

3D pens, stereometry, and primary school students: Results of a project

Emmanuel Fokides, Zoopigi Magkafa
fokides@aegean.gr, zwh.magafa@gmail.com

University of the Aegean, Department of Primary Education

Abstract

Students face quite a lot of problems in understanding concepts related to stereometry. 3D pens can be used in the teaching of a variety of subjects, providing better visualization of abstract concepts, while offering hands-on experiences to students. In light of the above, a project was implemented the objective of which was to examine whether 3D pens have an impact on students' learning of stereometry-related concepts. The target group was fifty primary school students aged 10 to 12. A within-subjects research design with two treatments was followed, meaning that the same students used two tools, namely 3D pens and conventional materials. It was found that, indeed, 3D pens can produce better learning outcomes compared to conventional materials. In addition, their impact on students' enjoyment while learning and on their motivation to learn was also positive, although they were harder to use than conventional materials. While the above results provide evidence for the educational value of 3D pens, further research is needed to find methods of integrating them into teaching and exploiting their educational potential.

Keywords: 3D pens, geometry, learning, primary school, stereometry

Introduction

The study of topics related to spatial geometry (stereometry), is an important branch of Mathematics education. Although it starts in the first grades of primary school, both students and teachers face quite significant problems. The former have trouble understanding concepts related to solid objects (e.g., how they are generated, their properties, and their elements), while the latter have trouble finding effective tools/methods to teach them. As far as students are concerned, most of their problems are because of their undeveloped spatial thinking (Gorovenko et al., 2021). Quite interestingly, this applies even to students whose academic performance is above average (Božić, 2019).

Visualization as well as multiple representation methods and tools are commonly employed in an effort to help students grasp concepts related to stereometry and overcome their difficulties. The role of technology is also very important. In fact, it can change the way Mathematics is taught as it facilitates learning while acting as a tool for collecting, organizing, and evaluating information to solve problems (Young, 2017). Moreover, technology provides dynamic tools, which can be used to improve students' attitudes toward mathematics, increase their motivation and improve their performance in mathematical activities (Ersoy & Akbulut, 2014).

A promising technology whose introduction into the educational environment is easy, due to its low cost, is that of 3D pens. Indeed, 3D pens can be applied in several areas of education such as Mathematics (e.g., Ng & Ferrara, 2020), STEM (e.g., Fidan et al., 2020), Chemistry (e.g., Oliveira et al., 2020), and Biology (e.g., Dousay & Weible, 2019). However, their educational value in subjects related to stereometry has not been sufficiently explored, especially when it involves primary school students.

Thus, it was deemed necessary to examine the educational use of 3D pens in the teaching of subjects related to stereometry, having as a target group fifth and sixth-grade (ten to twelve years old) primary school students. It has to be noted that the project builds upon the experiences gained in a previously

conducted pilot study having a similar target group and teaching subject. Details about the method that was followed and the results that were obtained are presented and discussed in the coming sections.

Background

Stereometry teaching/learning

Setting aside all the other problems students face when they learn maths, solid figures/objects pose additional ones. With regard to topics related to plane geometry, flat geometric figures can be relatively easily imagined and depicted on a plane. Alas, this does not hold true for stereometric figures, rendering hard the process of constructing them and solving stereometry problems. Marchis (2012) found that even adults have trouble drawing solid objects and describing their properties. Additionally, drawing a 3D object on a 2D medium (e.g., on a piece of paper) may lead to uncertainties and misunderstandings, because some details might not be accurately depicted. This, in turn, increases the likelihood of students not being able to understand the related concepts (Gorovenko et al., 2021).

Not only that, but students, especially the younger ones, have a yet not-well-developed spatial perception and reasoning. For example, it is difficult for them to imagine the spatial position of points, lines, and planes (Gorovenko et al., 2021). They also find it hard to imagine a solid and mentally "open"/spread it (Rososzczuk, 2015). Spatial reasoning depends on factors such as orientation in 3D space, the ability to find relationships, and the ability to transform objects (Clements & Battista, 1992; Pittalis & Christou, 2010). Cheng and Mix (2014) highlighted the importance of spatial reasoning, claiming that it has a significant impact not only on the learning of stereometry but also on Mathematics in general. Moreover, the mental visualization of solid objects (spatial imagination) is fundamental for understanding geometry in general. It depends on several factors such as spatial perception, the ability to recognize the individual geometric shapes of complex objects, the skill of mentally working with shapes, and the ability to find the properties and the relations between shapes (Vallo et al., 2015). As with spatial reasoning, spatial imagination is not well-developed in younger students (Chavez et al., 2005), rendering the understanding of stereometry concepts even harder. What is more, students lack the ability to realize how planimetric and solid objects are related and the skills required to work on projection drawings are insufficiently developed (Shabanova et al., 2020).

The teachers also consider stereometry a difficult-to-teach subject (Salman, 2009). Some suggested that given the difficulties students face and although they do not have well-developed spatial reasoning, the teaching of concepts related to stereometry should start as early as possible, even at the expense of the propaedeutic lessons related to geometry (Saparboev, 2020). Nevertheless, teachers employ several visualization techniques, with sketches/drawings being the most commonly used. That is because drawings are important for describing, understanding, and explaining the properties solid objects have (Kurtuluş & Uygan, 2010). Yet, drawings are not that effective, at least when compared to 3D wireframe models (Božić, 2019). Together with the fact that emphasis is given to the realistic representation of a solid object, the use of ICT tools seems logical. Indeed, the use of software for improving the teaching of stereometry has been the subject of a quite large number of studies (e.g., Gorovenko et al., 2021; Nikoloudakis et al., 2020; Rososzczuk, 2015; Shabanova et al., 2020). Dynamic geometry tools allow not only for the accurate and multiple representations of solid objects but also allow for the dynamic manipulation of their properties (e.g., rotation and size). The above, in turn, seems to have a positive impact on students' visual thinking, and, subsequently, on their understanding of stereometry subjects (Gorovenko et al., 2021).

3D pens

A variant of 3D printing technology is 3D pens, portable handheld devices which extract hot plastic or photopolymer resin at a constant rate at a point in the 3D space defined by their operators, allowing the creation of 3D objects (Dean et al., 2016). In other words, they are gadgets like hot glue guns, that extend the idea of drawing, because they provide the ability to draw not only on a flat surface but also in space (Horvath & Cameron, 2018). Some of their key advantages are their low cost (15-30€) and small size, which makes them easy to use and more affordable to replace, unlike 3D printers (Oliveira et al., 2020; Sousa et al., 2020). No software is needed and there is no need for detailed and hard-to-learn settings (e.g., leveling the printing bed); thus, they are more user-friendly (Fidan et al., 2020; Imeri et al., 2017). Moreover, 3D printers are very slow; in contrast, the speed with which a 3D pen produces an object depends on the movements of the user's hands.

On the other hand, in order to make an object, one has to practice and understand how a 3D pen operates; it is not uncommon for beginners to find it difficult to handle it (Okubo & Mizuno, 2018). Even more practice is required to create refined objects (Imeri et al., 2017). Therefore, they need some support to become adept users (Okubo & Mizuno, 2018). Even experts usually create 3D models by first drawing 2D sections and then assembling them to make the final model (Dean et al., 2016). Models of even simple objects tend to be fragile and there is no certainty about how practical a 3D pen can be for more complex tasks (Imeri et al., 2017; Horvath & Cameron, 2018). Therefore, there are doubts about the utilization of 3D pens in large-scale designs (Ng & Sinclair, 2018; Aguilar et al., 2020).

In addition, some safety issues may arise, as the nozzle is rather hot (around 240°C); thus, burns may occur (Horvath & Cameron, 2018). However, with proper guidance and supervision, this risk can be minimized (Dean et al., 2016). The edge of the 3D pen tends to become clogged and the device may jam during use (Fidan et al., 2020). Because 3D pens are controlled manually, the lack of precision makes their use in science and other fields difficult (Bernard & Mendez, 2020; Ng & Sinclair, 2018).

Nevertheless, it is safe to say that 3D pens are not seasonal gadgets. Their multifunctionality, convenient size, and affordable price render them an interesting alternative to 3D printers (Soldatov, 2017). In addition, while these devices are commonly marketed as "toys for children" (Sousa et al., 2020), they can be used in the teaching of many disciplines, such as geometry, crafts, arts, and biology (Tumas, 2018).

3D pens in education

The use of 3D pens in education is underpinned by several learning theories that emphasize active, experiential, and constructivist approaches to learning. These theories provide a framework for understanding how 3D pens can enhance educational experiences by promoting engagement, creativity, and deeper understanding of complex concepts. Firstly, the constructivist learning theory is the primary foundation for using 3D pens in education. This theory posits that learners construct knowledge through experiences and interactions with their environment. The hands-on nature of 3D pens allows students to engage in active learning by creating tangible models, which can help solidify abstract concepts into concrete understanding (Chun, 2022).

Additionally, the theory of embodied cognition is relevant in the context of 3D pens. Embodied cognition suggests that cognitive processes are deeply rooted in the body's interactions with the world. The physical act of drawing with a 3D pen can support learning by engaging motor skills and sensory feedback, which are crucial for understanding spatial and geometric concepts. As this theory supports the idea that learning is not just a mental activity but involves the whole body, it provides an explanation why 3D pens are a valuable tool for kinesthetic learners (Ng & Sinclair, 2018).

Moreover, the social constructivist theory, which emphasizes learning as a social process, is also applicable. According to this theory, knowledge is constructed through collaboration and dialogue

with others. The use of 3D pens in group projects or collaborative settings can foster communication and teamwork, as students work together to design and create models (Chen et al., 2021).

Finally, the theoretical foundations for the educational uses of 3D pens can also be found in experiential learning. The idea that education should be connected to real-world activities is originally attributed to Dewey (1902). Papert also emphasized the importance of learning through experiences (Papert & Harel, 1991). 3D pens help students acquire various skills through experiential learning, visualization, and learning by doing (Imeri et al., 2017). Not only that, but they allow users to produce physical objects out of imaginary or virtual ones, that can be experienced tangibly; this can lead to new forms of thinking (Dilling & Witzke, 2020).

Creative teaching means using imaginative approaches in order to make learning more interesting and effective (Joubert, 2001). Therefore, teachers can design activities that encourage students to create content related to specific science concepts. Indeed, teachers have noted that students prefer practical activities (de Souza Fleith, 2000). Ng and Ferrara (2020), through their research on 3D pens and what is learning as creation, demonstrated that physical objects enhanced students' understanding of mathematical ideas. This goes beyond the sociocultural assumptions that put students at the center of an activity and view the materials as mediators of learning. According to the authors, the materials are actively involved in mathematics and mathematical thinking. Reflecting on the implications of learning that arise through creation, they agree with Papert that creation enables students to become knowledge producers.

Drawing in 3D space, frees one's hand from the constraints that exist due to the use of paper and pencil (Ng & Sinclair, 2018), enhancing the experience of 2D designing. A shape drawn using paper and pencil can be turned into a physical object that can be held, moved, and rotated. This allows students to interact with objects in ways that were not possible with paper and pencil. This, in turn, allows for a better understanding of concepts that otherwise are difficult to grasp (Ng & Sinclair, 2018). In addition, Yavuz et al. (2020) reported that when students designed their objects, this created better visual memories, accelerated the assimilation process, and empowered other senses; thus, their experiences were enhanced. According to Stork et al. (2018), carefully planned and carried-out activities with 3D pens have the potential to increase students' motivation, enjoyment, collaboration, and creativity, which can lead to the improvement of their academic achievements.

In fact, 3D pens were used for the teaching of a variety of subjects. For example, they were used for introducing biomedical engineering to high school students, who worked for creating prosthetic limbs for their toys (Fidan et al., 2020). In chemistry teaching, students were able to draw most molecules with minimal errors (Bernard & Mendez, 2020). Similarly, Yavuz et al., (2020), analyzed the effects of 3D applications and pens on the spatial capacity of elementary science education students in organic chemistry classes. The results demonstrated that traditional organic chemistry courses do not have a significant effect on the development of spatial capacity, in contrast to 3D applications. Again, in the context of chemistry teaching, Smiar and Mendez (2016) found that most students had a better understanding of the concepts they were taught. In the field of biology, Dousay and Weible (2019), explored the role of 3D pens in promoting creativity during a lesson on mega-ecosystems, genetics, and heredity. They found that students considered the 3D pens both fun and difficult to use. Imeri et al. (2017) devised activities with 3D pens for fifth and sixth graders to learn more about engineering. The participating students showed enthusiasm for this technology. Jaksic (2015) examined the use of 3D pens for the enhancement and repair of 3D objects. Students gained hands-on experience and found 3D pens useful for post-processing their objects. In the context of history teaching, Horvath and Cameron (2018) used 3D pens for students to make Viking ships.

There are also examples in which 3D pens were used for the teaching of mathematical concepts. Students created objects and participated in research-based learning activities, where the concepts involved were the properties of prisms and cross-sections (Ng & Ferrara, 2020). The results showed that students did not perceive the above concepts as being abstract, but as something concrete that

arose from their hands and the objects they created. In the research of Ng and Sinclair (2018), 3D pens were used by students in the last grade of a secondary school in an activity related to the investigation of the properties of quadratic functions. The authors argued that the use of 3D pens allowed students to use gestures to explore and develop their understanding in order to draw in 3D space. They also observed new forms of thinking that allowed students to understand the curve and tangents to the curve in both a physical and an abstract sense. Hoopes (2018), investigated the effectiveness of 3D pens as assistive teaching tools during a trigonometry course. The author concluded that these tools were more effective for students who struggle to understand such concepts. In a camp for teaching mathematical modeling, students stated that they liked to be creative and have practical experiences on how to make geometric shapes using 3D pens (Roberts et al., 2018). Yet, it seems that there is a lack of studies in which 3D pens were used for the teaching of stereometry-related subjects having primary school students as the target group.

Method

Reflecting on the research presented in the preceding sections, it can be concluded that 3D pens were used in a variety of learning domains and that they present an interesting educational potential. However, it is also true that the relevant research is still rather unsystematic. Moreover, their use in Mathematics education and comparisons with other tools/materials are limited. Taking together the above, it was decided to extend a previously conducted pilot study and examine more systematically whether 3D pens have a measurable impact on primary school students learning regarding concepts related to stereometry and whether the results are better (or worse) compared to conventional teaching tools/materials. Furthermore, it was deemed important to examine students' learning satisfaction when they use 3D pens. That is because learner satisfaction is a strong predictor of the learning outcomes (Li & Tsai, 2020). Out of the many factors that shape learner satisfaction, it was decided to examine four in this study, namely ease of use, motivation to learn, enjoyment, and subjective usefulness. Thus, the following hypotheses were examined:

- H1. The use of 3D pens results in a better understanding of concepts related to stereometry, compared to conventional teaching materials.
- H2a-d. Students believe that 3D pens compared to conventional teaching materials: (a) offer a more enjoyable learning experience, (b) are more useful (meaning that they facilitate their learning more), (c) are easier to use, and (d) offer them more motivation to learn.

A within-subjects research design with two treatments/conditions was followed. This means that the same students used two tools, namely 3D pens and conventional teaching materials. The reasons for following this design were: (i) smaller sample sizes are required, without compromising the results' validity, (ii) the confounding effects of individual differences are avoided, as the treatments involve the same subjects, and (iii) because the participants function as their own controls, the variance among groups is not an issue (Keren, 2014). To address the disadvantages of within-subjects design, three measures were taken. To avoid the fatigue effect (e.g., students' loss of interest due to previously contacted lessons during their school day), all sessions were conducted on the same days of the week and at the same teaching hours. To avoid the carryover and context effects, the use of the tools was randomized and students were not informed which tool they were going to use in each session. The most important disadvantage is the practice effect. That is because if the learning material is the same in both conditions, participation in the first one almost certainly has a positive impact on the learning outcomes of the second (as students have already learned something). To avoid this, the learning material was not the same in the two conditions, but it was comparable/equivalent. The issue will be further elaborated in section "Materials and apparatus." Moreover, on the basis of the experience gained in the pilot study, it was decided to increase the number of sessions (and their duration, as it will be further elaborated in a coming section) and conduct four per tool, so as to increase the data reliability.

Participants and sample size

An a priori power analysis was conducted for estimating the desired sample size. For that matter, G*power was used and the objective was to be able to detect medium-size effects with more than enough power. On the basis of Cohen's (2013) guidelines, having a within-subjects design with two conditions, four sessions per tool, a f_{Cohen} of .25, a power of .95, and a probability error of .05, the estimated sample size was between twenty-four to fifty students, depending on the correlation among the repeated measures (values between .3 and .7 were used).

The second issue to address was the students' age group. Subjects related to stereometry are taught quite early, but the most complex ones are taught in the last two grades of primary school. Thus, it was decided fifth and sixth-grade students (ages ten to twelve) to be the target group. A total of fifty students were recruited attending a primary school in city omitted for review. It has to be noted that the participating students did not have any prior experience in using 3D pens.

The university's ethical committee provided its approval for the project. Moreover, because the study involved minors, students' parents and legal guardians provided their written consent.

Materials and apparatus

An issue that had to be resolved was related to the study's design and the learning content/material. In between-subjects designs, the material is the same across groups. This cannot be done in within-subjects designs because of the order effect. One way to overcome this problem is to make sure that the learning material in all treatments, though not identical, is as equipollent as possible. This means that it has to have the same activities/tasks, cognitive load, terms/concepts, and difficulty level. As the study's learning/teaching subject was stereometry, two solids were selected, namely the rectangular parallelepiped and the square pyramid. Both can be relatively easily constructed using conventional materials or 3D pens. Moreover, their properties and the mathematical calculations required for estimating their volumes and areas are neither too easy (e.g., as in a cube) nor too hard (e.g., as in a cylinder or sphere). A second measure that was taken was not to teach all the subjects/concepts related to one solid using one tool but to split them and teach half of the concepts using conventional materials and the other half using 3D pens (Table 1). For example, the area of the square pyramid was taught using conventional materials, while its volume was taught using 3D pens. The exact opposite was done for the rectangular parallelepiped.

Saparboev (2020) suggested two types of tasks/assignments: (i) tasks for creating spatial images and (ii) tasks for performing operations on those images. He also suggested that students should be trained to (i) visualize objects in the form of geometric figures, (ii) look at unusual examples, and (iii) break down complex objects into simpler ones. The material included in the school textbooks provided the basis for the development of the study's learning content. Following Saparboev's guidelines, it was re-arranged and enriched with additional activities/tasks, exercises, and images, in order the subjects discussed to be thoroughly presented/examined. The resulting material was transcribed into eight worksheets (four for each tool, one for each session).

Table 1. The learning content per session and per tool

Tool	Session/Learning content
Conventional materials	Rectangular parallelepiped spread
	Faces, edges, and vertices of a square pyramid
	Square pyramid area
	Rectangular parallelepiped volume
3D pens	Pyramid spread
	Faces, edges, and vertices of a rectangular parallelepiped
	Rectangular parallelepiped area
	Square pyramid volume

Although students worked in groups of three (see section "Procedure"), due to budget restrictions each group had two 3D pens at their disposal. As for the conventional materials, these were straws, colored sheets of paper, and plasticines.

Instruments

For examining what students learned, eight quizzes were devised (one for each session). Besides right-wrong and fill-in-the-blanks questions, they included exercises asking students to convert units of measurement, to draw the spread of various solids or to imagine what solids can be created out of given spreads, to calculate the volume, surface, number of faces, edges, and vertices of solids, and to draw solids of given dimensions. A sample of the questions included in these quizzes can be found in Appendix A. A pre-test following the same logic was also devised, having questions from all the subjects/concepts students were going to be taught and it was administered before the beginning of the sessions. That is because it was considered important to control for students' prior knowledge, as it was possible to have been taught similar subjects in previous grades.

For examining H2a-d, a questionnaire was used. It consisted of items examining four factors, namely subjective usefulness, enjoyment, ease of use, and motivation, in accordance with H2a-d. The items were drawn from a validated scale (Fokides et al., 2019), and were adapted to suit the study's needs. A four-point Likert-type scale (strongly disagree = 1 to strongly agree = 4) was used for presenting them. The questionnaire can be found in Appendix B. It was administered two times, during the last time a tool was used.

Procedure

Constructivism and connectivism provide the theoretical foundations for teaching stereometry (Lebamovski & Gospodinov, 2019). The former suggests that group work and students' collaboration on specific tasks allow them to experiment and discover; thus, learning is fostered. The latter, at its core, puts emphasis on experiential learning, prioritizing actions and experiences over the idea that knowledge is propositional (Siemens, 2005). The above, together with Bybee's (2009) 5Es instructional model provided the basis for the study's teaching framework, described below. It has to be noted that in order to avoid difficulties during its implementation, the participating teachers attended a session in which it was described, examples were given, and a teaching session was simulated. Moreover, in a session before the beginning of the project, the participating students were given 3D pens and practiced using them by making 2D and 3D objects (e.g., flowers and animals). This preliminary session was considered important as students did not have any prior experiences in using these devices and also safety issues were discussed.

Students worked in groups of three, and the sessions lasted three teaching hours so that students to have enough time to conduct all the activities and reflect (Figure 1). There were five stages in each session:

- Stage 1, Engage. The teachers introduced the session's main concept(s), presented examples derived from everyday life, and initiated a round of discussion among students. The objective was to trigger students' interest in the topic.
- Stage 2, Explore. During this stage, students studied the material included in the worksheets and recorded their ideas, explanations, and views. For example, they were asked to guess the shape of the spread of the square pyramid (without actually disassembling this solid), make it using 3D pens, and write down their views regarding the number and the type of geometric figures it consists of. In another session, they were asked to name the faces, edges, and vertices of the rectangular parallelepiped and then make one, marking the above with different colors.
- Stage 3, Explain. At this stage, the groups communicated their ideas and conclusions from the previous stage and discussed them with the other groups. When a consensus was reached, the

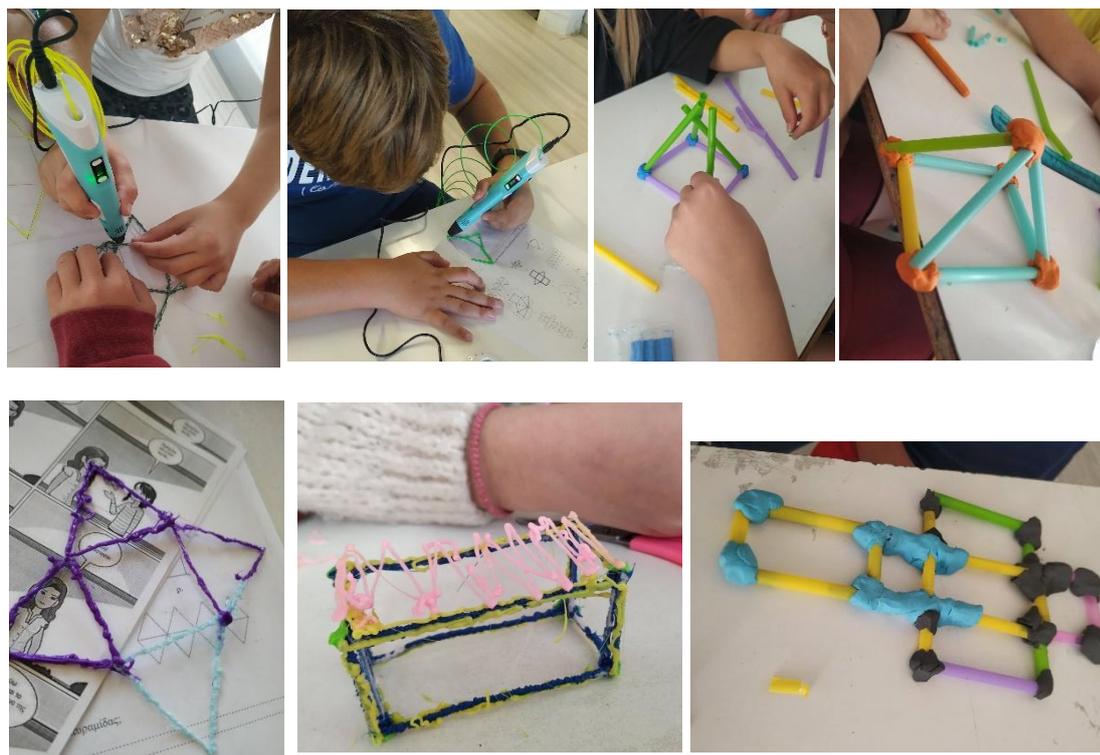


Figure 1. Screenshots from the sessions

groups recorded their final conclusions on the worksheets. In addition, they revisited the artifacts they created and corrected them (or made new ones).

- Stage 4, Extend. The purpose of this stage was to further explore the session's main concepts. For example, they were asked to find alternative spreads of the rectangular parallelepiped and make them. In another session, the groups exchanged their square pyramids and were asked to calculate their areas or volumes. As in the Explore and Explain stages, students recorded their views and presented them to their classmates.
- Stage 5, Evaluate. During the final stage, the teachers and students discussed the problems the latter faced during the previous stages. Moreover, the students solved problems related to the session's concept(s).

The role of the teachers was that of facilitators of the learning process; rather than giving direct answers to students' inquiries, they indirectly guided them through discussions, hints, and by drawing their attention to what was important.

Results

Initial data processing

None of the participants was absent in any session; therefore, all data were eligible for the subsequent analyses. A 100-point scale was used for grading the evaluation quizzes and two new variables were calculated, representing the average student's score per tool. Next, the questionnaires' internal consistency was examined (using Cronbach's α). It was found more than acceptable, as there were no cases in which the α (either the overall or for any factor) dropped below the recommended minimum value of .70 (it was between .76 to .89) (Taber, 2018). Following that, eight new variables were calculated (four for each tool) representing the average score per factor, per participant. SPSS 28 was used for all the analyses presented in the coming sub-sections. Readers can find the descriptive statistics for the study's variables in Table 2.

Table 2. Descriptive statistics for the study's variables

Variable (N = 50)	min	max	M	SD
Pre-test	9.00	54.00	22.88	9.69
Evaluation quizzes 3D pens	44.75	91.75	72.86	9.70
Evaluation quizzes conventional materials	41.25	88.00	67.91	9.92
Enjoyment 3D pens	2.33	4.00	3.42	0.33
Enjoyment conventional	2.33	4.00	3.14	0.45
Usefulness 3D pens	3.00	4.00	3.37	0.24
Usefulness conventional	2.67	4.00	3.27	0.29
Ease of use 3D pens	2.00	3.67	2.54	0.38
Ease of use conventional	3.00	4.00	3.05	0.31
Motivation 3D pens	2.67	4.00	3.44	0.35
Motivation conventional	2.33	4.00	3.22	0.40

As mentioned in a previous section, it was considered necessary to control for the effects of students' prior knowledge on the learning outcomes, as it was possible to have acquired some knowledge in previous grades. Since the experimental setup was within subjects, a repeated measures Analysis of Covariance (ANCOVA) was the appropriate statistical procedure for analyzing the results from the evaluation tests. Before proceeding, it was checked whether the data were suitable for this kind of analysis and no problems were noted. It was also checked whether the questionnaires' data were suitable for repeated measures Analysis of Variance (ANOVA), and, again, no problems were noted.

Analysis of the evaluation tests

The ANCOVA analysis (Table 3), revealed that the main effect of the pre-test was not significant [$F(1, 48) = 0.09, p = .760$], meaning that students' prior knowledge was unrelated to the results in the evaluation tests in both tools. The main effect of the within-subjects factor (the 2 tools students used) was significant [$F(1, 48) = 13.26, p < .001$], indicating that the learning outcomes differed significantly between the two tools (in favor of 3D pens). Moreover, the effect size was large ($\eta_p^2 = .213$).

As expected (because students' prior knowledge was unrelated to the results in the evaluation tests), the interaction effect between students' prior knowledge and the within-subjects factor was not significant [$F(1, 48) = 0.07, p = .795$]. From the above, it can be concluded that students' performance was better when they used 3D pens; thus, H1 is confirmed.

Table 3. Repeated measures ANCOVA results

Source	SS	df	MS	F	p	η_p^2
Between-Subjects						
Pre-test	17.67	1	17.67	0.09	.760	.002
Residuals	9210.67	48	187.97			
Within-Subjects						
Evaluation tests	107.20	1	107.20	13.26	<.001	.213
Pre-test*Evaluation tests	0.553	1	0.553	0.07	.795	.001
Residuals	396.26	48	8.087			

Note. SS = sum of squares; MS = mean square, η_p^2 = partial eta squared effect size

Table 4. Repeated measures ANOVA results

Factor	Source	SS	df	MS	F	p	η_p^2
Enjoyment	Within factor	2.02	1	2.02	34.75	< .001	.410
	Residuals	2.91	49	0.06			
Usefulness	Within factor	0.29	1	0.29	5.16	.027	.094
	Residuals	2.78	49	0.06			
Ease of use	Within factor	6.50	1	6.50	51.54	< .001	.508
	Residuals	6.30	49	0.13			
Motivation	Within factor	1.34	1	1.34	13.86	< .001	.217
	Residuals	4.84	49	1.00			

Analysis of the questionnaires

On the basis of the results presented in Table 4, the following can be concluded:

- Enjoyment. The main effect for this within-subjects factor was significant [$F(1, 49) = 34.75, p < .001$], meaning that students enjoyed the learning process more when they used the 3D pens ($M = 3.42, SD = 0.33$) rather than when they used the conventional materials ($M = 3.14, SD = 0.45$). The effect size was very large ($\eta_p^2 = .410$). Thus, H2a is confirmed.
- Usefulness. The main effect for this within-subjects factor was significant [$F(1, 49) = 5.16, p = .027$], meaning that students considered the 3D pens ($M = 3.37, SD = 0.24$) as being better learning facilitators, compared to the conventional materials ($M = 3.27, SD = 0.29$). The effect size was medium to large ($\eta_p^2 = .094$). As a result, H2b is confirmed.
- Ease of use. The main effect for this within-subjects factor was significant [$F(1, 49) = 51.54, p < .001$], meaning that students considered the conventional materials ($M = 3.05, SD = 0.31$) as being easier to use compared to the 3D pens ($M = 2.54, SD = 0.38$). The effect size was very large ($\eta_p^2 = .508$). Therefore, H2c is rejected.
- Motivation. The main effect for this within-subjects factor was significant [$F(1, 49) = 13.86, p < .001$], meaning that the 3D pens ($M = 3.44, SD = 0.35$) motivated students to learn more than the conventional materials ($M = 3.22, SD = 0.40$). The effect size was large ($\eta_p^2 = .217$). Consequently, H2d is confirmed.

Additional analysis

Given that the previous analyses revealed that there were statistically significant differences between the two tools, regarding both the learning outcomes and the factors that were examined in the questionnaires, an additional analysis was conducted, the purpose of which was to examine the impact of the latter on the former. For that matter, two multiple regression analyses (one for each tool) were performed, using the Enter method. The mean scores in the evaluation tests were treated as the dependent variables, while the questionnaires' factors were treated as the independent ones. As is evident in Table 5, in both tools, except for Usefulness, all the other factors had a statistically significant impact on the learning outcomes.

Table 5. Results of the multiple regression analysis

Model summary		$F(4, 45) = 11.98, p < .001, R = .714, R^2 = .510$				
Factors	<i>B</i>	<i>SE B</i>	β	<i>t</i>	<i>p</i>	
3D Pens	Enjoyment	9.76	3.64	.33	2.68	.010
	Usefulness	0.22	4.92	.01	0.05	.964
	Ease of use	7.60	2.88	.30	2.64	.011
	Motivation	8.96	3.40	.32	2.63	.011
Model summary		$F(4, 45) = 9.91, p < .001, R = .680, R^2 = .463$				
Factors	<i>B</i>	<i>SE B</i>	β	<i>t</i>	<i>p</i>	
Conventional materials	Enjoyment	7.01	2.59	.32	2.71	.009
	Usefulness	0.65	4.05	.02	0.16	.873
	Ease of use	9.54	3.59	.30	2.66	.011
	Motivation	8.83	3.17	.36	2.79	.008

Note. *B* = unstandardized beta coefficient, *SE B* = standard errors for *B*, β = standardized error coefficient

Discussion

A number of interesting observations were brought into light through the results analysis, worth of further discussion. A statistically significant difference in favor of 3D pens was noted regarding the impact the two tools had on students' learning. This finding, provides further support to studies with similar results, either in the context of Mathematics education (e.g., Hoopes, 2018; Ng & Ferrara, 2020; Ng & Sinclair, 2018; Roberts et al., 2018) or in the context of other learning subjects (e.g., Bernard & Mendez, 2020; Fidan et al., 2020; Smiar & Mendez, 2016). Yet, one might say that this difference was not that prominent. Indeed, the difference between the two tools in the evaluation quizzes was less than 7% ($M = 72.86, SD = 9.70$ for 3D pens and $M = 67.91, SD = 9.92$ for conventional materials). While students' prior knowledge was practically insignificant ($M = 22.88, SD = 9.69$ in the pre-test), they were able to answer correctly around 70% of the questions in the evaluation quizzes, regardless of the tool they used. This means that both tools helped them to learn quite a lot. In this respect, skeptics might question the value of 3D pens, and argue that it is not worth the trouble of introducing them in education, given that the already well-established tools (i.e., the conventional materials) produce good results. Others might counter-argue that, in education, even the small differences are important, either because they have a cumulative effect or because it is unknown what impact they might have at a later stage. The above can be viewed as part of the continuing and still unresolved debate regarding the educational value of ICT tools.

Leaving aside this debate, plausible explanations for the study's outcomes have to be provided. This is not an easy task, given that the relevant literature is rather limited. It can be suggested that the teaching method had an impact on the results. Although this assumption is logical, it cannot be used for explaining the differences in the learning outcomes, as the same method was followed for both tools.

It can also be supported that it was the tool per se that made the difference. In fact, others noted that 3D pens helped students to understand to a greater extent some concepts that they found difficult to grasp when paper and pencil or computers were used (Fidan et al., 2020; Hoopes, 2018; Ng & Sinclair, 2018). Then again, this explanation is also not a sound one. In this study, the 3D pens were compared neither with paper and pencil nor with computer applications; students created solids using conventional materials (straws and plasticine). Given that, in both cases, the participating students

acquired knowledge through hands-on experiences as they were creators of physical objects. Therefore, it can be assumed that the benefits suggested by experiential learning (Dewey, 1902; Papert & Harel, 1991), as well as embodied cognition (Ng & Sinclair, 2018), manifested in both cases.

Even though the above do not offer an acceptable explanation for the learning outcomes, the results in the questionnaires can offer one. Generally speaking, learner satisfaction is a predictor of the learning outcomes (Li & Tsai, 2020). In this study, four were examined, namely ease of use, motivation to learn, enjoyment, and subjective usefulness. The data analyses indicated that these factors, except for subjective usefulness, indeed had a positive impact on the learning outcomes of both tools (see Table 5).

Moreover, students' enjoyment was greater when they used 3D pens (see Table 4), confirming past research in which it was found that these devices offer enjoyable learning experiences to users (e.g., Dean et al., 2016; Dousay & Weible, 2019; Fidan et al., 2020, Stork et al., 2018). The same applied to motivation to learn, again confirming past research (e.g., Ng & Ferrara, 2020; Ng & Sinclair, 2018; Stork et al., 2018; Yavuz et al., 2020). Taking together the above, it can be theorized that because students were more motivated to learn and because they enjoyed the learning process more when they used the 3D pens, their learning outcomes were better compared to conventional materials. This argument is in line with Stork et al. (2018), who supported that carefully planned and carried-out activities with 3D pens have the potential to increase students' motivation and enjoyment, which can lead to the improvement of their academic achievements.

Then again, the participating students considered the 3D pens as harder to use as noted in previous studies (e.g., Dean et al., 2016; Dousay & Weible, 2019; Imeri et al., 2017). As this factor also had a positive impact on the learning outcomes, it can be supported that, the results might have been even better if students did not have trouble using the 3D pens.

Implications for research and education

The study contributes to the research regarding Mathematics education as it (i) examined the use of 3D pens for teaching stereometry, which are not often used for this purpose, (ii) quantified the learning outcomes and contrasted them with those of conventional materials, and (iii) quantified the impact of certain factors on the learning outcomes. Because of the above, implications for those involved in the hardware industry, researchers, and education stakeholders can be recognized. For example, it was found that motivation and enjoyment significantly impacted the learning outcomes in both treatments. Consequently, educators can come up with even more interesting and fun activities for further enhancing both factors. Students found the 3D pens less easy to use compared to conventional materials. Though it was not a surprising finding, because it had an impact on the outcomes, those involved in the hardware industry and researchers, have to consider methods for making 3D pens easier to handle and more accurate. They also have to find ways of making them safer to use.

On the basis of the study's findings, it can be supported that the integration of 3D pens into everyday teaching practices is rather appealing. Yet, there are two issues that have to be addressed. First, sound teaching frameworks are needed. In this study, one such was proposed. Then again, researchers can test other frameworks that might prove to be more effective. Second, each session lasted for three teaching hours. Although this allowed all the activities to be conducted in full and meticulously, in real-life conditions this duration is unrealistic. However, it is logical to support that when teaching involves activities in which students have to be creators of artifacts/content, more time than the usual one-teaching hour is needed. Education policymakers and professionals working in the education sector need to realize this and reform the curricula structure and time allocation accordingly.

Limitations and future work

The study is subject to a number of limitations, the first one being the sample size. Although it was adequate (from a statistical standpoint), it could have been larger, allowing for more confidence in the results. The same can be said for the number of sessions. Only a limited number of stereometry concepts were tested; thus, it is unknown how students might have performed in different ones. Moreover, the focus was on a specific age group; therefore, the generalizability of the results can be questioned.

The above can serve as guidelines for future research. Diverse age groups and subjects, as well as larger sample sizes and an increased number of sessions, will provide more concrete evidence for the educational value of 3D pens. The attitudes of students and educators towards these devices are also worth exploring. The same applies to other teaching frameworks which might prove to be more effective. Comparative studies contrasting the results of 3D pens and other technology tools will also be interesting. Finally, longitudinal studies are definitely needed. That is because technology gadgets are prone to what is called the "wow effect," which is the overexcitement of students when they use for the first time a technological artifact (Kamstrupp, 2016). The wow effect can have a diverse impact on the results, although it diminishes over time.

Conclusion

In the study at hand, 3D pens were used, in order to examine their impact on students' learning in subjects related to stereometry. Their relative ease of use and their low cost are their biggest advantages. The results of comparing 3D pens and conventional teaching materials demonstrated that the former produced better learning outcomes. Furthermore, students enjoyed the learning process and were more motivated to learn. On the negative side, the conventional materials proved to be easier to use, although this was expected. In conclusion, despite its limitations, the study contributes to the existing, but limited, body of research, on the impact of 3D pens on Mathematics education, confirming that these devices have an interesting educational potential. Apparently, there is room for further research to explore both the possibilities they offer and how they can be integrated into everyday teaching.

References

- Aguilar, L. G., Petroni, J. M., Ferreira, V. S., & Lucca, B. G. (2020). Easy and rapid pen-on-paper protocol for fabrication of paper analytical devices using inexpensive acrylate-based plastic welding repair kit. *Talanta*, *219*, 121246. <https://doi.org/10.1016/j.talanta.2020.121246>
- Bernard, P., & Mendez, J. D. (2020). Drawing in 3D: Using 3D printer pens to draw chemical models. *Biochemistry and Molecular Biology Education*, *48*(3), 253-258. <https://doi.org/10.1002/bmb.21334>
- Božić, R. (2019). The application of modern technology in teaching and learning stereometry. In J. Milinković & Z. Kadelburg (Eds.), *Proceedings of the Scientific Conference Research in Mathematics Education* (pp. 102-111). Mathematical Society of Serbia.
- Bybee, R. W. (2009). *The BSCS 5E instructional model and 21st century skills: A commissioned paper prepared for a workshop on exploring the intersection of science education and the development of 21st century skills*. BSCS org. https://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_073327.pdf
- Chavez, O., Reys, R., & Jones, D. (2005). Spatial visualization: What happens when you turn it? *Mathematics Teaching in the Middle School*, *11*(4), 190-196. <https://doi.org/10.5951/MTMS.11.4.0190>
- Chen, J., Xiang, S., Yuan, Y., & Zeng, Y. (2021). The exploration and practice of 3D printing pen in primary school education. *Proceedings of the International Conference on Diversified Education and Social Development (DESD 2021)*, 6-11. Atlantis Press. <https://doi.org/10.2991/assehr.k.210803.002>
- Cheng, Y. L., & Mix, K. S. (2014). Spatial training improves children's Mathematics ability. *Journal of Cognition and Development*, *15*(1), 2-11. <https://doi.org/10.1080/15248372.2012.725186>
- Chun, H. (2022). A study on the design education method using 3D pen in an era of manufacturing change. *Nanotechnology for Environmental Engineering*, *7*(2), 461-465. <https://doi.org/10.1007/s41204-021-00174-5>

- Clements, D. H., & Battista, M. T. (1992). Geometry and spatial reasoning. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 420-464). Macmillan.
- Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Routledge. <https://doi.org/10.4324/9780203771587>
- de Souza Fleith, D. (2000). Teacher and student perceptions of creativity in the classroom environment. *Roeper Review*, 22(3), 148-153. <https://doi.org/10.1080/02783190009554022>
- Dean, N. L., Ewan, C., & McIndoe, J. S. (2016). Applying hand-held 3d printing technology to the teaching of VSEPR theory. *Journal of Chemical Education*, 93(9), 1660-1662. <https://doi.org/10.1021/acs.jchemed.6b00186>
- Dewey J. (1902). *The child and the curriculum*. The University of Chicago Press.
- Dilling, F., & Witzke, I. (2020). The use of 3D-printing technology in calculus education: Concept formation processes of the concept of derivative with printed graphs of functions. *Digital Experiences in Mathematics Education*, 6, 320-339. <https://doi.org/10.1007/s40751-020-00062-8>
- Dousay, T. A., & Weible, J. L. (2019). Build-a-bug workshop: Designing a learning experience with emerging technology to foster creativity. *TechTrends*, 63(1), 41-52. <https://doi.org/10.1007/s11528-018-0364-8>
- Ersoy, M., & Akbulut, Y. (2014). Cognitive and affective implications of persuasive technology use on mathematics instruction. *Computers & Education*, 75, 253-262. <https://doi.org/10.1016/j.compedu.2014.03.009>
- Fidan, P., Wendt, S. L., Wendt, J., & Fidan, I. (2020). Enhancing STEM education: Learning about biomedical engineering with 3-D Pens (resource exchange). *Proceedings of the 2020 ASEE Virtual Annual Conference Content Access*. ASEE. <https://doi.org/10.18260/1-2--34573>
- Fokides, E., Atsikpasi, P., Kaimara, P., & Deliyannis, I. (2019). Let players evaluate serious games. Design and validation of the serious games evaluation scale. *International Computer Games Association Journal*, 41(3), 116-137. <https://doi.org/10.3233/ICG-190111>
- Gorovenko, L. A., Aleksanyan, G. A., & Rovenskaya, O. P. (2021). Arrangement of the learning process within the framework of stereometric topics of Mathematics based on dynamic applets. *Proceedings of the Second Conference on Sustainable Development: Industrial Future of Territories (IFT 2021)*, 658-662. Atlantis Press. <https://doi.org/10.2991/aebmr.k.211118.116>
- Hoopes, E. (2018). *The effects of using 3D printed manipulatives in college trigonometry* [Doctoral dissertation, Youngstown State University].
- Horvath, J., & Cameron, R. (2018). *Mastering 3D printing in the classroom, library, and lab*. Apress. <https://doi.org/10.1007/978-1-4842-3501-0>
- Imeri, A., Russell, N., Rust, J., Sahin, S., & Fidan, I. (2017). MAKER: 3D pen utilization in 3D printing practices. *Proceedings of the 2017 ASEE Virtual Annual Conference Content Access*. ASEE.
- Jaksic, N. I. (2015). BYOE: Using 3D pens for enhancement and rework of 3D-printed parts. *Proceedings of the 2015 ASEE Annual Conference & Exposition* (pp. 26-317). ASEE. <https://doi.org/10.18260/p.23656>
- Kamstrupp, A. K. (2016). The wow-effect in science teacher education. *Cultural Studies of Science Education*, 11, 879-897. <https://doi.org/10.1007/s11422-015-9684-6>
- Keren, G. (2014). Between-or within-subjects design: A methodological dilemma. In G. Keren & C. Lewis (Eds.), *A handbook for data analysis in the behavioural sciences* (pp. 257-272). Psychology Press. <https://doi.org/10.4324/9781315799582-14>
- Kurtuluş, A., & Uygan, C. (2010). The effects of google sketchup based geometry activities and projects on spatial visualization ability of student mathematics teachers. *Procedia-Social and Behavioral Sciences*, 9, 384-389. <https://doi.org/10.1016/j.sbspro.2010.12.169>
- Li, D. C., & Tsai, C. Y. (2020). An empirical study on the learning outcomes of e-learning measures in Taiwanese small and medium-sized enterprises (SMEs) based on the perspective of goal orientation theory. *Sustainability*, 12(12), 5054. <https://doi.org/10.3390/su12125054>
- Marchis, I. (2012). Preservice primary school teachers' elementary geometry knowledge. *Acta Didactica Naporensia*, 5(2), 33-40.
- Ng, O. L., & Ferrara, F. (2020). Towards a materialist vision of 'learning as making': The case of 3D printing pens in school mathematics. *International Journal of Science and Mathematics Education*, 18(5), 925-944. <https://doi.org/10.1007/s10763-019-10000-9>
- Ng, O. L., & Sinclair, N. (2018). Drawing in space: Doing mathematics with 3D pens. In *Uses of technology in primary and secondary mathematics education* (pp. 301-313). Springer. https://doi.org/10.1007/978-3-319-76575-4_16
- Nikoloudakis, E., Choustoulakis, E., Kontadaki, S., & Nikoloudakis, D. (2020). Leveraging ICT to improve the understanding of stereometry among students in primary education. *International Journal of Novel Research in Education and Learning* 7(4), 33-44.
- Okubo, M., & Mizuno, Y. (2018). Influence of interactive learning support system using augmented reality on 3D object drawing. *Journal of Advanced Mechanical Design, Systems, and Manufacturing*, 12(6), 110. <https://doi.org/10.1299/jamdsm.2018jamdsm0110>
- Oliveira, F. M., Melo, E. I., & Silva, R. A. (2020). 3D Pen: A low-cost and portable tool for manufacture of 3D-printed sensors. *Sensors and Actuators B: Chemical*, 321, 128528. <https://doi.org/10.1016/j.snb.2020.128528>
- Papert, S., & Harel, I. (1991). Situating constructionism. *Constructionism*, 36(2), 1-11.
- Pittalis, M., & Christou, C. (2010). Types of reasoning in 3D geometry thinking and their relation with spatial ability. *Educational Studies in Mathematics*, 75(2), 191-212. <https://doi.org/10.1007/s10649-010-9251-8>

- Roberts, T., Jackson, C., Mohr-Schroeder, M. J., Bush, S. B., Maiorca, C., Cavalcanti, M., Schroeder, D. C., Delaney, A., Putnam, L., & Cremeans, C. (2018). Students' perceptions of STEM learning after participating in a summer informal learning experience. *International journal of STEM education*, 5(1), 1-14. <https://doi.org/10.1186/s40594-018-0133-4>
- Rosozczuk, R. (2015). Application of Cabri 3D in teaching stereometry. *Advances in Science and Technology Research Journal*, 9(26), 148-151. <https://doi.org/10.12913/22998624/2382>
- Salman, M. F. (2009). Active learning techniques (ALT) in a Mathematics workshop; Nigeria primary school teacher's assessment. *International Electronic Journal of Mathematics Education*, 4(1), 23-35. <https://doi.org/10.29333/iejme/228>
- Saparboev, J. (2020). Levels and criteria of development of students' spatial representation in teaching geometry. *European Journal of Research and Reflection in Educational Sciences*, 8(4), 106-111.
- Shabanova, M., Bezumova, O., Kotova, S., & Zatsepina, E. (2020). Augmented reality in teaching and learning stereometry: the experience of the pilot schools. *Proceedings of the ICERI2020*, 1054-1062. IATED. <https://doi.org/10.21125/iceri.2020.0298>
- Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology & Distance Learning*, 2(1), 1-9.
- Smiar, K., & Mendez, J. D. (2016). Creating and using interactive, 3D-printed models to improve student comprehension of the Bohr model of the atom, bond polarity, and hybridization. *Journal of Chemical Education*, 93(9), 1591-1594. <https://doi.org/10.1021/acs.jchemed.6b00297>
- Soldatov, A. (2017). The use of 3D pen in the process of teaching technology students. *Proceedings of Olympiáda techniky Plzeň 2017*, 133-137. DSpace University of West Bohemia.
- Sousa, L. R., Duarte, L. C., & Coltro, W. K. (2020). Instrument-free fabrication of microfluidic paper-based analytical devices through 3D pen drawing. *Sensors and Actuators B: Chemical*, 312, 128018. <https://doi.org/10.1016/j.snb.2020.128018>
- Stork, M. G., Goode, H., Jeter, R., & Zhang, J. (2018). Embracing the power of digital in literacy education: Evaluating the effectiveness of digital activities. *Journal of Formative Design in Learning*, 2(2), 82-101. <https://doi.org/10.1007/s41686-018-0022-8>
- Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education*, 48(6), 1273-1296. <https://doi.org/10.1007/s11165-016-9602-2>
- Tumas, A. (2018). *Improving learning processes at schools by integrating new technologies: Case: Grib Oy* [Bachelor's thesis, Lahti University of Applied Sciences].
- Vallo, D., Rumanova, L., & Duris, V. (2015). Some spatial competencies and formalism in solutions of stereometrical tasks. *Procedia-Social and Behavioral Sciences*, 197, 2320-2324. <https://doi.org/10.1016/j.sbspro.2015.07.260>
- Yavuz, S., Büyükeksi, C., & Çolakoğlu, Ö. (2020). Effect of 3D applications in organic chemistry lesson on students' spatial ability. *Online Science Education Journal*, 5(1), 1-8.
- Young, J. R. (2017). Technology integration in mathematics education: Examining the quality of meta-analytic research. *International Journal on Emerging Mathematics Education*, 1(1), 71-86. <https://doi.org/10.12928/ijeme.v1i1.5713>

Appendix A

Sample questions from the quizzes

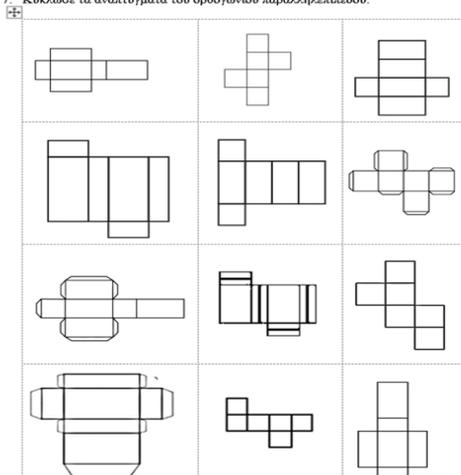
Κατασκευάσε με τη βοήθεια χαρτίου ή χαρτονιού μια τετραγωνική πυραμίδα με εμβαδόν ολικής επιφάνειας μεταξύ 20 τ.εκ. και 50 τ.εκ.

Γράψε τι τιμές (αριθμούς) χρησιμοποιήσες για:

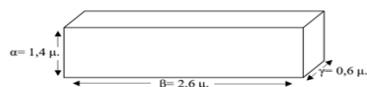
α. το μήκος των πλευρών της βάσης της τετραγωνικής πυραμίδας;

β. το ύψος της παράπλευρης έδρας (απόστημα) της τετραγωνικής πυραμίδας;

7. Κόκλωσε τα αναπτύγματα του ορθογώνιου παραλληλεπίπεδου:

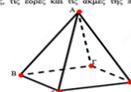


2. Πόσα τετραγωνικά μέτρα (τ.μ.) ύφασμα χρειαζόμαστε για να ντύσο:



- την παράπλευρη επιφάνεια του ορθογώνιου παραλληλεπίπεδου της παραπάνω εικόνας;
- τις επιφάνειες των δύο βάσεων του ορθογώνιου παραλληλεπίπεδου της παραπάνω εικόνας;
- την ολική επιφάνεια του ορθογώνιου παραλληλεπίπεδου της παραπάνω εικόνας;

10. Γράψε τις κορυφές, τις έδρες και τις ακμές της παρακάτω τετραγωνικής πυραμίδας:



Κορυφές:	
Έδρες:	
Ακμές:	

11. Σημτώσε με Σ (Σωστό) ή Λ (Λάθος) τους παρακάτω ισχυρισμούς:

α. Η τριγωνική και η τετραγωνική πυραμίδα έχουν τον ίδιο αριθμό ακμών.	
β. Η τριγωνική και η τετραγωνική πυραμίδα έχουν διαφορετικό αριθμό κορυφών.	
γ. Η τριγωνική και η τετραγωνική πυραμίδα έχουν διαφορετικό αριθμό έδρων.	
δ. Η τριγωνική και η τετραγωνική πυραμίδα έχουν τον ίδιο αριθμό ακμών, έδρων και κορυφών.	

Appendix B

The questionnaire's items

Factor	Item
Enjoyment	It was fun to view the learning material using this device*
	I felt bored while viewing the learning material using this device **
	I really enjoyed studying with this device
	I felt frustrated while viewing the learning material using this device **
Effectiveness	I felt happy while viewing the learning material using this device
	I felt that this device facilitated my learning
	With this device, it was much easier to learn compared to the usual teaching
	This device made learning more interesting
	I felt that this device helped me to increase my knowledge of the subjects it presented
	With this device, I felt that I understood the basics of what I was taught
	I will definitely try to apply the knowledge I learned with this device
Ease of use	It was easy to learn how to use this device
	The device was not complicated at all
	I think that most will quickly learn how to use this device
	I didn't have to learn much to be able to use this device
	I didn't need help from someone to use this device because it was easy to figure out how to control it
Motivation	It was easy for me to become skillful in using this device
	The use of the device kept my attention on what I saw until the end
	When I was using the device, I felt like I wanted to learn even more
	The device prompted me to want to learn more

Note. * = the word "device" was replaced by "conventional tools" or "3D pen," depending on the tool students used; ** = the scoring for this item was reversed

To cite this article: Fokides, E., & Magkafa, Z. (2024). 3D pens, stereometry, and primary school students. Results of a project. *Themes in eLearning*, 17, 73-88.

URL: <http://earthlab.uoi.gr/tel>