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PAPER

The Role of 3D Printing in Science, Technology, Engineering, and Mathematics (S.T.E.M.) Education in General and Special Schools

Chrysovalantis Kefalis[1,2](✉), **Constantine Skordoulis**[2], **Athanasios Drigas**[1]

[1]N.C.S.R. "Demokritos", Athens, Greece

[2]National and Kapodistrian University of Athens, Athens, Greece

vkefalis@iit.demokritos.gr

ABSTRACT

This paper explores the significant role of 3D printing and digital applications in enhancing science, technology, engineering, and mathematics (STEM) education in both general and special schools. With the advent of the Fourth Industrial Revolution, the integration of these technologies into educational systems has become increasingly critical. This study reviews various study works that demonstrate how 3D printing technology enriches learning by fostering critical thinking and problem-solving skills and offering a more interactive and engaging educational experience. Special attention is given to its impact in special education, where it facilitates inclusive learning and aids in creating tailored educational tools. A case study from a vocational high school in Greece is presented, showcasing the successful implementation of a 3D printing and educational robotics club. This club highlights the practicality and effectiveness of 3D printing in enhancing student engagement and learning outcomes. The paper concludes by emphasizing the transformative potential of 3D printing in preparing students for future challenges and advocating for its wider adoption in STEM education.

KEYWORDS

3D printing, science, technology, engineering, and mathematics (STEM) education, digital applications, inclusive learning, educational robotics

1 INTRODUCTION

Digitization and the Fourth Industrial Revolution (Industry 4.0) arguably constitute the main drivers transforming productive activities in modern societies. These emerging needs are changing not only our way of life but, importantly, the educational needs and requirements of citizens, leading to an increasing demand for new digital skills in recent years, a trend predicted to accelerate in the future [1], [2].

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Education plays a role in preparing students for the future; however, the drastic changes render the mere use of a computer in the classroom insufficient.

3D printing, an advanced additive manufacturing method, is significantly transforming biomedical engineering by enabling the creation of complex medical devices and tools directly from digital models. This technology, which contrasts sharply with traditional methods like milling and molding, allows for the rapid production of models with intricate designs. It is particularly impactful in medical fields where precision and customization are paramount.

In biomedical applications, 3D printing is extensively used for surgical planning, medical education, and the fabrication of personalized medical devices. For example, it allows for the precise construction of anatomical models for surgical preparation, improving outcomes in complex procedures. Notably, the technology has been pivotal in developing patient-specific prosthetics, including intricate components like cardiac stents and orthopedic implants tailored to individual anatomical requirements [3].

These emerging needs are changing not only our way of life but, importantly, the educational needs and requirements of citizens, leading to an increasing demand for new digital skills in recent years, a trend predicted to accelerate in the future [1], [2]. Education plays a role in preparing students for the future; however, the drastic changes render the mere use of a computer in the classroom insufficient.

Under these circumstances, the importance of education in science, technology, engineering, and mathematics (STEM) fields plays a central role in education. STEM education fosters innovation, critical thinking, and problem-solving skills essential for the future competitiveness of students. 3D printing technology is a valuable teaching resource within STEM education. 3D printing allows the creation of digital model's layer by layer and enhances students' abilities in problem-solving, collaboration, communication, and critical thinking. It supports the transition from traditional educational methods to more dynamic, 3D learning experiences [4].

The purpose of this paper is to briefly explore the use of 3D printing in STEM educational settings and also present the application of a 3D printing club in a vocational school in Greece.

2 3D PRINTING IN STEM EDUCATION

In the evolving landscape of STEM education, the advent of 3D printing technology marks a pivotal shift, reshaping teaching and learning paradigms.

Sun and Li [4] discussed the integration of 3D printing technology into STEM education, underscoring its transformative potential in educational methodologies. It references the "STEM 2026: A Vision for Innovation in STEM Education" report by the United States Institute and the US Department of Education, which outlines a future vision for STEM education. This vision encompasses various aspects such as practical community involvement, innovative activity design, enriched educational experiences, dynamic learning spaces, effective learning measurement, and a supportive social and cultural environment. The report posits that 3D printing can create realistic learning scenarios for students, making education more engaging and relevant by linking it to real-world contexts and problems. They also emphasized the role of 3D printing in facilitating cross-disciplinary integration within STEM education, which is crucial for nurturing students' visual and spatial abilities and fostering their capacity for independent innovation. It illustrates how 3D printing technology can be applied across various disciplines, enhancing the learning experience by providing tangible teaching aids and fostering a blend of theoretical knowledge and practical application. In particular, it highlights the use of 3D printing in art and mathematics education, where complex concepts and geometric shapes can be visualized and made more comprehensible to students. This approach not only aids in understanding but also stimulates interest and creativity in learning.

In a study conducted by Lin et al. [5] that focused on the impact of 3D printing technology and modeling principles on the engineering design process and knowledge structures of senior high school students, the study involved 43 male 10th-grade students from two classes in a senior high school, with one class serving as the experimental group using 3D printing in STEM project-based activities and the other as a control group without 3D printing. The methodological approach included in-depth interviews, the flow-map method, and the meta-listening technique, analyzing key variables like extent, correctness, integration, availability, and information processing strategies. The findings revealed that the experimental group showed improvement in explaining concepts and demonstrated notable progress in modeling and feasibility analysis, suggesting that 3D printing and modeling principles aided in developing a deeper understanding in these areas. These findings indicate the potential for future study to further explore the impact of multiple modeling tasks on students' study design abilities.

Kamat and Nasnodka [6] examined the impact of multiple factors, including 3D printing, on behavioral, cognitive, emotional, and tech engagement among 318 STEM students, employing elastic net regression for analysis. The investigation was centered on how these factors influence student engagement in different aspects of their educational experience. The results revealed key influences across the four engagement types. In behavioral engagement (BE), cognitive engagement (CE), and emotional engagement (EE), teacher-student interaction (TSI), assignment completion rate (ACR), and class participation (CP) consistently emerged as positive drivers. conversely, external stressors (ES) and class size (CS) were found to negatively impact engagement levels across these categories. Notably, Tangible Visualization with 3D Printing (TV3DP) demonstrated a neutral to positive effect, indicating its potential for enhancing engagement, though its impact varied depending on the specific engagement type and subject material. In the context of tech engagement (TE) within learning management systems (LMS), similar trends were observed. ACR and TSI positively influenced TE, suggesting effective utilization of digital platforms. Again, ES negatively affected engagement, while TV3DP showed a neutral to positive influence, underscoring its possible role in enhancing digital learning experiences when integrated effectively with LMS. These findings provide valuable insights into the factors influencing student engagement in STEM education, particularly highlighting the varied impact of 3D printing technology.

Bicer et al. [7] explored the impact of informal STEM learning through a project-based approach, specifically focusing on 3D printing activities. Conducted at a two-week STEM summer camp in 2016 on a university campus in central Texas, it involved 95 high school students (32 female and 63 male) from a diverse range of ethnic backgrounds. The students, selected on a first-come, first-served basis without consideration of academic ability, STEM interest, ethnicity, or gender, were introduced to a hands-on learning environment that blended theory with practical application. In the camp, students engaged in 3D printing and project-based learning (PBL) activities. They utilized CAD software such as Sketch-Up® and XYZ to design and build 3D objects. The curriculum emphasized the engineering design process, encompassing steps from problem identification to reflection. The main project required students to create an educational object using 3D printing, adhering to specific design and size constraints. The learning outcomes targeted skills in scaling, spatial awareness, engineering principles, science and mathematics vocabulary, and technology usage. This approach allowed students to experience the iterative nature of engineering design, tackling common design challenges and refining their projects based on feedback and testing. The effectiveness of this educational intervention was assessed through a pre-post survey conducted via Qualtrics, using Likert-scale questions to gauge students' learning and perceptions. Although the specific results of this survey were not detailed in the accessed section of the manuscript, they likely provided valuable insights into how the PBL approach influenced students' engagement with STEM subjects, their comprehension of engineering and design principles, and their ability to apply theoretical knowledge in practical settings. This study underscores the value of PBL in stimulating student interest and competence in STEM fields, especially through creative and application-based methods such as 3D printing.

In a study performed by Yi Lin et al. [8], which involved 196 high school students from Taiwan and used a quasi-experimental design to investigate the impact of repetitive modeling in STEM activities on student imagination and interest in STEM careers. Specifically, the activity focused on designing a vibration isolator using 3D printing. The methodology included evaluating students' imaginative capabilities and their interest in technology and engineering careers, both before and after the project. The study found that repetitive modeling significantly enhanced students' imaginative skills and increased their interest in pursuing careers in technology and engineering.

In the field of geometry, Lam Ng and Huiyan Ye [9] conducted a study that employed a mixed-methods design-based study approach. It involved 117 Primary 6 students (ages 11–12) from two Hong Kong schools, focusing on learning 3D geometry through handheld 3D printing pens. The methodology included pretests and posttests to gather quantitative data on students' understanding before and after the intervention. Additionally, classroom observations and analysis of created artifacts provided qualitative insights. The results showed significant improvements in students' comprehension of 3D geometry, demonstrating the effectiveness of the embodied, hands-on learning approach facilitated by 3D printing technology. This method enhanced students' spatial visualization skills and deepened their understanding of geometric properties.

Study carried out by Novak and Wisdom [10] examined the effects of a 3D printing PBL approach on preservice elementary teachers' attitudes towards science. The participants were 42 preservice teachers (one male) in their junior or senior year at a large midwestern university in the USA. They engaged in a three-week project involving the design and testing of 3D-printed boats to explore concepts of buoyancy and density. The methodology included pre- and post-intervention surveys measuring science teaching anxiety, self-efficacy, interest in science, and content knowledge. Key findings included a significant decrease in participants' science teaching anxiety and improvements in their science teaching efficacy, science interest, and perceived competence in K-3 technological and engineering design science standards. However, the intervention did not significantly increase their science content knowledge. The study highlights the potential of 3D printing projects to enhance preservice teachers' attitudes towards science teaching.

Study work by Dilling and Witzke [11] at the University of Siegen, Germany, focused on the use of 3D-printed graphs in understanding the concept of derivatives in calculus education. The methodology involved a qualitative case study with five 10th-grade students who had been introduced to differential calculus. These students interacted with the software Graph Printer and 3D-printed graph models, completing various tasks and questionnaires. The study, which lasted about three hours for each group, was videotaped and analyzed using qualitative content analysis. The findings revealed that the use of 3D-printed models facilitated the students' understanding of the derivative concept. Specifically, the study identified three main categories: subjective domains of experience (SDE), concept formation derivatives, and objects of reference. These categories highlighted how students used their previous experiences, interacted with the 3D models, and referred to empirical objects to develop their understanding of calculus concepts, particularly the derivative. The students' experiences with the 3D models and software helped them to visualize and physically interact with mathematical concepts, enhancing their conceptual understanding in a novel and engaging way.

The study conducted by Schelly et al. [12] and [13] at Michigan Technological University focused on the use of open-source 3D printing in education. Twenty-two middle and high school teachers participated in a 3- and 1/2-day workshop to learn and implement this technology. They constructed 3D printers with the aim of integrating them into their curricula. Teachers found the workshop transformative, reporting increased empowerment and potential for educational impact. They envisioned 3D printing as a tool for engaging students across various subjects, fostering a shift from passive learning to active creation. A year after the workshop, the use of 3D printers varied among schools, indicating diverse levels of integration. The study highlighted the importance of hands-on technological experiences in education, underscoring the role of teacher training and curriculum development in maximizing the benefits of innovative technologies such as 3D printing.

2.1 3D printing in medical or assistive devices

3D printing has revolutionized the creation of customized medical and assistive devices, offering tailored solutions for individual needs. This section explores various studies that highlight the application, challenges, and educational integration of 3D printing in healthcare, demonstrating its potential and practicality in enhancing patient care and learning outcomes.

In a case study on co-designing an assistive device using 3D printing, conducted at a rehabilitation institute involved in the OpenCare project, a middle-aged woman with severe upper extremity impairments participated in creating a device to aid in eating [14]. The methodology incorporated a literature review, a pilot survey at a conference that showed a strong interest among individuals with disabilities in making their own devices, and a detailed case study using digital fabrication tools, including 3D printers and user-friendly, collaborative CAD software. The device's effectiveness was evaluated using the individually prioritized problem assessment (IPPA) questionnaire, which revealed that while the device facilitated some improvement in performing daily tasks, the participant did not find it practical enough for regular use compared to receiving assistance. The process involved about 14 hours of 3D printing and significant time from the participant and facilitators, illustrating both the empowering potential of digital fabrication in custom assistive device production and the challenges related to time investment and device practicality.

In a study assessing the use of 3D printing to enhance learning in mechanical component design [15], researchers introduced 3D printing into a mechanical engineering course to evaluate its impact on students' learning outcomes. The course aimed to help students overcome the challenges of transitioning from virtual designs to real-world applications, enhance creativity, and understand the complexities of mechanical design, which include drawing, statics, dynamics, and material mechanics. Methodologically, the course included creating 3D models of assistive devices, followed by actual printing to materialize these designs, which helped bridge the gap between theoretical designs and tangible outcomes. This hands-on approach was anticipated to enhance the learning experience by integrating practical skills with theoretical knowledge. The effectiveness of this educational innovation was measured using pre- and post-course questionnaires that assessed various aspects of student learning and engagement. The results indicated significant improvements in understanding and applying mechanical design principles, suggesting that 3D printing could effectively enhance mechanical engineering education by providing students with a more interactive and practical learning experience.

A study conducted by researchers from Penn State University [16] focused on evaluating the effects of a professional development (PD) program on high school biology and technology and engineering (T&E) teachers' perceptions of incorporating 3D printing into biomedical engineering education. The PD, attended by 26 teachers from 13 school districts in Pennsylvania, consisted of two 10-hour online sessions featuring expert presentations on 3D printing applications in biomedical fields. Surveys administered before and after the sessions revealed that while overall perceptions about the utility of 3D printing did not significantly change ($p = .058$), there was a significant increase in the intent to use 3D printing in future instruction ($p = .002$). Additionally, the results showed a gender difference, with male teachers reporting a significantly greater positive change in perceptions than female teachers ($p = .048$). The study underscores the influence of PD in enhancing educators' intentions to integrate advanced technologies such as 3D printing into their curricula, although it suggests varying impacts based on gender.

Researchers collaborated with physical therapy professors and students at a medical university to explore the integration of 3D printing into a graduate-level physical therapy course [17]. The methodology involved surveys and collaborative design sessions, engaging both practicing physical therapists (PTs) and PT students to assess perceptions and practical applications of 3D printing in clinical settings. The results indicated that 3D printing is a viable tool for creating customized, economical assistive technologies. Key findings highlighted the need for improvements in novice 3D modeling software and identified challenges such as adjusting prototype fidelity and selecting appropriate printing materials. The study contributes valuable insights into the incorporation of 3D printing in healthcare education and the development of assistive devices.

2.2 3D printing in special education

In the dynamic field of special education, 3D printing emerges as a transformative tool, revolutionizing learning experiences for students with diverse needs.

Study work by Andic et. al. [13] involved 38 participants (31 students without disabilities and seven with disabilities) across five primary schools in Montenegro. It explored the impact of 3D printing on the verbal and nonverbal interactions between these students in an inclusive educational setting. The methodology included classroom observations, audio and video recordings, and questionnaires. Results showed no significant statistical difference in positive interactions between students with and without disabilities but a significant difference in negative verbal interactions. Both groups positively viewed cooperative learning with 3D printing, noting enhanced communication and learning. The study contributes to understanding the socio-affective dynamics of inclusive education with technology integration.

The study [18] was conducted by researchers from the University of Maryland, Baltimore County, and the University of Colorado, Boulder. It explored the use of 3D printing in special education across three sites: two schools (one for students with cognitive impairments and another for those with vision impairments) and a national organization's technology division supporting blind individuals. Methodologically, the study involved classroom observations, interviews with teachers, therapists, and technical experts, and co-design efforts with occupational therapists. The study found that 3D printing serves multiple functions in special education, including fostering STEM engagement, aiding in the creation of educational tools, and producing custom adaptive devices. Despite the potential benefits, significant challenges were identified, including a steep learning curve for 3D design software, the need for substantial technical support, and concerns about printer safety and reliability. The study recommends more accessible 3D printing and modeling software, the sharing of existing 3D models, and cautious resource allocation considering printer reliability and training time.

A team from the University of Maryland, Baltimore County, conducted a study study [19] that focused on teaching 3D printing skills to a group of 12 students, half of whom had intellectual disabilities (ID). The course emphasized entrepreneurship and included students aged 18–27. Methodologically, it combined interviews with mainstream 3D printing educators, a one-on-one instructional case study, and a semester-long integrated course. The findings demonstrated that students with ID could effectively learn and apply 3D printing skills, fostering confidence and employability. Challenges included technical issues with 3D printing and the complexity of software tools. The course's success suggested positive implications for inclusive education and employment for people with ID.

3 CASE STUDY IN VET EDUCATION—3D2ACT PROGRAM

In the 2022–2023 school year, the 1st Vocational high school of Salamis, Greece, operated a STEM group: 3D Printing and Educational Robotics. This group was conducted outside the regular teaching schedule throughout the school year, with both students and teachers participating voluntarily.

The implementation of this particular action was prompted by the invitation the school received to implement the pilot application of the educational package produced within the framework of the European Erasmus+ program: 3D2ACT Fostering Industry 4.0 and 3D Technologies through Social Entrepreneurship: An Innovative Programme for a Sustainable Future, which encourages students to acquire basic skills in areas such as 3D design and printing technologies. This invitation for the pilot application at the said school represented a prime opportunity to implement a STEM teaching approach, combining 3D skills with experiences in applications and teachings related to the field of educational robotics, which have been conducted over the last nine years at the school.

The purpose of this section is to present the application of the 3D Printing and Educational Robotics Club, highlighting the dynamics developed, the challenges, and the outcomes such an application can have in the environment of vocational education.

3.1 Methodology of implementation

A group of ten freshmen from a high school STEM club embarked on a project without any previous exposure to 3D printing or educational robotics. This project was divided into two stages. Initially, the students learned about 3D design and printing.

Following this, they moved on to the practical aspect, where they individually designed, created, assembled, and programmed their own robots, guided by worksheets.

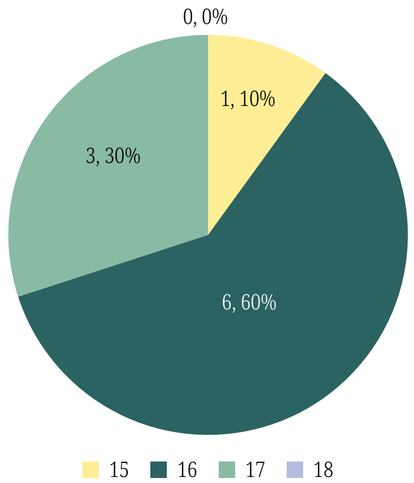

Fig. 1. Age range of students

The data, as depicted in Figure 1, indicates that these students were in the 15–17 age range, predominantly around 16 years old. These participants were all novices in 3D printing, and three faced challenges in learning. Furthermore, Figure 2 reveals a significant gender disparity: 80% of the participants, or 8 out of 10, were male.

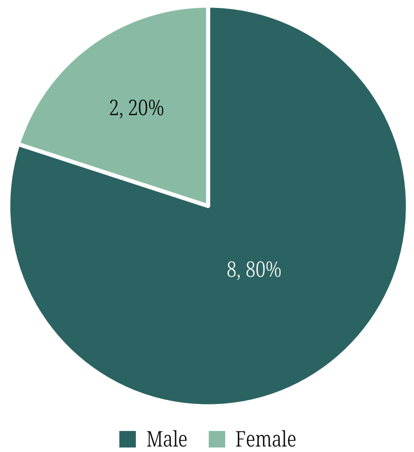

Fig. 2. Gender of participating students

Pilot sessions for the 3D2ACT program were conducted face-to-face, with students participating in an after-school 3D printing club. These sessions were supplemented by online, self-guided learning through a digital e-learning and collaboration platform. This platform offered extensive materials on 3D printing and social entrepreneurship, in addition to facilitating group discussions and communication. The following is a concise overview of the initiatives undertaken within the STEM Club at the 1st Vocational High School of Salamis.

3D design and printing. The instructional content for the introductory phase of 3D printing was organized across two progressively challenging levels. Initially, students who were new to 3D technologies were introduced to 3D printing through activities aimed at developing fundamental skills for their initial printing tasks.

Subsequently, in a more advanced phase, they engaged in guided projects to design and create 3D models usable in daily life. This approach was underpinned by the differentiated blended learning method [20]. The students accessed these resources through the e-learning and collaboration platform of the 3D2ACT project. The 3D design tool they utilized was freely available online software that did not require installation. This format allowed students to learn at their own pace, extending their study beyond classroom sessions. Additionally, they completed some of the worksheets in their personal time.

Educational robotics. Educational robotics is an ideal application area for the STEM teaching methodology, as it encompasses the interdisciplinary essence central to this educational strategy. The curriculum was structured around the dimensions and functions of various components (mechanical, electrical, and electronic) along with their aesthetic aspects. This enabled students to familiarize themselves with both standard and innovative components and technologies, including the integration of their functionalities.

Throughout the program's execution, we encountered a number of challenges. Issues with infrastructure were somewhat mitigated by allocating extra 3D printer access to students outside regular club hours. A notable number of students initially expressed skepticism and unease towards this novel educational method, which was quite different from their usual morning school routine. This resulted in some reluctance to participate. Being a completely new initiative, the program also presented difficulties in comprehension, requiring students to adapt and become accustomed to the new methods. In response, we employed various tailored teaching strategies to cater to the diverse educational needs and learning paces of the students. While some students rapidly developed proficiency in 3D design, printing, and robotics, others required more time to grasp these concepts. Therefore, our instructional approach was modified to offer extra support to those who needed it while simultaneously providing more challenging tasks to the quicker learners. Our educational resources were designed for flexibility, where accessible from any location via the platform, and allowed students to advance at their own pace. Furthermore, the smaller class sizes enabled educators to offer individualized assistance where needed.

3.2 Results

Upon concluding the STEM club activities at the 1st Vocational High School of Salamis, we sought feedback from the students on the 3D printing curriculum. The ensuing data is depicted in Figure 3, which presents a comprehensive overview of the students' assessments regarding the 3D printing learning materials.

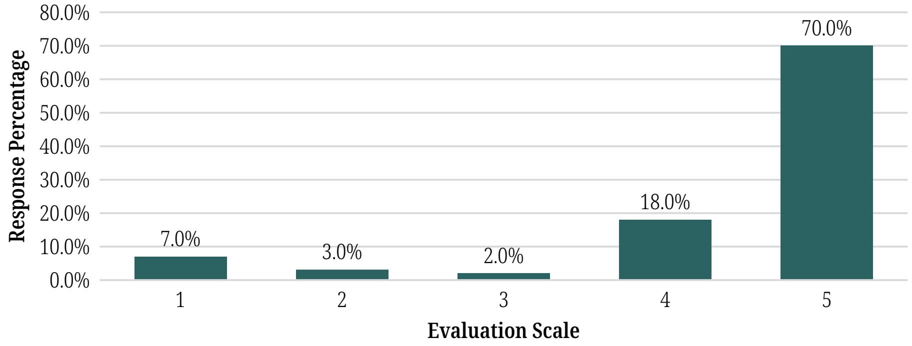

Fig. 3. Evaluation of 3D printing learning material by students

A primary analysis of the graph clearly shows that a considerable majority of the students, precisely 88%, expressed different degrees of positive reception towards the 3D printing educational materials and the teaching approaches used. This observation is especially noteworthy given that these students had no previous background in 3D printing.

Further examination is provided by the following table, which breaks down the evaluation of the 3D printing learning material. It details the percentage breakdown for each response category, adhering to the defined 5-point Likert scale that measures levels of agreement.

Table 1. Students' evaluation of 3D printing material items

3D Printing Material	Strongly Disagree	Disagree	Neither Agree/Disagree	Agree	Strongly Agree
A1. The content of 3D printing classes was interesting.	0.0%	0.0%	0.0%	0.0%	100.0%
A2. The content of 3D printing classes was useful.	0.0%	0.0%	0.0%	10.0%	90.0%
A3. I had previous experience in the field of 3D printing.	70.0%	30.0%	0.0%	0.0%	0.0%
A4. The content of the classes was compatible to the level of my knowledge.	0.0%	0.0%	0.0%	70.0%	30.0%
A5. It was easy for me to attend the classes.	0.0%	0.0%	20.0%	50.0%	30.0%
A6. The duration of the classes was adequate.	0.0%	0.0%	0.0%	50.0%	50.0%
A7. The structure (organization) and the development of the material (Units/Chapters) have helped me to assimilate the new knowledge.	0.0%	0.0%	0.0%	0.0%	100.0%
A8. The instructions and the presentation of the material were comprehensible and clear.	0.0%	0.0%	0.0%	0.0%	100.0%
A9. The worksheets have helped me to understand the material that was taught.	0.0%	0.0%	0.0%	0.0%	100.0%
A10. The whole material has helped me to learn in a productive way.	0.0%	0.0%	0.0%	0.0%	100.0%

Table 1 illustrates the findings from the 3D printing class survey, which indicate overwhelmingly positive feedback from the participants. Every respondent (100%) strongly agreed that the 3D printing class content was engaging and beneficial. A majority of them (70% strongly disagreed, 30% disagreed) were novices in the field, yet they found the material appropriately tailored to their level of knowledge (100% agreed or strongly agreed).

Responses varied slightly regarding the convenience of attending the classes, with 80% agreeing or strongly agreeing and 20% remaining neutral. However, the duration of the classes was unanimously considered fitting by all respondents (100% agreed or strongly agreed). The organization and structure of the material received high acclaim, with complete agreement among respondents that it facilitated the assimilation of new knowledge. Additionally, the clarity and comprehensibility of instructions and presentations were unanimously appreciated. The worksheets were unanimously seen as beneficial in understanding the content, and the material was universally regarded as conducive to productive learning.

While the study's limited scope precludes broad generalizations, the results indicate a successful implementation of the 3D printing and educational robotics club at the 1st Vocational high school of Salamis, significantly enriching the school's environment. Students acquired competencies in contemporary 3D design and printing technologies, grasped the scientific concepts behind 3D printing, identified the components and operations of a 3D printer, and understood the practical implications and career prospects of 3D printing. They also comprehended the advantages, challenges, pros and cons of 3D printing, including the process, software, and additional equipment needed for creating a 3D print. Furthermore, they developed skills in coding and learned about the collaborative functions of microprocessors, sensors, actuators, and mechanical components, as well as the application of the 'circular' engineering design process (EDP) method [21].

At the school year's conclusion, the club members organized a showcase of their work for the entire school community. This event offered students, educators, and parent's insights into the capabilities of 3D printing and robotics. The event also sparked interest among many students in joining a similar club in the following academic year. A particularly notable outcome of the differentiated teaching approach was the significant progress observed in student G, diagnosed with autism spectrum disorder (ASD) and possessing normal intellectual capabilities but facing substantial social skill challenges. To support Student G, teachers implemented several tailored strategies. They provided one-on-one sessions to help him understand the social cues and collaborative aspects of the club activities better. Visual aids and step-by-step guides were used to simplify complex tasks, making them more accessible. Teachers also facilitated peer mentoring, pairing Student G with fellow club members who demonstrated empathy and leadership skills. This nurturing environment not only helped him integrate better into the team but also built his confidence. His involvement in the club was highly rewarding, culminating in his successful presentation of his work to the whole school, which was a proud moment for everyone involved.

4 CONCLUSION

The exploration of 3D printing and its applications in STEM education, both in general and special schools, demonstrates its significant transformative potential. The integration of 3D printing into educational settings has been shown to enhance student engagement, foster creativity, and improve understanding of complex concepts across various STEM disciplines.

Key findings from various studies indicate that 3D printing aids in the development of critical thinking and problem-solving skills and promotes a more dynamic, hands-on learning experience. This technology has been effective in bridging theoretical knowledge and practical application, making learning more relevant and engaging. In particular, its application in geometry education, engineering design processes, and the visualization of complex mathematical concepts such as derivatives has yielded positive educational outcomes.

In the context of special education, 3D printing has emerged as a powerful tool for inclusive learning, enhancing interactions between students with and without disabilities and supporting the development of custom educational and adaptive tools. The technology's adaptability and the hands-on experience it provides have proven beneficial in engaging students with diverse learning needs, including those with cognitive or vision impairments.

The case study from the 1st Vocational High School of Salamis further underscores the effectiveness of 3D printing in education. The 3D Printing and Educational Robotics Club demonstrated that students without prior experience in 3D printing could not only grasp the technology but also apply it creatively to projects. The club's success in fostering skills in 3D design, printing, and robotics, and the positive feedback from students, parents, and educators alike, highlight the practicality and appeal of incorporating 3D printing into the curriculum.

Furthermore, the case study also illustrates the importance of differentiated teaching methods and the need for schools to adapt their infrastructure and teaching approaches to accommodate new technologies like 3D printing. The positive change observed in students, especially those with learning difficulties such as ASD, points to the inclusive nature of this technology.

In light of these findings, it is evident that 3D printing technology holds immense potential for enhancing STEM education. Its ability to provide hands-on, experiential learning, coupled with the growing importance of digital skills in the modern world, makes it a valuable addition to educational curricula. Future study and applications should continue to explore and expand the use of 3D printing in education, ensuring that students are equipped with the skills and knowledge necessary to thrive in a rapidly evolving technological landscape.

Last but not least, we emphasize the significance of all digital technologies in the field of education and especially in STEM for all, which are very effective and productive and facilitate and improve the assessment, the intervention, and the educational procedures via mobile devices that bring educational activities anywhere [22], [23], various ICT applications that are the main supporters of education [24], [25], and AI, STEM, games, and robotics that raise educational procedures to new performance levers [26], [27], [28]. Additionally, the improvement and blending of ICTs with theories and models of metacognition, mindfulness, meditation, and emotional intelligence cultivation [1], [22], [23], [24], [25], [27], [28], [29], [30], [31], [32], [33], [34], [35] accelerates and improves even more STEM educational practices and results, both in general and special schools.

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6 AUTHORS

Chrysovalantis Kefalis is a PHD Candidate at N.C.S.R. “Demokritos” and National and Kapodistrian University of Athens (E-mail: vkefalis@iit.demokritos.gr).

Constantine Skordoulis is a Professor at the Department of Primary Education, National and Kapodistrian University of Athens (E-mail: kskordul@primedu.uoa.gr).

Athanasios Drigas is a Research Director at N.C.S.R. ‘Demokritos’, I.I.T, Net Media Lab & Mind-Brain R&D, Agia Paraskevi, 153 10, Athens, Greece (E-mail: dr@iit.demokritos.gr).