The effect of 3D Printing technology on primary school students' content knowledge, anxiety and interest toward science

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Abstract

3D printing (3DP) technology can serve as a powerful learning and educational tool that can support and inspire students' creativity. This study investigates the effect of an experimental educational scenario, focused on 3DP and design printing, on students' conceptual understanding, interest and anxiety. The study's sample included 111 primary school students divided into two group: The Experimental Group which used 3DP technology and the Control Group which used everyday materials. Students in both groups were taught the concept of friction, and the factors it depends on via a constructivist teaching approach. The study's results demonstrate the positive effect of 3DP technology on students' conceptual understanding of the force of friction. Additionally, students' interest in science was not affected in any negative manner and students' anxiety was curbed. This study provides implications and limitations for 3D printing integration in STEM education.

Key words: 3D printing technology, interest, anxiety, science, friction

Introduction

Seeing that science and the real world are intimately connected, endorsing a dynamic learning environment in a science classroom is essential. For this reason, new generations of teachers are encouraged to make better use of technology (ICT tools, 3DP, tablets, smartphones) that can model, visualize and simulate abstract concepts and natural phenomena, enhance teaching and conceptual development and serve as a learning aid to teach Science (Kalogiannakis, & Papadakis, 2017; 2019; 2020; Kaya et al. 2019: Kwon, 2017; Leinonen at al., 2020; Novak & Wisdom, 2018; 2020; Trust & Maloy, 2017). Therefore, "understanding the impact of technology and finding the best ways to integrate technology into the classroom is critical for improving students' performance" (Kwon, 2017, p. 37).

3DP technology is "a maker-centered educational tool" and "an emerging educational technology that has the potential to foster real change in education" (Novak & Wisdom, 2020, p. 731). In their review, Novak & Wisdom (2020) highlight that 3D printing technology develops skills (communication, inquiry, collaboration), provides students with "playful and experiential learning experiences" and "presents students with real-world problems that require skills that cut across the disciplines" (p. 732). Additionally, 3DP technology may impact cognitive and affective outcomes such as conceptual understanding, mastery of content, attitudes and motivation (Cheng et al. 2020), “introduce students to the procedures and practices of 3D modeling”, “promote creativity, technology literacy, problem solving, perseverance and critical thinking” and support “teamwork, communication, decision making, mathematical reasoning, and adaptability among students” (Trust & Maloy, 2017, p. 265).

This research study aims to investigate the effect of a school-based project assigned to 5th and 6th grade students of Primary School which includes the use of 3DP technology, in an educational scenario based on constructionism, as an aid to understand an abstract scientific concept, reduce student anxiety and increase their interest toward science. Due to student misunderstandings around concepts of mechanical systems, the concept of friction was specifically chosen as it’s a common example encountered in real life, and students already hold several pre-conceived beliefs and ideas before it’s formally taught in school (Besson, 2007).

This paper first presents a literature review on STEM, 3DP technology and student misconceptions on the concept of friction. The study’s methodology, results, discussion and conclusions follow, and finally, implications and limitations are discussed.

STEM – 3D Printing

In recent years, much focus has shifted to STEM education (Science, Technology, Engineering, Mathematics), which, in practical terms, has become a priority in European curricula. To this effect, innovative cooperation programs are being created and the need for an interdisciplinary approach to Mathematics, Science and Technology is now all the more urgent.

STEM education is a unique field in that it offers a learning environment in which students are able to explore, invent and discover via real-life problems and situations presented to them (PCAST, 2010). The combination of four scientific areas enables students to make connections among disciplines, and create new ones, which in turn promotes innovative thinking and “forms connections between theory and reality” (Chien, 2017, p. 2942). As a whole, STEM creates a learning environment where students acquire 21st century skills, and more so, are given the opportunity to build on such skills (Narum, 2008).

3DP is the “process of creating an object using a machine that puts down material layer by layer in three dimensions until the desired object is formed” (Educause Learning Initiative, 2012, p. 1). This process involves designing a 3D model of the desired object on computer-aided design (CAD) software, and finally printing the outcome from a 3D printer (Trust & Maloy, 2017). 3DP may help students develop a better understanding, because the teaching process takes on a different dimension: 3DP is an alternative process that helps clarify abstract scientific concepts, therefore providing real learning connections via a physical model (Lipson, & Kurman, 2013). Moreover, students’ learning performance improves thanks to a hands-on experience (Hsiao et al., 2019).

As such, 3DP technology can serve as a powerful learning tool because it introduces students to the design school of thought - a strategic practice entrenched in Engineering – and offers greater possibilities to apply scientific knowledge in the classroom as it engages students in technical processes (National Research Council, 2012).

Researchers agree that 3DP can support learning, foster creativity and observation in many disciplines such as chemistry/biochemistry (3D prints of elements and molecules), biology and anatomy/medicine (3D print models of bones), engineering (development of novel tools to solve problems), mathematics (creation of 3D mathematics models), and astronomy (exploration of NASA models) (“Using 3D Print Models in the Classroom”, 2020; Ford & Minshall, 2019). Also, its potential implementation has been explored in history and social studies classrooms (Maloy et al., 2017), science (Grant, MacFadden, Antonenko, & Perez, 2017) and special education (Buehleret et al. 2016).

Many studies have explored the implementation of 3DP from primary/elementary to tertiary educational settings (Chen et al., 2014; Cheng et al., 2020; Chien, 2017; Ford & Minshall, 2019; Hsiao et al. 2019; Kalogiannakis, & Papadakis, 2017; 2019; 2020; Kwon, 2017; Leinonen at al., 2020; Novak & Wisdom, 2018; Trust & Maloy, 2017). However, there are relatively few studies that consider 3DP use in primary education. Specifically, in primary education, Chen et al. (2014) examined the effectiveness of 3D printing on the mental rotation ability of student (age 10). Their findings showed that students' mental rotation ability rapidly developed, girls' spatial ability was faster than boys, and the 3DP course significantly developed the mental rotation ability of boys. Easley et al. (2017) exploring the use of 3DP in order to engage underrepresented students in STEM, indicated that students practiced STEM skills, developed communication, and experienced applied STEM problem solving. In mathematics, students' performance on surface area tasks using software and die cutters to print physical models from digital designs improved in the post-intervention tests (Corum, & Garofalo, 2015). In a Greek context, various literacy (e.g. technological) and creative capacities improved among high school students after a three-month project on open source 3DP and design activities (Kostakis et al., 2015).

The concept of friction and student misconceptions

Students overall struggle to understand concepts around mechanical systems which are part of their everyday lives. The concept of friction is one such example, where students tend to develop preconceived beliefs and ideas about its purpose before it's formally taught in school (Besson et al., 2007).

According to several studies, students confuse the properties of friction, misconstrue how friction affects material bodies, and how it exerts itself on the latter (Besson et al., 2007; Hancer & Durkan, 2008). Many students see friction as a force of resistance, which affects and exerts itself on the moving object but always travels opposite to movement. Students often report that friction depends on the surface area of the moving object. They also confuse static friction with sliding friction and most view friction as something undesirable, thus finding it difficult to understand that in many cases, friction is in fact advantageous.

Methodology

Research objectives

This research study aims to investigate the effect of a school-based project assigned to 5th and 6th grade students of Primary School which includes the use of 3DP technology, in an educational scenario based on constructionism, as an aid to understand the abstract scientific concept of friction, reduce student anxiety and increase their interest toward science. Their outcomes were compared with those of students who were taught the same educational scenario but with the use of everyday materials and objects.

The six Research Questions (RQ) below set out to investigate:

RQ 1: How does the use of 3D Printing technology affect students' conceptual understanding (conceptual change) of the force of friction?

RQ 2: How does the use of 3D Printing technology affect students' anxiety toward science?

RQ 3: How does the use of 3D Printing technology affect students' interest toward science?

RQ 4: Are there differences between the experimental and control groups on the conceptual understanding of the force of friction?

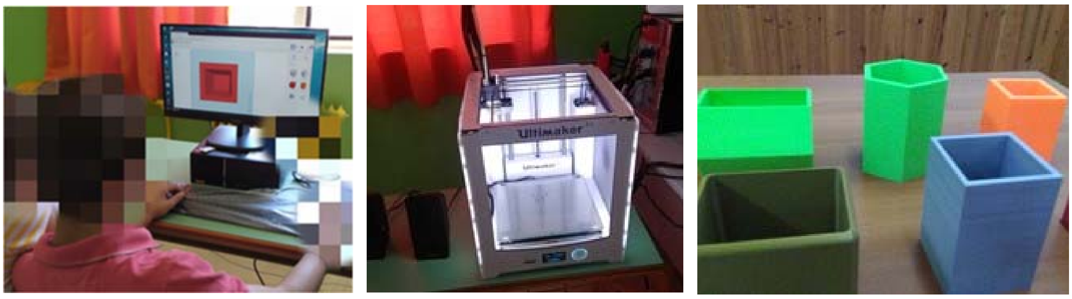
RQ 5: Are there differences between the experimental and control groups in terms of students' anxiety toward science?

RQ 6: Are there differences between the experimental and control groups in terms of students' interest toward science?

Sample – Research process

The experiment was conducted in two phases. Initially a pilot study was carried out to trial, test and improve the research tools and thereafter the main study was performed and finally conclusions were drawn.

The main study was conducted in February 2020 to a sample of 5th and 6th grade Primary School students who were divided into a control and experimental group via the convenience sampling method (Creswell, 2014). A total of 111 students from three primary schools in the Prefecture of Thesprotia, Northwestern Greece participated in the study. Of these, 39 students were in the 5th grade and 72 in the 6th grade. The control and the experimental groups consisted of 58 and 53 students respectively. The control group worked in their classrooms and performed the experiments using everyday objects and materials. The experimental group worked in their school's computer lab, which had a 3D printer and all necessary infrastructure to carry out the project. The students in the experimental group performed the experiments with objects they created themselves on the laboratory's computers, and 3D printing software Cura, Tinkercad. Thereafter, students in the experimental group constructed their objects with the help of 3D printer Ultimaker 2+ using the appropriate PLA plastic thread (Figure 1).



Picture 1. Design and construction of 3D objects

Both groups took a pre-test assessing their knowledge on the "Factors affecting the force of Friction" module and performance scores were compared among the two groups, prior to the classroom intervention. No statistical differences were found among the pre-test scores in both groups.

Students of both groups had no previous knowledge on the concept of the force of friction. An information meeting with the teachers preceded, in order to ensure that the classroom intervention would be delivered consistently among all schools. The experimental group students were taught the module and were trained in 3D printing.

Both groups were taught the concept of the force of friction and the factors it depends on, via the 5E Model which is based on the constructivist learning theory (Bybee et al., 2006). This teaching model engages students in guided research and focuses on determining, shifting and revising initial perceptions, using home materials and objects students bring to the classroom, and experiments are performed with dynamometers (improvised and ready-made).

The teaching approach included the following five phases (Table 1):

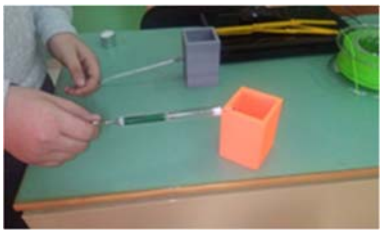
Table 1. Phases of teaching approach

Phase	Description
1. Initiation	**Drawing** the **interest** of students • by identifying their initial perceptions • establishing questions for students to investigate with everyday life examples
2. Investigation	**Design** and **experiment** performed by students • purpose: answer questions established in Phase 1

	• use of worksheets (**determine the research objective, formulate hypotheses, identify variables, describe the experimental process, use of materials, execute the experiments** mainly with everyday materials, **record data**)
3. Interpretation	• **Data processing** • **Drawing conclusions** • **Determining** the relevant **laws** of Physics
4. Application	**Application** of **knowledge** acquired by students to new problems (mainly from their daily life)
5. Evaluation	• **Reflections** of students on the learning process • **Comparison** of **initial** and **final answers**

Description of teaching process

The same teaching process was delivered to both the control and experimental groups (Table 2). However the experimental group students performed the experiments with objects they constructed using the 3D printer, prior to which students had been properly pre-trained in 3D printing technology (use of Tinkercad software, 3D print display, 3D design).




Picture 2. The Experimental team performs the experiments

Table 2. Classroom intervention

Description of classroom intervention (Control Group and Experimental Group)	
Module: "Factors affecting the Force of Friction"	
Duration: 3 teaching hours	
Vocabulary: friction, surface area, type of surface, weight	
Teaching objectives: For students to experimentally identify the factors affecting the force of friction	
Instruments and materials for each group	
boxes, rulers, tape measure, rubber bands, plastic straws, adhesive tape, scissors, paper, sandpaper, self-adhesive rough surface, markers.	
Phases of intervention	
Control group intervention	**Experimental group intervention**
Phase 1: Initiation. Draw student interest (1 teaching hour)	
• The initial interest is recorded on the worksheet. • After randomly dividing the students into the control and experimental groups, each group is handed a sheet of paper and from a projector, power point slides are presented which include relevant module questions. • Students record their answers.	
Phase 2: Investigation. Students design and conduct the experiments in order to answer their initial questions	
• Discussion on the selection of objects needed to perform the experiments	• Design and construction of objects via Ultimaker 2 3D printer (Picture 1)
• **1st experiment:**	

a) The students place each box-object on their desk and pull it with the dynamometer (Picture 2). b) As the box is pulled, the spring dynamometer is elongated further seeing that static friction is greater than sliding friction. We ask students to record their measurements on the magnitude of deformation as the box starts to slide on their desk. c) Students attempt to pull the box over a sheet of paper and then over sandpaper, which they had previously taped to their desks. d) After completing the experiment, they record their observations by comparing their measurements in all three cases. Students observe that friction depends on the type of surface being rubbed. • They repeat the previous experiment by place various objects in the box. Here, they discover that friction depends on the weight of the body that slides.	
• **2nd experiment**: a) Students pull the object with the dynamometer, once where its small surface touches the desk and then where its large surface touches the desk and discover that elongation is the same in both cases. b) With their markers, students mark a starting position on the floor. Here they place an item and the rubber band at the starting position. After stretching and releasing the rubber band, students monitor, measure and record the end position, i.e. where the item stops for every case. • The groups perform their experiments in a circular fashion. All students use every materials and tool.	
Phase 3: Interpretation. Data processing, drawing conclusions, formulation of corresponding laws of Physics.	
At this phase, the teacher encourages classroom discussion. Students share their observations during the experiments and draw conclusions. The teacher then leads a structured discussion with questions.	
Phase 4: Application. Application of the knowledge acquired by students to new problems, mainly encountered in their daily life, and feedback.	
Summary work: groups share the results of their observations and findings and record their conclusions.	
Phase 5: Assessment. Reflection on the learning process and comparison between their initial and final answers.	
Students complete a questionnaire assessing their knowledge on the force of friction.	

Structure of the final questionnaire

The final questionnaire included three sections (Appendix):

A) The first section (Section A) asks students to state their sex, grade and classroom.

B) The second section (Section B) includes closed- and open-ended questions, which explore students' knowledge and perceptions on the concept of friction. All items are based on content from the school textbook, and each item was examined by a panel of researchers and experts who were well-acquainted with the literature and research area, in order to establish face validity, as well as ensure the content and cultural appropriateness of the questionnaire.

The KR20 coefficient for the test was 0.61 and considered to be reasonable (Glen, 2020).

C) The third section (Section C) of the questionnaire explores students' attitudes towards science, especially their interest and anxiety levels in science, and consists of 21 statements answered on a five-point Likert scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = I strongly agree). An initial pool of 25 items were created (Çetinkaya & Taş, 2015, Chen et al., 2016; Deci et al., 1994, Koka & Hein, 2003; Novak & Wisdom, 2018) and translated into Greek following the International Test Commission (ITC) guidelines for test adaptation (Hambleton, 2001) and suggestions from Beaton, Bundardier, Guillemin, & Feraz (2000). The translated items were pilot tested to a small sample of students (N=24) in the target population to examine appropriateness with regards to the content of items, clarity of meaning, language consistency and wording.

A Principal Components Analysis (PCA) with oblique rotation was used to determine correlations between the variables. To determine the number of factors, five criteria were used (factor structure coefficients of 0.30 or greater, scree plot, factors with eigenvalues greater than 1.0, correlation with other resulting factors, the conceptual meaningfulness of factors). Furthermore, the Kaiser-Meyer-Oklin Test (K.M.O) for sampling adequacy (accepted level >.50, Kaiser, 1970) and Bartlett's test of sphericity (Bartlett, 1950) were calculated to verify the appropriateness of both EFA and CFA. The K.M.O. was .79 and the Bartlett's test of sphericity was statistically significant (601,093, $p<.05$), supporting the factorability of the correlation matrices (Benishek & Lopez, 2001; Kaiser, 1970; Pett, Lackey, & Sullivan, 2003; Raob, Oshaibat, & Lan, 2012; Stevens, 1992; Williams, Brown, & Onsman, 2010).

EFA results, using PCA and oblique rotation criteria (to simplify the identification of components), revealed two factors, with eigenvalues exceeding 1.00. The number of factors was also confirmed with the visual inspection of the scree-plot, indicating a sudden drop at the beginning with the second factor. All items exceeded .40 on their factor, and these two factors accounted for 43.78%. Four items with similar loadings on two factors were deleted.

Table 3: Number of items, eigenvalues, % of total variance and a-Cronbach

Factors	Number of items	Eigenvalues	% of the total variance	α Cronbach
Anxiety	9	2.47	11.74	.87
Interest	12	6.73	32.04	.77

Internal consistency of the overall questionnaire was .88. Cronbach's α reliability for the two factors of the questionnaire was .87 and .77, respectively (Table 3).

The questionnaire was distributed to students before and after the classroom intervention. In the statistical analysis, the values of the negatively formulated items were reversed.

The study included 6 variables (science content knowledge, anxiety and interest of students before and after the teaching intervention). Specifically, for each variable the score was calculated from the sum of questions corresponding to each variable. For the content knowledge questions, each wrong answer received a zero (0) score and each right answer received a one (1) score.

A high score on the anxiety variable demonstrated low anxiety toward science. A high score on the interest variable demonstrated great interest toward science.

Results

Descriptive statistics

The research sample consisted of 111 students in the 5th and 6th grades of Primary School. Of these, 58 students made up the Control Group, and the remaining were included in the Experimental Group. 53.2% were boys and 46.8% were girls. 35.1% of the sample consisted of 5th grade students and 64.9% of 6th grade students. The variable means, standard deviations, minimum and maximum values for the control and experimental groups are presented in Table 4 below.

Table 4. Record of variable means, standard deviations, minimum and maximum values for the Control Group (CG) and Experimental Group (EG)

Pre	Post

	Content Knowledge		Interest		Anxiety		Content Knowledge		Interest		Anxiety	
	CG*	EG**	CG	EG	CG	EG	CG	EG	CG	EG	CG	EG
N	52	48	42	39	50	40	52	52	49	50	52	51
Mean	55,88	51,35	77,26	79,15	79,47	78,67	69,12	91,29	79,05	79,77	83,29	82,05
SD	14,67	12,36	13,68	14,41	12,69	16,20	18,56	9,64	13,60	13,28	12,28	12,26
Minimum	29,41	29,41	38,33	30,00	42,22	22,22	29,41	64,71	41,67	23,33	48,89	51,11
Maximum	88,24	76,47	100,00	96,67	95,56	100,00	100,00	100,00	100,00	98,33	100,00	97,78

*Control Group, **Experimental Group

Statistical comparisons among the mean differences of student scores on science content knowledge

The Kolmogorov-Smirnov Test evaluated the normal distribution of variables regarding students' scores on content knowledge before and after the classroom intervention for both groups and showed that the distributions were not normal. Responses were recoded. Specifically, a correct answer = 1, an incorrect answer = 0, and the score was calculated in %. The results of the descriptive analysis and the Wilcoxon signed-rank test are presented below.

Pre and post comparisons between the control and experimental groups

The Wilcoxon signed-rank test shows that the students in the control group had a higher score (22.41) after the classroom intervention with a statistically significant difference (9.67), z = -4.748, p <0.001. Similarly, the students in the experimental group had a higher score (23.50) after the classroom intervention with a statistically significant difference (.00), z = -5.938, p <0.001.

Pre and post comparisons between the control and experimental groups

Tables 5 and 6 show the statistical analysis on the comparison of results regarding the science content knowledge of students in the experimental and control groups.

The Mann-Whitney U test revealed that student scores, in both groups, before the classroom intervention did not show a statistically significant difference, U = 1039.500, z = -1.451, p = 0.147. However, the students of the experimental group had a higher score with a statistically significant difference after the classroom intervention as opposed to the control group, U = 412,000, z = -6,171, p = .000.

Table 5. Mann-Whitney Test Statistics

	Pre						Post					
	Content knowledge		Interest		Anxiety		Content knowledge		Interest		Anxiety	
	CG	EG	CG	EG	CG	EG	CG	EG	CG	EG	CG	EG
N	52	48	42	39	50	40	52	52	49	50	52	51
Mean Rank	54,51	46,16	38,48	43,72	45,66	45,30	34,42	70,58	49,09	50,89	53,38	50,59
Sum of Ranks	2834,5	2215,5	1616	1705	2283	1812	1790	3670	2405,5	2544,5	2776	2580

Table 6. Test Statistics

	Content knowledge Pre	Content Knowledge Post	Interest Pre	Interest Post	Anxiety Pre	Anxiety Post
Mann-Whitney U	1039,500	412,000	713,000	1180,500	992,000	1254,000
Wilcoxon W	2215,500	1790,000	1616,000	2405,500	1812,000	2580,000
Z	-1,451	-6,171	-1,003	-,312	-,065	-,476
Asymp. Sig. (2-tailed)	,147	,000	,316	,755	,948	,634

Statistical comparisons among the mean differences of student scores on their anxiety and interest levels toward science

Pre and post comparisons on the anxiety and interest levels of the experimental group

The Wilcoxon signed-rank test revealed increased interest from the experimental group students (19.25) after the classroom intervention, but without a statistically significant difference, (16.68), z = -, 517b, p > 0.001.

Respectively, their anxiety dropped (20.15) after the classroom intervention, with a statistically significant difference (20.15), z = -2.069b, p <0.05.

Pre and post comparisons on the anxiety and interest levels of the control group

The Wilcoxon signed-rank test revealed that students in the control group showed reduced interest (17.54) and a similar reduction in anxiety (21.71), without a statistically significant difference after the classroom intervention, both for interest (17.54), z = -1.660b, p> 0.001 and anxiety (21.71), z = -2,309b, p> 0.001.

Pre and post comparisons on interest and anxiety levels between the control and experimental groups

Tables 5 and 6 show the statistical analysis on the comparison of results among the experimental and control groups regarding the interest levels of students.

The Mann-Whitney U test shows that student interest for both groups before and after the classroom intervention did not show a statistically significant difference, U = 713.000, z = -1.003, p = .316 and U = 1180.500, z = -.312, p = .755 respectively.

Similarly, the anxiety level of students in both groups before and after the classroom intervention do not show a statistically significant difference U = 992.000, z = -.065, p = .948 and U = 1254.000, z = -.476, p = .634 respectively.

Conclusions – Discussion

The main purpose of this study was to investigate the effect of a 3DP technology intervention in a science project on students' anxiety, interest and conceptual understanding. A constructivist teaching approach was used. More specifically for RQ 1, the statistical analysis revealed that students' conceptual understanding of the force of friction improved after the intervention and at the same time students performed better than those of the control group (RQ 4). In other words, while classroom interventions and experiments, whether performed with everyday objects or objects constructed with 3D printing, can increase students' conceptual understanding, worth mentioning is the statistically significant difference when scores are compared among the groups. The process of planning, designing, testing the artefacts, as well as students' collaboration in order to create objects that meet specific criteria, the hands-on activities as well as the tactile perception of artefacts might help students improve their conceptual understanding and build engineering skills too.

For RQ 2 and RQ 3, the analysis showed that students' anxiety decreased but interest remained the same respectively.

As for the interest and anxiety levels of students toward science, the responses of both groups to the statements showed no statistical significant differences before and after the classroom interventions (RQ 5 and RQ 6). It is worth noting that a particularly high interest level was found toward science for both groups, before the beginning of the classroom intervention, and an improvement was noted regardless of the choice of teaching intervention. Moreover, the effect of the classroom intervention, both with and without the use of 3D Printing technology, on the anxiety level of students toward science proves to be similarly beneficial.

This research reveals the positive effect of 3DP on the conceptual understanding of the force of friction and the factors it depends on - a finding consistent with recent research conducted with middle and high school students in other subject areas (Hsiao et al., 2019; Kostakis et al., 2015; Leduc-Mills & Eisenberg, 2011; Şen et al., 2020).

The study confirms that 3DP technology can serve as a powerful STEM learning tool, as it introduces students to the design school of thought, a strategic practice common in Engineering, offering greater opportunities for students to apply scientific knowledge in the classroom and solve technical problems (National Research Council, 2012).

The findings support the views of other researchers who agree that 3DP can inspire learning, creativity and perseverance (Buehleret et al., 2016; Chien, 2017; Ford & Minshall, 2019; Gross et al., 2014; Maloy et al., 2017; Vaccarezza & Pappa, 2015).

Implications

3DP technology could be integrated both as an innovative educational tool in the Natural Sciences curriculum for Primary and Secondary Education, to improve student engagement and understanding of STEM subjects, promote their interest in STEM, as well as in teacher education and training programs. Finally, worth noting is that comparative studies of classroom interventions using 3D printing, while very recent, demonstrate the tool's effectiveness in teaching science. Overall, classroom intervention comparisons allow to draw very useful conclusions, which can contribute to increased teaching and learning efficacy on the concepts and phenomena of science. Therefore, further research is needed on appropriate interventions that would encourage the learning and understanding of other concepts and phenomena of science, such as the floating of objects, etc. This in turn would identify criteria to devise appropriate classroom interventions, including having students construct their own objects using 3D printing applications, or use ready-made objects, or a combination of these to successfully introduce students to other fields of science.

Limitations

While the two classroom interventions did not demonstrate the same effectiveness in students' conceptual understanding of the force of friction, it should also be noted that both interventions present their own challenges in an everyday school environment and depend on teaching approaches as well as other factors, such as the availability of appropriate tools and materials in schools. More specifically, if modern computer labs are lacking or 3D printers are not available, use of the appropriate software will not be possible. Finally, the study's small sample size is a limitation and additional teaching time may be needed in order to train students in designing more complicated artefacts.

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