Come to STEAM. We have cookies!

[1]Eva Ulbrich[1], Branko Anđić[2], Diego Lieban[3], Julia Handl[1] , Renáta Vágová[4] and Zsolt Lavicza[1]

[1]Johannes Kepler University Linz, Austria; eva.ulbrich@gmx.at, points.edges@gmail.com, lavicza@gmail.com
[2]University of Montenegro; brankoan@yahoo.com
[3]IFRS, Brazil / Johannes Kepler University Linz, Austria; diegolieban@yahoo.es
[4]Constantine the Philosopher University in Nitra, Slovakia; renata.vagova@ukf.sk

Abstract

In STEAM education, 3D printing can be valuable especially for creating custom teaching material. Moreover, it can be used to create tangible visualisations of virtual concepts as are used in mathematics. As a motivational and learning bonus, it utilizes concepts of constructivism. However, learning to search for, create, and finally produce 3D models can be challenging for teachers. To help them, we developed a workshop introducing 3D printing in ten schools to around 200 teachers. In this workshop, we used the artwork we found in schools to support teachers in learning to create customized 3D printable cookie cutters. We experienced a motivational boost leading to more engagement, longer workshops, and a better understanding by teachers of how to create and print 3D models.

Introduction

Visualisations are a powerful tool to communicate mathematical concepts [15]. This also applies in schools where visualisation plays a vital role in students' understanding of concepts in Science, Technology, Engineering, Art, and Math (STEAM) education, especially in subjects such as mathematics.

There are several options for on screen three-dimensional (3D) visualisations for STEAM education including virtual and augmented reality and 3D graphics. Gilbert [5] suggests that both a visual representation of teaching content for students as well as developing the students' skills for visualisation is important. For Knill and Slavkovski [8], 3D visualisations in comparison with visualisations in two dimensions can also be made tangible and thus have a different quality. As a result, they can be manipulated using the student's bare hands. This property allows them to perceive and investigate a tangible visualisation of a mathematical concept by a variety of additional attributes, such as texture or weight. Knill and Slavkovski [8] argue that mathematical exhibits such as in the science museum in Boston or in the Museum of Math in New York which display tangible representations as a form of 3D visualisations make mathematics more accessible and inspire artists.

Producing tangible visualisations can be done in a reasonable time using 3D printing compared to other ways of creating items using techniques such as carving or casting. Knill and Slavkovski [8], for example, use 3D printing to visualise a variety of mathematical proofs. Vanscoder [17] also mentions the high value of a 3D printed representation of mathematical concepts as a tangible visualisation. He furthermore talks about how prototyping is a vast contribution to learn engineering skills and art by, for example, the possibility of printing even electronics using conductive ink or 3D scanning. Producing items using 3D printing also offers the creation of adapted or personalised objects which otherwise have to be custom-made. It thus allows the creation of tangible visualisations that can be produced by teachers or students themselves aiming at their specific needs and interests.

Manipulatives and especially personalised or adapted teaching aids have the potential to improve the learning experience. Kolb & Bauback [10] and Druin [3] indicate that 3D printing allows students to gain knowledge by building objects. Students not only can apply a variety of STEAM topics when creating 3D prints, but also they can create something fulfilling their own wishes, inspirations and needs. Inspiration for object creation and the power to enact it can be an important motivational boost. Moreover, building objects is one of the most important characteristics of constructivist learning.

Teachers should understand which options they have using a technology such as 3D printing and how to use the technology's potential during class for their subject. To do that, they need to know how 3D printing machines work as well as how to get or create 3D printable models. In addition, using a technology can require extra effort. Used in lessons, 3D printing contains characteristics of an interactive lecture which requires interacting skills and also of a workshop which needs a good structure and preparation for resources [13]. Moreover, 3D printing is highly dependent on the quality of the 3D model which needs to be created in a software. This virtual model has to be designed cleverly to prevent difficulties during 3D printing. Even the positioning of the 3D model on the printer bed changes the outcome. In the beginning, all of these "tricks" have to be thought of, practiced, and might be challenging.

In the literature , there is some research on how students perceive and use technology, but little about what teachers need to learn. Not many papers are focused on investigating the challenges of teachers or the reasons leading them to avoid some new tools. The availability of facilities and the usability of software tools are named amongst the most important prerequisites needed to use technologies [7, 9]. But not only availability is necessary. Already in 1986, Cuban [2] wrote about teachers' decisions of technology integration being based on their personal perceived usefulness. They only used it if their personal effort was worth the outcome. Also, the usefulness of the technology integration into lessons plays an important role in teachers' decisions. Lam [11] conducted a study with language teachers who were supposed to use computers in their lessons. These teachers used computers provided only when they were convinced of their beneficial aspects for students. Teachers also have to be confident in their abilities to use a technology [18]. They can be intimidated or embarrassed if they have the feeling that their students are better in something. Teachers have to feel secure and need to be confident in their skills with technology.

In this paper, we will present how we conducted workshops in ten schools in Montenegro to motivate overcoming the aforementioned challenges. The main idea was to teach teachers to find or design an object, to create a 3D model of it, and finally to 3D print it for their lessons in the best possible way. We introduced the benefits of 3D printing to about 200 teachers from various subjects (English, chemistry, physics, informatics, mathematics, arts) giving them the opportunity to try out 3D printing. Our specific aim was to trigger discussion and collaboration between them. Each workshop followed a specific structure which is explained in the following sections in more detail. The workshops lasted between three and six hours depending on time constraints and teachers motivations. Our workshop team consisted of two biology teachers specializing in teaching disabled students, three math teachers using 3D printing, and two 3D printing experts. One of the biology teachers also had the role of a translator.

Math and 3D printing: presenting examples in a workshop

At the beginning of each workshop, we presented our best examples for how mathematics teachers can benefit from 3D printing. Then, we gave teachers 3D printable puzzles [12] to play with which were created on the GeoGebra [6] platform. GeoGebra [4] can be used to create exercises and even 3D models. These puzzles usually caught the teachers' attention throughout the workshop breaks. Afterwards, we explained how they can create their own 3D models or find them on the Internet. In general, we divided the workshop into two main parts separated by a break. The first part had a presentational and inspirational character where we presented them ideas for how 3D printing could be used in real-life situations. The second part focused on gaining experience in 3D modeling and 3D printing. To show teachers the first live printing, we used a Fused Filament Fabrication (FFF) printer. We explained the connection between printing volume and printing time. We also brought misprints from our previous workshops, as a motivational step, to show them that even experts make mistakes.

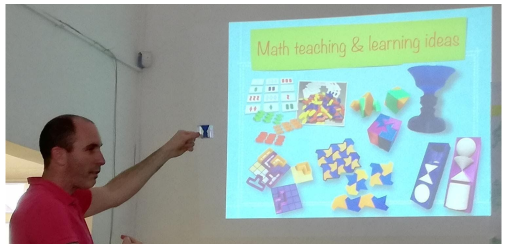
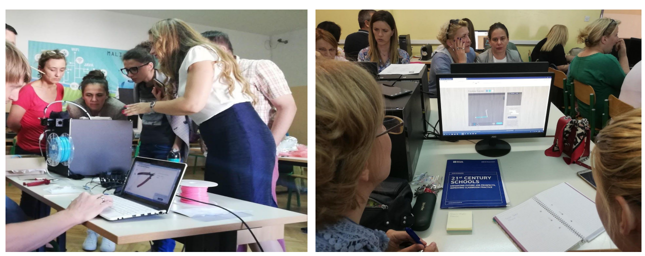


Figure 1: *FFF printed objects in math.*

After showing examples of FFF printing developed and used during math lessons in part one as shown in Figure 1, the objective of the second and more hands-on part of the workshop was to find or design objects, to create a 3D model of them, and finally to 3D print them. At first, we showed them free online sources for where to get 3D models for downloading. Next, we let them experiment with free online 3D modelling tools that are simple such as CookieCaster [1]. In case teachers were interested in more complex modeling, we showed more free online tools like TinkerCAD [16] and OpenSCAD [14].



(a) *(b)*

Figure 2: *Teachers (a) observing a FFF 3D printer in action, (b) using CookieCaster in groups.*

Teachers were divided into groups of two or three members as shown on Figure 2. Each member of the group was given a certain responsibility, such as operating the computer, taking notes, or making sure to understand how the printing process works, as shown in Figure 2b. The teachers responsible for using the printer were given extra instructions related to setting up and using a 3D printer in depth. These instructions were also documented in an online book on the platform GeoGebra which is available at https://www.geogebra.org/m/hdqxz2vj. The book was extended during workshops whenever questions arose so teachers could be more engaged in the 3D modeling and 3D printing instead of making notes.

Cookie Cutter modeling and printing

As we divided the workshop in two parts, in the beginning of the second part we introduced an online tool named CookieCaster allowing the creation of a cookie cutter from any image. We found some clear outlined pictures on the Internet and imported them to CookieCaster to demonstrate a simple way of 3D modelling. Following these steps, the teachers were challenged to try the tool themselves.

The workshop progressed as follows:

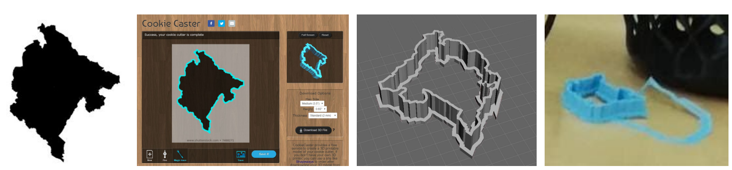
- First, we showed them how to create cookie cutters by using mathematical concepts like manipulating nodes and edges in CookieCaster. Teachers experimented with Bezier curves, used geometry and observed proportions.
- Second, we asked them to browse for a distinctly outlined picture they liked.
- Third, we invited the teachers to create their cookie cutter model from the outline and 3D print it.
- In the end, teachers were encouraged to develop ideas about implementing CookieCaster and 3D printers in their classrooms.

Using CookieCaster, the teachers had to use knowledge about geometry, rotation, volume, vectors, scaling and more concepts. In addition, the teachers had to rotate an object cleverly to explore printing times and material consumption. Furthermore, they investigated the relevance of minimum wall thicknesses and useful heights using spatial thinking and anticipation of applied physics. They also used computational thinking and experienced applied constructivism. The impacts were all directly visible to the teachers in the 3D objects and turned the cookie cutters into tangible visualisations of math.

We then gave them feedback on producibility, including the height of cookie cutters and the relation to printing time. We also discussed the effects of the objects in later use, for example if a cookie cutter created very thin parts of a cut out dough which could get burned in the oven. The purpose was to have them think about real life implications of the printable items they would create with their students. By combining images, math, food and 3D printing, we wanted to inspire them to think about and develop interdisciplinary future projects. Our goal was for them to use their various realms of expertise to strive for a common goal and explore ideas rather than having math as focus. Finally, we asked them to put the cookie cutter model onto a USB drive for their colleagues operating the FFF 3D printer.

Teachers catching fire

The technology of 3D printing can not only produce visualisations used in mathematics education but the creation and production of items that employ a variety of skills used in engineering, art, physics and science. So, we expected teachers in workshops to be motivated by knowing about the benefits for their students first hand. However, it seemed many of them only passively consumed the presentation and some of them did not show interest in trying out the technology themselves. Even though they had fun playing with the puzzle cubes, they did not ask us how to create them. Questions about which tool to use for creating 3D models were rare; instead, the teachers asked about finding already existing models.



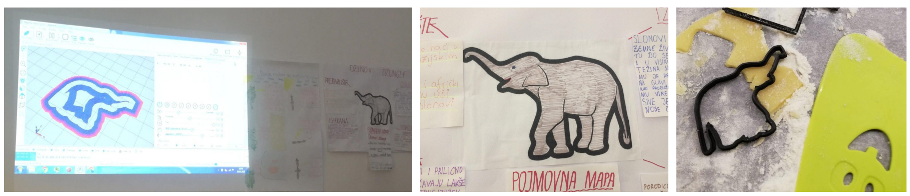
(a) (b) (c) (d)

Figure 3: *(a) Map of Montenegro, (b) the map in CookieCaster, (c) the map as a 3D model, (d) the map of Montenegro as a printed object.*

We thought that a cookie cutter in the shape of Montenegro, as shown in Figure 3, might be relatable and therefore more motivational to them. So we produced a Montenegro cookie cutter on the fly in the first part of the workshop, and then showed them the creation of this specific cookie cutter in the second part.

The Montenegro cookie cutter helped in raising their attention and they started to develop their own cookie cutter ideas. However, we still did not get any questions about how more complex shapes can be created for 3D printing. We kept printing the Montenegro cookie cutter during the theoretical presentation, in the following workshops, but we felt that we might need something more.

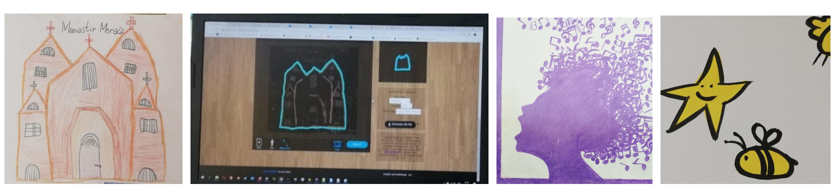
Now that we knew that a familiar image worked better and that it made the teachers make more effort, we thought about how to increase this effect. We searched for something they would not expect in a presentation and that was even more personal to them. We added a picture from a student's painting at the first presentation which surprised and impressed the teachers, we thought about using art from the schools to raise attention. The teachers were excited that we were able to use a picture from their school on a presentation slide without having visited the school previously. Our approach to add this excitement to the learning experience of the teachers was by using artwork we found in the schools for the creation of a cookie cutter.



(a) (b) (c)

Figure 4: *(a) Our first cookie cutter generated from wall art in a school, (b) the picture in more detail and (c) the cookie cutter print of the first part of the workshop later tested for christmas applications.*

During the first part of the workshop, we searched the school for pictures or posters the school had put up looking for artwork with a clear outline. The first art we used to explain 3D printing was the drawing of an elephant we found directly beside the projection of the presentation as shown in Figure 4. Since the elephant picture was right beside the projection, the teachers had a direct link between the image and the 3D model. This direct connection allowed them to observe principles such as scaling, rotation, layer thickness, and printing time. This workshop featuring the elephant picture was set in the late afternoon so we expected an average to short duration. In contrast, it took longer than the workshop we had on the same day in another school due to teachers' motivation. They were eager to develop their own cookie cutter ideas and worked collaboratively, sharing their expertise with each other.



(a) (b) (c) (d)

Figure 5: *(a) Artwork from a poster about a monastery (b), the monastery processed in CookieCaster. (c) Art near a music classroom, (d) art on a school hallway.*

We kept utilizing this elephant experience in later workshops by creating simple printable items out of art we found in schools. Each school we visited displayed art by either students or teachers which we were able to use for the creation of cookie cutters, examples shown in Figure 5 a, c, d.

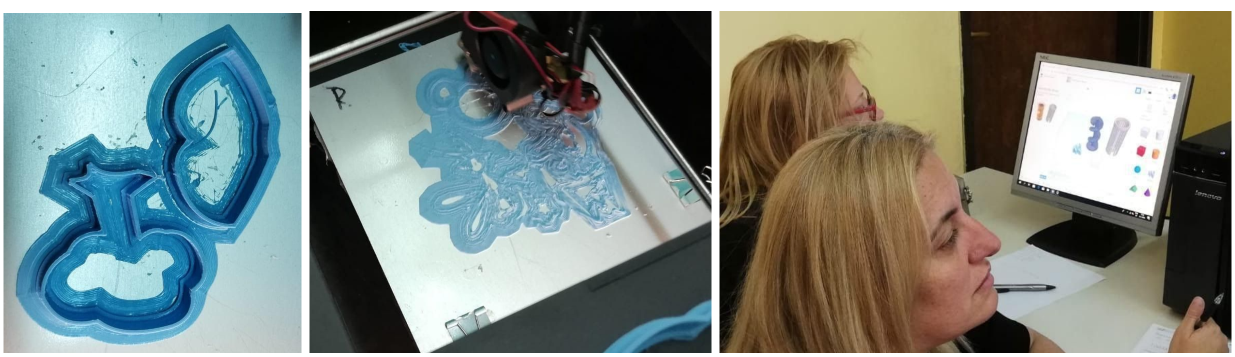
Results

During the first workshops, teachers passively listened to our presentations, and we were sometimes asked only to present theory. They hesitated to create their own 3D models and use the 3D printer. In contrast, when using the art from schools as a motivator, teachers were more engaged. After using the technique to gather images and art from around the school, we experienced a higher motivation and longer alertness. Our perception was that teachers were positively surprised when using art from their school in the workshops.

The improvements we perceived were:

- Teachers started asking questions more frequently, which we used on the fly for the FAQ section.
- The workshops took longer: while they were about three to four hours before, they then took four to six hours. Even workshops late in the evening were longer.
- Teachers were not satisfied with creating simple models, they demanded to be shown more complex tools than CookieCaster.
- The teachers responsible for 3D printing learned how to use the printer more intensely because they had more objects to train with.
- They understood quicker how to avoid unprintable parts and create usable cookie cutters.

The last workshop's motivation was especially high, likely because we were more experienced at understanding teacher's needs. In the beginning of this final workshop, teachers first made critical comments regarding the technology. After taking a picture of a monastery from their students' artwork as shown in Figure 5 a, they engaged intensely in the process. This again led to the creation of many cookie cutters and they were highly interested in the generation of modeling more complex shapes.



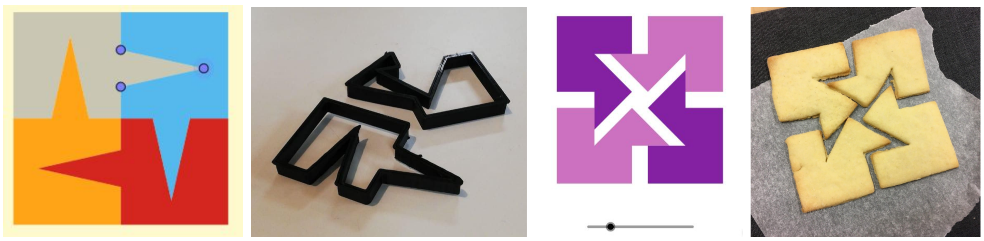
(a) (b) (c)

Figure 6: *(a) Some cookie cutter examples from teachers, (b)printing practice with more cookie cutters from teachers. (c) Teachers exploring more complex shapes in TinkerCAD.*

After showing them TinkerCAD and assisting them in the creation of more complex objects, as shown in Figure 6 c, they had many questions and wanted to practice even more complex 3D modeling. We introduced OpenSCAD to the teachers which can be useful in teaching geometry and programming. This workshop took six hours which was twice the time of the first workshop's duration due to the teacher's engagement and requests for more exercises.

Conclusions and Outlook

We combined 3D printing and art displayed in schools to introduce 3D modeling to teachers by creating cookie cutters. Based on their feedback, a rise in engagement and questions, an increased number of created models, and longer workshop times, we consider the approach to have a positive effect on motivation. Using art to create 3D models additionally inspired teachers to collaboratively create their own tools to utilize in their lessons. This showed us that using art as a motivating factor can help teachers to focus on and enjoy the opportunities of a technology and overcome resentments. In the future, we want to learn more about a teacher's needs and expectations using technologies by evaluating questionnaires.



(a) (b) (c) (d)

Figure 6: *(a) A GeoGebra applet about disecting a cube, (b) turned into cookie cutters ,(c) another dissection of a cube, (d) cube parts turned into an edible cookie puzzle.*

Another future prospect we want to investigate is a possible benefit to students' motivation of creating cookie cutters using 3D printing. In addition to the discussed use case, cookie cutters can not only be used to practice geometric maths and Bezier curves. Puzzle cubes which can be created using GeoGebra and the creation of cookie cutters in the same shape, as shown in Figure 6, could assist in learning the transition from a virtual to a physical world. The link between mathematical optimisation problems like the usage of dough and geometrical cookie cutters can be tackled in a fun way in the classroom. We believe this application of constructivism and computational thinking in combination with cookies could be especially motivating for students of a younger age.

Acknowledgements

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In this project we conducted workshops involving around 200 teachers in 10 schools in Montenegro and Bosnia. The goal was to enable teachers from inclusive schools to develop and produce customized materials for their students.

Implementing organizations:

- School “Radojica Perović”, Podgorica, Montenegro
- Johannes Kepler University, Linz, Austria
- State Publishing House – Textbook and Teaching Aids, Podgorica, Montenegro
- Elementary School “Zalik”, Mostar, Bosnia and Herzegovina
- NGO “CELULA”, Montenegro.

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