3D printing and working on projects. The process of 3D printing in the classroom had several phases: the idea, the connection of the idea to the curriculum content and students' knowledge, virtual modeling and preparation for 3D printing, 3D printing with a printer, and analyzing and observing results.

Following this pattern, we entered the first step of 3D printing in the classroom which was collecting students' ideas that would be transferred into reality. For example, when students learned about geometrical solids, their idea could be turned into printing a tetrahedron. This idea could be used to closely examine the properties of tetrahedrons. After this step students can proceed to two further steps: virtual modeling and preparing files for 3D printing. There are many opportunities for students to model an object for 3D printing. Programs like Sketchpad, Thingiverse, Tinkercad, or Geogebra offer pre-prepared files or provide the possibility of modeling different objects independently in an easy and intuitive way. After modeling and preparing files for 3D printing and obtaining a real model with 3D printers, students can observe the result and reflect on the whole process highlighting problems, obstacles and mistakes that happened during the process. By analyzing mistakes students could gain valuable knowledge about curricular content and new features of the software and enhance future 3D printing activities. Even at this stage of the working process, mistakes could open new learning opportunities for experimentation and investigation.

In the middle of 2019, the school in Ruski Krstur was given a generous opportunity to have a 3D printer from Johannes Kepler University, so students (13-15 years old) had the possibility of working on several projects that combined not only science, technology, engineering, and math, but also aesthetic and artistic aspects and develop their understanding of sustainability and environmental issues. Fruitful collaboration and innovative activities were interrupted by the global pandemic when teaching activities were shifted to the online environment, and after a while into a hybrid environment that combined online and real-life environments.

Since Serbian students came back to school in September 2020, we started to work on the hybrid educational model. The hybrid model means that students get instructions in the classroom, but also in the online environment. In Petro Kuzmjak School, students were having 30 minutes lessons in person, and additional activities were conducted in the online classroom. There were also possibilities for students to attend lessons exclusively online if that was their choice.

During this period, we developed certain approaches and lesson plans on how to apply 3D printing in the classroom.

We based our study and lesson design on the Experiential Learning Theory emphasizing the importance of experience and its role in the learning process (Kolb, 1984). This theoretical framework proposes that any experience could be transformed into a reliable source of knowledge and make learning more meaningful. It proposes a process of four stages: experiencing, reflecting, thinking, and acting. In our case our objectives of the study were connected to those stages: thinking: introduction of new technologies, acting 3D printing modeling, experiencing: getting final physical result and reflecting: observation of the result and making improvements.

Mostly we applied 3D printing in the mathematical hybrid classroom, but also in the lessons for sustainability and art lessons (Budinski et al., 2019). As we had to adjust to the situation in many aspects of life, we also had to adjust our 3D printing activities to the situation during the pandemic. We decided to continue with our 3D printing activities since students showed great interest in 3D printing in previous activities. In Figure 1. we can see students of Petro Kuzmjak School observing the 3D printing process in the classroom.

We decided to use 3D printing in teaching geometry, and we observed students' activities in the final grade of primary school, (grade 8) with students 14-15 years old, during their lessons about geometry. 30 students participated in the activities. The curriculum requirements propose teaching students about space geometry. After the lessons, students should know the definition of geometrical solids and recognize their main features. Students should recognize a polyhedron as a geometrical solid consisting of polygons. Students should also know to determine diagonals in both cases, polygons, and polyhedrons. Moreover, students should distinguish between convex and concave polyhedrons.

To visualize geometrical concepts of polyhedrons students used GeoGebra (www.geogebra.org) and learned how to recognize a polyhedron's sides, edges, and vertices. GeoGebra helps in visualization and makes

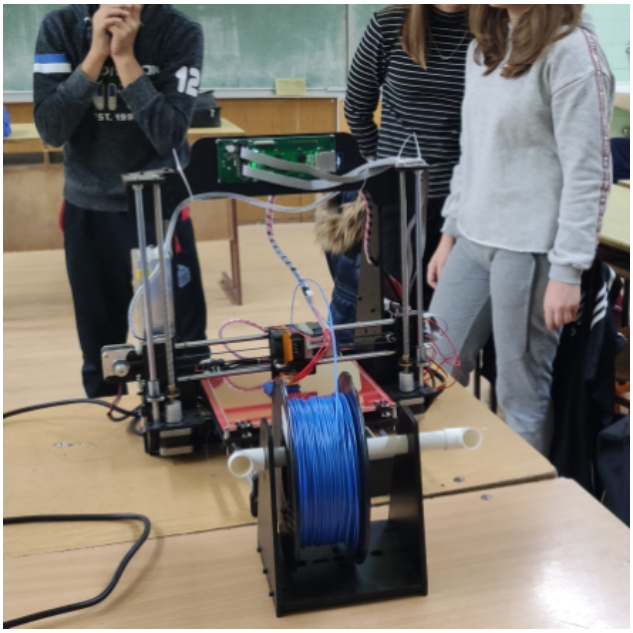

Figure 1: Activities of 3D printing in the classroom before global pandemic.

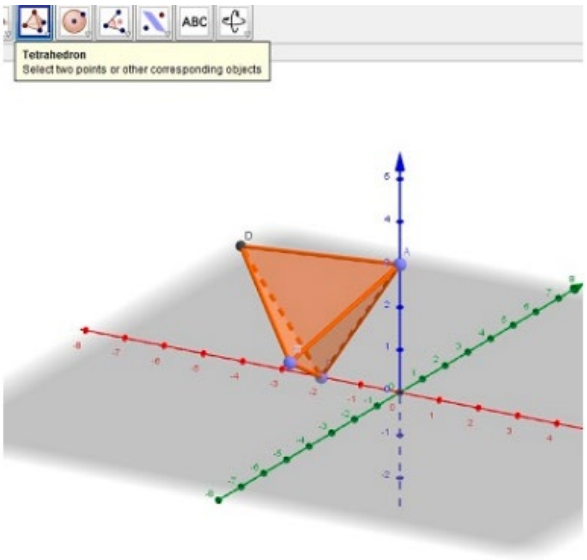

Figure 2: Student's model of tetrahedron in Geogebra.

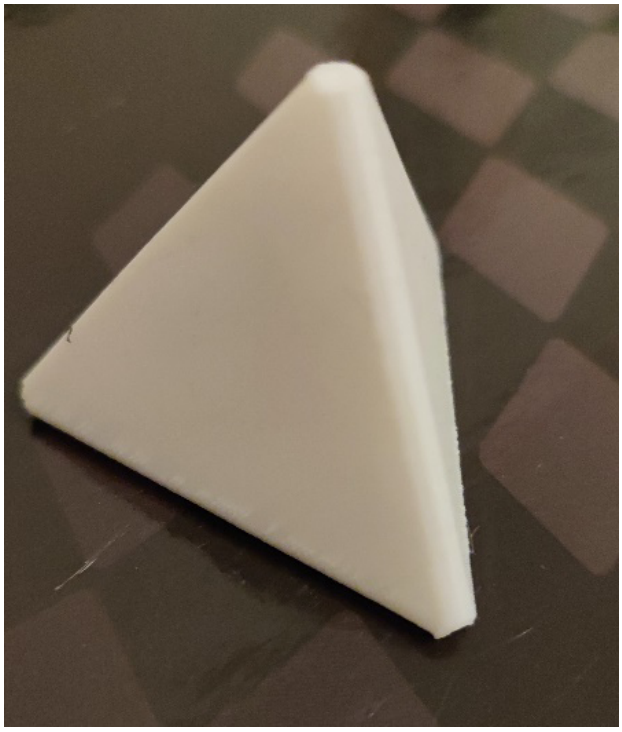

Figure 3: A tetrahedron results of 3D printing.

geometry clearer to students, easy to understand because of its dynamic visualization features. To achieve those educational goals, students received instruction sheets for two tasks. The first task was given in the online classroom. It required the students to model geometrical objects using GeoGebra. The task was to model different types of pyramids, for example with a triangular or square base, but also to model regular or irregular pyramids. Results and solutions were sent to the online classroom as a file ready to 3D print, so the teacher could print the solids. During the process, students needed to collaborate and communicate with the teacher in the online environment through messages and emails.

In Figure 2 we can see the student's solution where the model of a tetrahedron was made. Through this task, students could explore the properties of the created regular polyhedron regarding its sides, edges, and vertices.

After that, the teacher checked the students' solutions, and if they were acceptable, 3D printed them. After returning to school, students could analyze the printed solids. They focused on correct as well as incorrect solutions to draw conclusions out of the mistakes for further learning processes. The mistakes and failed attempts showed as a useful source of information for students. In Figure 3 we can see one of the 3D printed results was correct.

In the discussion, students mentioned problems they had while working on their tasks. Firstly, students needed lots of help to finish their tasks. The communication was slowed down since they had to send messages to ask about what was unclear to them. Although students already were familiar with GeoGebra, they had to spend more time on the tasks than expected. Some students submitted an incorrect but printable solution to the task which was 3D

printed anyway. These wrong solutions were discussed, mistakes were identified, and therefore these solids served as an opportunity for further learning processes.

4 Discussion

The specific objectives, that we based our study on, were to communicate innovative approaches with students in hybrid classrooms; to teach students to understand the 3D printing process; to connect geometrical content with the real-world settings; and to learn from our class design mistakes through continuous monitoring of environments and pedagogies.

In this study, we applied 3D printing technology to contribute to teaching practices. We developed practical examples that could be used in mathematical classrooms equipped with 3D printers. After delivering the experimental program, we have collected valuable observations. All students participated in our activities and all students completed the entire process, starting from an idea and mathematical object to modeling and preparing files for 3D printing, and finally the actual 3D printing. Five students were completely successful and have finished the process of mathematical modeling and 3D printing without any problems. All other students completed the process with some assistance of teachers and through several attempts. Since the application of 3D printing in mathematical classrooms introduces different approaches, where even incorrect solutions become valuable for learning, we followed various activities of students. From our observations, it is clear that even students who were not successful in the entire process benefited in their learning experiences. For example, this is how a student who did not finished the process successfully described the learning process: "I have chosen to create a tetrahedron. When I created the first model in GeoGebra, it was not correct since it was a pyramid with a square base. I forgot that a tetrahedron is consisted of all equilateral triangles". Other students had a problem with preparing their files for 3D printing. It was described in the following way: "I have chosen to print a prism with a square base. It was easy to create prism using GeoGebra. The problem was that I did not understand that 3D printer cannot print the file directly, it has to be saved with proper extension. My task was not finished, so I have to explore more things about 3D printing. They can print files only with proper extension." One student had the following remarks: "I have chosen to model a pyramid with a square base. I have trouble to find proper functions in GeoGebra to create desired pyramid. After I finished my work, I have observed the final 3D printed product. It was nice to hold it in my hand, it was real". By analyzing students' difficulties in online classrooms, we could say that there were mainly problems in connecting mathematical content with modeling in digital environments and using GeoGebra. Also, some students had the problem of preparing files properly for 3D printing.

Since this study focused on exploring the process of connecting mathematical theoretical content with digital environments, modeling and 3D printing in hybrid education settings, the observation showed that students were searching for solutions from more than one attempts. Moreover, students considered steps such as information-gathering and connecting to the theoretical content, modeling, and analyzing. Our observations on the application of 3D printing to the hybrid classroom were just based on several activities during the pandemic. In the hybrid classroom the application of 3D printing was meaningful and connected the students to the understanding of mathematics. It provided not only real-world experience for students, but also physical tactility. Our example is the applicable example for the classroom recommended by relevant literature which suggests providing real world experience to the learners and physical representations of the mathematical models, since the result was 3D printed models. Also, these activities contributed to problem solving, decisions making and computer literacy (Radniecki, 2017 and Novak & Wisdom, 2018).

5 Conclusions

Regarding our objectives, we were working on raising students' awareness of the potential of 3D printing for modern society and the economy in which they participate. In the hybrid classroom settings, we introduced students to the innovative approach even though conditions were hard, for example, not all students had access to the internet, it required time to receive feedback from students and so the process was much slower than expected. The good side was that, regardless of the obstacles, students' engagement and their interest in 3D printing activities were evident during all stages of this project. That was helpful for reaching two other objectives, which were understanding the 3D printing process and learning abstract mathematical content in an online and real environment employing new technologies. Students got

a clearer picture of the mathematical content they must know and how it can be applied in the real-world situation. The project contributed to hybrid education and offered a balanced connection between the virtual and real world. In this approach students had an opportunity to learn from their mistakes and trials which required additional patience form both sides, students', and teachers'. The 3D printing process requires many settings, and that was a good opportunity to discuss the mathematical content.

This initial study showed the potential benefits of 3D printing application and the need for developing strategies for 3D printing application to learning mathematical content. It would be beneficial to observe this approach in both regular and online settings and compare results. Also, statistical results regarding students' knowledge would be efficient way of showing the real potential of this approach. For now, it could be a problem since schools need to be equipped with the proper 3D printing technology.

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