Enhancing Creativity and Problem-Solving Skills Through 3D Printing in Greek Education

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Abstract

This study examines the integration of 3D printing (3DP) technology in Greek education and its effects on creativity and problem-solving skills. The research designed and implemented a national CAD and 3DP contest and online asynchronous courses for teachers and students, aiming to demonstrate best practices and foster multidisciplinary integration of 3DP. Using Project-Based Learning (PBL) and Design Thinking (DT) frameworks, the study assessed through the process the creativity and problem-solving skills with adapted VALUE rubrics. Data from 358 students in 66 teams across 42 schools showed significant improvements in creativity and notable problem-solving abilities. The diverse participation highlights 3DP's potential to modernize education and bridge educational gaps. This research underscores the importance of innovative teaching methods, and the democratizing potential of emerging technologies can have in education.

Keywords: 3d Printing, creativity, problem solving.

Introduction

3D printing, also known as additive manufacturing, creates physical objects from digital designs by layering materials, unlike traditional subtractive manufacturing, which involves cutting material from a solid block. Although its origins date back to the 1980s, 3D printing has rapidly evolved and become more accessible over the past decade (Lipson & Kurman, 2013). The process starts with creating a digital model using computer-aided design (CAD) software. This model is then sliced into thin layers, guiding the printer to build the object layer by layer. Various materials, including plastics, metals, ceramics, and biomaterials, can be used (Gibson, Rosen, & Stucker, 2014). Common 3D printing technologies include Fused Deposition Modeling (FDM), Stereolithography (SLA), and Selective Laser Sintering (SLS). FDM involves extruding melted filament through a heated nozzle, SLA uses a laser to harden liquid resin, and SLS fuses powdered material with a laser, allowing complex structures to be created (Chua & Leong, 2015). The applications of 3D printing are expanding across various fields. In medicine, it is used to create custom prosthetics, implants, and bio-printed tissues. The aerospace and automotive industries use it to produce lightweight, complex parts. Importantly, 3D printing is also making significant impacts in education by providing hands-on learning opportunities that enhance creativity and innovation (Berman, 2012). Since 3D printing will be a part of many future jobs, customizing the students to the technology will promote their future carriers.

In educational settings, 3D printing enriches learning from elementary schools to universities. In primary and secondary education, it introduces students to advanced

technologies, teaching subjects like mathematics, science, engineering, and art through practical applications (Chua & Leong, 2015). For example, students can print geometric shapes to understand mathematical concepts or create models of historical artifacts to deepen their understanding of history and culture (Novak & Wisdom, 2018). In higher education, 3D printing facilitates innovative research in fields such as engineering, architecture, and medicine, allowing students to design and test prototypes or create anatomical models for study (Lipson & Kurman, 2013; Ford & Minshall, 2019). The integration of 3D printing in education supports Project-Based Learning (PBL) and Design Thinking (DT). PBL involves students in group projects where they identify an inquiry question, brainstorm solutions, and create tangible artifacts, enhancing skills like communication, collaboration, and creativity (Bell, 2010). DT aligns with constructivist theories, emphasizing hands-on, task-oriented activities. It engages students in solving real problems through empathy, ideation, prototyping, and testing, fostering a culture of experimentation and innovation (Wenger, 2009). 3D printing as an educational tool has been shown to enhance creativity, which stands as a key 21st-century skill alongside critical thinking, collaboration, and communication (Beghetto, 2007; Glăveanu, 2015; Sternberg, 2012). Studies have reported positive teachers' perceptions in using 3D printing to develop creativity (Trust, & Maloy, 2017). More research is needed on pedagogical practices as well as evidence on students' engagement that proves such development.

In this context, an important challenge is to determine which and how 3D printing activities promote creativity and problem-solving competencies. To address this, the present study proposes a structured combination of PBL, online courses, and face-to-face collaboration with support from geographically dispersed mentor teachers. This approach aims to facilitate the incorporation of 3D technologies and design thinking into school practices, build a community of students and teachers, and cultivate competencies relevant to current and future careers.

To guide this investigation, the study posed two core research questions:

1. To what extent does student participation in 3D design and printing activities improve their creativity skills when guided by a design thinking framework? and
2. How do students develop problem-solving skills through a structured 3DP design challenge, and what are the measurable outcomes?

These questions led to the formulation of two corresponding hypotheses: that students would improve their creativity skills (H1) These questions led to the formulation of two corresponding hypotheses:

- **H1**: Students would improve their creativity skills through their engagement with the 3DP activities and the design thinking approach.
- **H2**: Students would demonstrate enhanced problem-solving abilities through participation in the structured 3DP contest.

These hypotheses form the foundation of the study's design and analysis.

Methodology

Since the introduction of 3DP in the Greek educational curriculum, either as possible part of a formal education initiative and for a limited number of grades or in non-formal settings, is a new process and, in mostly an unknown territory, we had to find ways to promote its introduction to a wider audience, both geographically and for all the school grades. To this end we have designed and implemented the following two actions:

- A national CAD and 3DP Contest: This contest is addressed to all interested teachers along with their students to form groups, work on a sustainability problem at their environment, and propose a solution presented in the form of a 3D model, an analysis report and a presentation of the whole process.
- Online Asynchronous Courses: To support teachers and students willing to get involved but feeling uncomfortable due to a lack of training, we designed and offered two online

asynchronous courses of 8 weeks each, on CAD and 3DP, namely "Teachers ST3dM" and "Students ST3dM." These courses introduced CAD and 3DP. In the design this courses we followed common steps of action research, including setting goals, defining research theory, identifying research questions, collecting and analyzing data, reporting results, and identifying required improvements (Sagor, 2000).

By providing a structured training and practices, these actions aimed to simplify 3DP technology integration into educational environments and create a community of students and teachers through forum discussions. The above educational environment also highlighted the potential for 3DP to facilitate project-based learning and interdisciplinary collaboration, key components of innovative and effective education.

Study Design

The research was conducted in the context of this national 3D design and printing contest implemented over five consecutive years. Each year's implementation included asynchronous online support courses for both students and teachers, access to instructional videos, activities, and collaborative design tasks. The participants were grouped into student teams from across Greece, including rural and urban areas, general and special education schools.

The study embraced an interventionist logic, involving cycles of design, implementation, evaluation, and redesign. Data was collected from two main sources: (a) students' work within the platform and their interaction with learning resources (used primarily for creativity evaluation), and (b) final essay submissions by each team (used for problem-solving evaluation). All activities and assessments were carried out with the support of mentor teachers, under real classroom or extracurricular settings.

The study focused on two educational levels—primary and secondary—and used adapted VALUE rubrics for the assessment of the two targeted skills. Creativity was evaluated through a time-based approach, using three evaluation checkpoints across the learning process. Problem-solving was assessed using a single evaluation of the teams' final design essay.

This multilevel research approach—spanning different educational levels, school types, and geographical areas—enabled a robust triangulation of findings. The combination of qualitative and quantitative data, collected through students' digital artifacts and reflective reports, strengthened the validity of the results and provided a comprehensive understanding of how 3DP-enhanced PBL and DT practices support 21st-century skill development in real-world educational contexts.

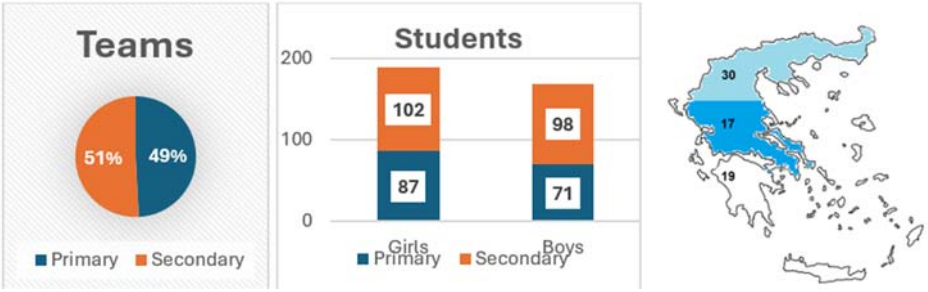
Theoretical Base

The course integrates Project-Based Learning (PBL) and Design Thinking (DT) to enhance student engagement and skill development in the 3D design and printing contest. PBL is a student-driven and teacher-facilitated approach that organizes learning into student group projects. Initially, students formulate an inquiry question, brainstorm procedures, and identify necessary materials. They actively collaborate, set project goals, and solve authentic problems, culminating in the creation of a tangible 3D printed artefact and ultimately select a way to demonstrate what they have learned through a project. This approach has been shown to cultivate 21st-century skills such as communication, negotiation, collaboration, and creativity (Bell, 2010; Karaçalli & Korur, 2014). Incorporating DT into the course aligns with the theory of Constructivism, which emphasizes hands-on, task-oriented, self-directed activities aimed at design and discovery. Constructivism suggests that learners build their own mental structures through interactions between their experiences and ideas (Piaget, 1954; Wenger, 2009). Concurrently, the DT process involves understanding user needs, defining a problem statement, generating innovative ideas, creating and testing prototypes, and iterating based on feedback. DT engages students in the solution of real problems using a human-centered approach, encouraging empathy and active participation in social communities. This method aligns with Wenger's social theory of learning, which focuses on learning as social

participation. By engaging in these practices, students develop identities related to their communities, shaping not only what they do but also who they are and how they interpret their actions. Both PBL and DT focus on key outcomes related to 21st-century skills, including teamwork, problem-solving, and creativity.

Sample

The importance of our study is highlighted by the extensive and diverse sample of students and teachers involved in the national CAD and 3D printing contest as well as in the asynchronous courses. Sixty-six teams from forty-one schools completed the course tasks and submitted their artifacts to the 3D printing contest for the 2022–2023 school year. This numerically significant and geographically diverse participation, spanning all school levels, *ensured* a good representation of various demographic and educational backgrounds, allowing us to generalize the outcomes of the impact of 3D printing in education. Our national contest included students from schools all over Greece, from primary to secondary education, from public schools, private institutions, vocational schools, and special education as presented in table 1 and table 2. Specifically, thirty teams from primary education and thirty-six teams from secondary education were involved. Of these, 30 teams were from northern Greece, 17 from central Greece, and 19 from southern Greece and the islands. Forty-one teams represented public schools, while twenty represented private institutions. The participants were boys and girls from various economic backgrounds, residing in villages, islands, or major urban centers across Greece. In primary education, 87 girls and 71 boys participated. In secondary education, the participants included 102 girls and 98 boys, resulting in a balanced sample of 189 girls and 169 boys overall. These different contexts and socioeconomic environments established a rich dataset for analysis and are illustrated in Figure 1.



(a) **(b)** **(c)**

Figure 1.α) percentage composition of participating teams. b) Total students by level and gender. c) Geographical mapping of teams origination.

Table 1. Composition of participating teams

Sector	Girls	Boys	Teams	Students
Primary	**87**	**71**	**30**	**158**
Secondary	**102**	**98**	**36**	**200**
Junior High	*60*	*47*	*16*	*107*
High School	*42*	*51*	*20*	*83*
Special Ed.	*8*	*7*	*3*	*15*
VET	*8*	*13*	*5*	*21*
Total	**189**	**169**	**66**	**358**

Table 2. Detailed Teams Origination

Origin	Teams
Northen Greece	30
Central Greece	17
Southern Greece	5
Greek Islands	14
Public School	*41*
Private School	*20*

Furthermore, the asynchronous courses were designed in a way to address a wide range of participants as shown in Table 3, including teachers from various disciplines with no prior experience in 3D printing. This multidisciplinary involvement was crucial as it provided a holistic view of how 3D printing technology could be integrated into different subject areas. Teachers from STEM fields, as well as from arts, humanities, and vocational training, all contributed their unique perspectives, experiences, and perceptions, enriching the study's findings. By involving educators from such varied backgrounds, we were able to capture a broad dataset of educational practices and the diverse ways in which 3D printing can be applied to enhance learning and creativity.

Table 3. Participating teachers by discipline

Discipline	Educators
ICT	16
Science	10
Engineer	7
Primary Teacher	8
Math	2
Kindergarten	2
Arts	2
Literature	2
TOTAL	49

This broad and inclusive sample framework not only reinforces the reliability of our findings but also sets the stage for exploring how such diversity influenced the effectiveness of the intervention, as elaborated in the following sections on evaluation tools and data analysis.

Data collection

The data collection was conducted using three different methods. Each team submit to the contest three deliverables. They had to compose an essay for their entire work during their preparation of the artifact, a presentation of their total work and a file in .stl format of their final 3D design.

1. Their essays and presentations provided a rich dataset for the research. Students were required to describe their experience participating in the 3D designing and printing contest, beginning with a brief introduction of their team and the sustainability problem they selected to find a solution, along with the reasons for their choice. They were to present their brainstorming process, sources of inspiration, and any challenges they faced, detailing how they overcame these challenges and any innovative elements they included in their design. Additionally, they described how they organized their teams, distributed

tasks, and the communication methods they used. They highlighted the biggest teamwork, technical, or design obstacles they encountered and their approaches to overcoming them, providing specific examples. They explained the new skills or knowledge acquired, the process of learning to use the 3D design software and printer, and how they handled technical difficulties. Finally, they reflected on their satisfaction with the final product, what went well, and what they would do differently if given another chance, including any feedback received from teachers, peers, or judges. They also identified the skills they developed during their participation and their thoughts on how they might use these skills in the future. They concluded by summarizing their overall experience, what they gained from it, and any final thoughts on the importance of such projects in education.

2. Third deliverable was their 3D design file in .stl format.
3. Finally, we evaluate their deliverables on assessments of the courses as also their contribution to the forum.

To evaluate the essential learning outcomes on this research, we utilized the VALUE (Valid Assessment of Learning in Undergraduate Education) rubrics, developed by the Association of American Colleges & Universities (AAC&U,2009) for Creative Thinking and Problem Solving, to assess the skill development of primary and secondary education students participating in the 3D designing and printing contest.

Specifically, for the skills that we focus we used:

a. **Creative Thinking Rubric:** The Creative Thinking rubric focuses on students' abilities to acquire new competencies, take risks, solve problems, embrace contradictions, and demonstrate innovative thinking. In the context of the contest, students were asked to submit STL files of their designs along with reflective essays and presentations. We analyzed these STL files to evaluate the complexity and originality of the designs. The essays provided insights into the students' brainstorming processes, sources of inspiration, and how they overcame challenges. By mapping these aspects to the rubric criteria, we assessed the level of creativity demonstrated by each team.
b. **Problem Solving Rubric:** The Problem-Solving rubric evaluates students' skills in defining problems, identifying strategies, proposing solutions, implementing solutions, and evaluating outcomes. Students were required to describe their project from inception to completion, including the identification of specific problems and the strategies they employed to address them. The STL files showcased the final implementation of their designs, while the essays detailed the iterative process and decision-making involved. This comprehensive approach allowed us to assess their problem-solving abilities effectively.

Adaptation

Although VALUE rubrics were initially designed for higher education, they have been effectively adapted and utilized in secondary education settings to assess various student learning outcomes (Vrioni, A. et al, 2021). To perform suitable adaptations, we employed the Delphi method to refine and validate the assessment criteria. The Delphi method is a structured communication process that gathers insights from a panel of experts through multiple rounds of questionnaires (Yousuf, M. I., 2007). In this study, we selected three experts from various fields, including STEAM education, 3D printing technology, and educational assessment. Initially, we presented the existing VALUE rubrics to the experts for feedback on their relevance and clarity. Over the first two weeks of the asynchronous course, the experts reviewed the rubrics based on student assessments and overall engagement in the course, offering suggestions for modifications and improvements. We must state that the national competition was different for elementary, middle and high school. Although the central theme was sustainable development. For the primary school concerned their school, for the middle school their neighborhood and for the high school their city. Due to that it was

suitable to use the same original rubric to all levels. These rubrics were then applied to evaluate student engagement, providing a suitable framework for assessing creativity and problem-solving skills.

Application

To apply the VALUE rubrics, we first collected all necessary data, including STL files, reflective essays, presentations, and any supporting documentation such as online course logs from forums and activities. Each project was then evaluated against the relevant rubric criteria.

For **Creative Thinking**, we looked for evidence of innovation and originality in the 3D models presented by the STL files and creativity in overcoming design challenges as described in the essays. For **Problem Solving**, we analyzed the problem identification and solution implementation processes detailed in the essays and reflected in the design iterations. Each criterion was scored on a scale of 1-4 based on the evidence provided.

Detailed feedback was provided by three judges, each an expert in a different field. The first judge was a professor in higher education specializing in the didactics of science. The second judge was a lecturer in higher education at a School of Art, with expertise in Architecture and Art and Design studies. The third judge was a secondary education science teacher and PhD candidate researching the didactics of science, with expertise in special education. Each of them provided individually and independently their evaluations considering the VALUE rubric for each skill.

Results

We analyzed the data that was collected with JASP 0.18.3. In primary level 158 students join the course and 118 complete the tasks while in secondary level 187 students joined and 131 complete the tasks. The data that collected from the course was used for Hypothesis 1. Thirty teams submit their outcomes to the contest from the primary level and thirty-six from the secondary level. We evaluate those deliverables for both Hypothesis 1 and 2.

Hypothesis 1: Students under a design thinking intervention improve their creativity skills throughout the course of the contest.

The study aimed to evaluate the development of students' creativity during a course by analyzing assessments from three evaluators at two time points: the 4th week (t1) and the 8th week (t2). Descriptive statistics indicated that the mean creativity scores increased from t1 to t2 for all evaluators and levels in table 4. In total mean score increased from 2.770 (SD=0,347) to 3,410 (SD = 0,406) for primary and 2.639 (SD=0,442) to 3,513 (SD = 0,376) for secondary education Table 4. Detailed statistics for separate evaluators are provided in Table 4. Paired t-tests confirmed that these increases were statistically significant for all evaluators ($p < 0.001$). Additionally, Cronbach's alpha was calculated to assess the internal consistency of the evaluators' scores. The results showed internal consistency, with Cronbach's alpha values of 0.772 at t1 and 0.766 at t2 for primary and 0.828 t1 and 0.841 for t2 for secondary education level.

Table 4. Descriptive statistics as also ANOVA analysis for primary and secondary evaluation in the middle t1, and at the end t2, of the supporting course.

	t1_primary	t2_primary	t1_secondary	t2_secondary
Descriptive				
mean	2.770	3,410	2,639	3,513
std	0,347	0,406	0,442	0,376
Cronbach	0.772	0.766	0.828	0.841

The p-value for the Time factor is less than .001 in table 5, indicating a statistically significant difference in the scores before and after the intervention.

Table 5. Repeated Measures ANOVA Within Subjects Effects

Cases	Sum of Squares	df	Mean Square	F	p
Time	156.615	1	156.615	652.327	< .001
Residuals	32.652	136	0.240		
Evaluator	0.097	2	0.049	0.794	0.453
Residuals	16.649	272	0.061		
Time ✻ Evaluator	0.118	2	0.059	1.092	0.337
Residuals	14.656	272	0.054		

The high F-value (652.327) suggests a strong effect of the intervention over time. The p-value for the Evaluator factor is 0.453, which is not statistically significant. This indicates that there is no significant difference in scores between the different evaluators. The p-value for the interaction between Time and Evaluator is 0.337, which is not statistically significant. This suggests that the effect of time (before vs. after the intervention) on scores does not differ significantly between evaluators.

Hypothesis 2: Students under a design thinking intervention improve their problem-solving skills throughout their engagement in the 3d contest.

This hypothesis was tested gathering data from the final essays that teams submit for the contest. Evaluators following VALUE Rubric for problem solving skills, marked specific milestones that proof, problem definition, strategies, solution proposals and evaluation of their potential, methods of implementation and the evaluation of the outcomes that was described by the students. Descriptive statistics indicated that the mean problem-solving skills that presented during these activities was evaluated as 2.67 (SD = 0,31) for primary teams and 3,28 (SD = 0,29) for secondary education level teams. Detailed statistics for separate evaluators are provided in table 6.

Table 6. Descriptive analysis for problem solving skills evaluation

	Primary				Secondary			
	A1	**A2**	**A3**	**Average**	**A1**	**A2**	**A3**	**Average**
count	30	30	30	30	36	36	36	36
mean	2,58	2,76	2,68	2,67	3,22	3,38	3,24	3,28
std	0,41	0,46	0,41	0,31	0,37	0,43	0,47	0,29
min	2,20	2,20	2,20	2,20	2,60	2,60	2,60	2,80
max	3,40	3,40	3,40	3,13	3,80	3,80	4,00	3,80

Discussion

The broad participation in the contest and the courses highlights the national interest and readiness to adopt 3d technologies in education. Schools from remote villages to bustling urban centers demonstrated their commitment to integrating 3D printing into their curricula, reflecting a nationwide movement towards modernizing education through technology. The inclusion of students from different economic environments and from special education schools emphasizes the most the accessibility and potential of 3D printing as a tool for bridging educational gaps. By providing equal opportunities for students from various backgrounds to engage with cutting-edge technology, this research highlights the democratizing potential of 3D printing in fostering creativity and skill development across Greece.

Similar initiatives at an international level reinforce these findings. In the United Arab Emirates, the integration of 3D printing in interdisciplinary STEM activities led to improved student attitudes toward science and technology, particularly when supported by trained educators (Khurma et all, 2023). The Makers Empire program in South Australia has been implemented in over 270 schools, showing measurable gains in spatial thinking and STEM engagement (Bower et all, 2018). In the United States, high school students participating in NASA's HUNCH program used 3D design to develop lunar surface tools, significantly boosting their confidence and scientific thinking (NASA, 2024). Likewise, in Japan, 3D printing was used to enhance geoscience education and produce assistive devices for children, promoting both applied learning and community service (Chenrai, 2021). These examples illustrate the global momentum toward using 3D technologies to foster creativity, inclusion, and practical skills development in education.

Hypothesis 1: Students under a design thinking intervention improve their creativity skills throughout the course of the contest. Creativity was measured by defining student actions such as acquiring competencies, taking risks, solving problems, embracing contradictions, innovative thinking, connecting, synthesizing, or transforming during the online supporting course. The increase in mean scores for both levels confirms the hypothesis that such activities support the development of creativity skills. Furthermore, both levels reach high scores at the end of the contest and a lot of them reach the capstones in the 5 categories of the Value Rubric. Even from the first evaluation, the mean score in the 4th week, which was the midpoint of the process, was high for both levels, indicating that these actions are integral to 3D designing projects. Notably, primary students' initial scores were higher than those of secondary students. This difference may be attributed to developmental and pedagogical characteristics specific to younger learners. Primary students are generally more open to imaginative thinking, less inhibited by rigid academic expectations, and more inclined to engage in playful experimentation—factors that align closely with the elements assessed in creativity rubrics. Additionally, the early educational environment often encourages exploration and non-linear thinking, whereas secondary education tends to emphasize structure, correctness, and measurable outcomes, which may constrain risk-taking and originality at initial stages.

Cronbach's Alpha values indicated internal consistency in the evaluations, highlighting the moderating effect of VALUE rubrics in the review process. This approach helped the evaluators the most, allowing them to moderate the review process effectively by identifying specific milestones in students assessments.

Hypothesis 2: Students under a design thinking intervention improve their problem-solving skills throughout their engagement in the 3d contest. The essays submitted by the teams for the contest served as valuable sources for assessing the problem-solving skills demonstrated by teams at both levels. Most essays accurately described the given problem, proposed solutions, and evaluated these proposals. Design thinking helped students form strategies and suggest methods of implementation. Secondary students appeared to be more efficient in

these procedures compared to primary students, who displayed a more playful attitude and less commitment to the goal.

Regarding Hypothesis 2, all three evaluators concurred that assessing the improvement in problem-solving skills cannot be conclusively determined at this stage of the research. The primary limitation is the one-time evaluation since the essays were the only evidence reviewed. Although problem-solving skills were evident in various aspects of their activities, proving their usefulness, measuring improvement requires a follow-up evaluation. This could be achieved by reviewing submissions in future 3D contests. The decision that we made to use the original Value Rubrics for both levels enrich our toolset for this purpose. A second limitation is that this evaluation could not be conducted for individual students but only for the entire team, as the essays were a collaborative effort.

Additionally, a critical examination of the evaluation design reveals that the structure of the final team essays may not have been ideally suited for capturing the full range of individual problem-solving processes. The open-ended nature of the assignment, while encouraging autonomy, may have allowed some students to participate passively, making it difficult to assess individual engagement. A more scaffolded assignment design—with required steps such as problem identification, brainstorming logs, prototyping sketches, and individual reflections—could provide richer data for future assessments. In contrast, creativity in Hypothesis 1 was measured using data gathered from the supporting course, which allowed us to collect data on individual engagement and improvement over time. To address this limitation, future assessments should integrate activities where problem-solving skills are used into the course. This approach can provide evidence of individual contributions and improvements.

Conclusion

The use of Project-Based Learning (PBL) combined with Design Thinking methodologies has proven to be effective in engaging students in complex 3D designing creative processes. Through structured courses and the integration of a national contest, students were encouraged to apply design thinking principles to develop innovative solutions, thus fostering a deeper understanding and practical application of their skills. This approach not only motivated students but also provided a platform for showcasing their work and receiving constructive feedback.

Creativity was notably developed during the 3D designing and printing activities across both educational levels. The findings underscore that creativity can be cultivated effectively through iterative design processes and collaborative exploration. Primary students in particular exhibited high levels of creative engagement, suggesting that early exposure to such pedagogies may be especially impactful.

While the study provides valuable insights into the use of problem-solving skills, assessing improvement remains inconclusive due to the one-time evaluation of essays. The assessment of problem-solving skills highlighted important methodological limitations—most notably the lack of longitudinal, individualized data. Addressing these limitations in future research and practice will allow for a more robust understanding of how such skills evolve over time and across learner profiles.

Beyond student outcomes, this study illustrates the broader potential of 3D printing as a democratizing force in education. Its successful application in rural, urban, and special education settings suggests that it can bridge geographical and social disparities. Policymakers and curriculum designers are encouraged to invest in infrastructure, teacher training, and accessible platforms that can support sustained integration of 3D technologies into mainstream and inclusive education.

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