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Exploring the impact of 3D printing integration on STEM attitudes in elementary schools

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ABSTRACT

This study explored how students and teachers perceived the interdisciplinary integration of 3D printing technology in teaching and learning within the United Arab Emirates (UAE) elementary schools and its relation to students' attitudes toward STEM careers. The study participants were 148 students and seven teachers from two elementary schools in the UAE. Technological, pedagogical, and content knowledge framework was used to guide the planning and integration of 3D printing into teaching and learning. Both quantitative and qualitative data collection tools were used to collect data from students and teachers. The data collection tools included a student's survey, teachers' interviews, and students' focus group interviews. The study's findings confirmed those of existing literature, which stressed the positive perceptions of students and teachers regarding the interdisciplinary integration of 3D printing technology in teaching and learning. Furthermore, students' perception was positively correlated with students' attitudes toward STEM careers. However, the study found that teachers were more likely to implement 3D printing in their classrooms when they receive proper training on the pedagogical and technical aspects of 3D printing, and hence addressing the possible challenges of integrating this technology in teaching and learning.

Keywords: 3D printing, STEM, interdisciplinary integration, teacher's perception, student's perception

INTRODUCTION

Three-dimensional printers (3D printers) are used in healthcare, architecture, robotics, manufacturing, education, etc. (Jandyal et al., 2022). The education sector has long benefited from 3D printing. Using 3D printers, students design objects online and then print them as 3D models (Kaur, 2012). This approach, known as rapid prototyping, assists students in understanding the concept development process (Ford & Minshall, 2019). This process provides students ways to experiment and gain valuable experience through trial and error. Additionally, it enables them to practice problem-solving, as they identify design flaws prior to attempting further modifications. In addition, 3D printing helps students visualize abstract concepts such as mathematical equations and scientific concepts (Medina Herrera et al., 2019; Weisberg & Newcombe, 2017).

3D printing enables students to develop a genuine connection to the topic by physically manipulating pre-printed instructional aids or creating their own tools (Cheng et al., 2020). This hands-on component of 3D printing increases students' engagement and participation, especially K-12 students (Yuen, 2020). Therefore, integrating 3D printing in the classroom can promote learning, foster skill development, and boost student involvement. 3D project-based activities give teachers the ability to teach lessons with a creative twist while assessing student understanding at the same time (Lin et al., 2018).

An effective method to integrate 3D printing in the classroom is through interdisciplinary teaching. This approach enables students to utilize their skills and knowledge from multiple subjects to solve problems creatively and critically (Aydin-Gunbatar, 2020; Huri & Karpudewan, 2019; Yuceler et al., 2020). As a result, students gain a comprehensive understanding of the issue and provide thorough solutions. 3D printing aids this approach by facilitating the integration of STEM subjects. This approach is predicted to increase students' interest, motivation, and engagement (Han et al., 2021). It is used to help facilitate hands-on STEM experiments that enable students to understand the core concepts. In addition, researchers suggest that the use of 3D printing in the classroom inspires and empowers the next generation of students to focus on STEM education. 3D printing provides an opportunity to engage students in STEM concepts through designing and building activities. It can also encourage creativity, enhance attitudes toward STEM courses and jobs, and boost teacher's interest and engagement (Assante et al., 2020; Brannon et al., 2020; Grumman & Carroll, 2019; Pinger et al., 2020).

Despite the potential of 3D printing to improve teaching and learning. There is a lack of research studies in the field of education with respect to the interdisciplinary integration of 3D printing technology. This lack of research studies, particularly in the context of elementary schools in the United Arab Emirates (UAE), poses a significant problem. There is a critical knowledge gap regarding the effective implementation and integration of this technology. This knowledge gap hinders the understanding of how best to integrate 3D printing in the curriculum and limits its potential to support learning outcomes in the UAE educational system. Furthermore, teachers in the UAE schools lack adequate training in both the technical operation of 3D printers and the effective integration of this technology into their lessons, which presents a significant challenge. Without proper training and guidance, teachers may struggle to integrate 3D printing into their curriculum, thus limiting its potential impact on student engagement and learning. Therefore, there is a pressing need for research to address these challenges and provide valuable insights into effective strategies for integrating 3D printing technology in teaching and learning in the UAE elementary schools. By filling the existing knowledge gap, this research can inform the development of effective approaches that enhance student learning, engagement, and preparation for STEM careers in the UAE education system.

In addition, exploring teachers' and students' perceptions of the interdisciplinary integration of 3D printing in teaching and learning is a crucial step towards understanding how to effectively use this technology in elementary schools. By analyzing how teachers and students perceive this integration, researchers and educators can gain insight into the effectiveness of the technology in supporting student learning and engagement, as well as identify potential obstacles to successful integration. Understanding these perceptions can also inform professional development programs for teachers and promote student-centered learning by adapting activities and projects to meet student interests and requirements. Gaining valuable insights into the benefits and challenges brought by the integration of 3D printing technology can enable educators to develop effective strategies to enhance student learning and engagement. Therefore, the research questions for the current study are:

1. What is the relationship between students' perception of the integration of 3D printing into teaching and learning and students' attitude toward STEM careers?
2. What are teachers' perceptions of the interdisciplinary integration of 3D printing technology in teaching and learning?
3. What are the challenges and issues faced by teachers in integrating 3D printing into their lessons?

THEORETICAL FRAMEWORK

This study explores the integration of 3D printing technology in teaching and learning within the UAE elementary schools and its relation to students' attitudes toward STEM careers. The theoretical framework that was used to guide this study is pedagogical, technological, and content knowledge (TPACK). It was used to guide 3D printing planning and integration. TPACK provides a framework for analyzing the complex interactions between technology, pedagogy, and content knowledge.

Technology knowledge (TK) component of TPACK refers to the technological knowledge. It focuses on the knowledge of the tools and technologies used in teaching and learning. Teachers and students need to have a basic understanding of the technical aspects of 3D printing, such as designing 3D models and operating the 3D printer. This technical knowledge is essential for effective teaching and learning (Mishra & Koehler, 2006). To attend to this component in the current study, teachers were trained fully in the 3D design software (TinkerCad) and the operation of the 3D printers. In addition, mini trainings were conducted during the implementation related to the technical operation of the 3D printing and its maintenance. Furthermore, in collaboration with information technology (IT) teachers, the curriculum was adjusted to incorporate TinkerCad into IT lessons to train the students in using it. TinkerCad is a widely used 3D modeling software that enables users to create and manipulate 3D models using a simple and intuitive interface (Cline, 2015). It is a browser-based tool that requires no installation or special hardware, making it easily accessible to students and teachers alike (V, 2023). TinkerCad is an important technological aspect of TPACK in this study, as it is the software used by teachers and students to create and print 3D models. Previous research has shown that TinkerCad is effective in teaching students 3D design and modeling skills (Martinez & Stager, 2013). TinkerCad also allows teachers to create and share 3D design projects with their students, providing them with engaging and challenging learning opportunities (Alamr, 2021).

TinkerCad is an important technological aspect of the TPACK model that enables effective integration of 3D printing technology in teaching and learning that promote students' interest in STEM careers (Bhaduri et al., 2021). For example, designing and modeling objects in TinkerCad can help students develop a strong foundation in computer-aided design (CAD) (Ng & Chan, 2019), which is essential for careers in engineering, architecture, and product design. Additionally, TinkerCad allows students to explore and experiment with various concepts in physics and mathematics, which are crucial for careers in fields such as robotics, aerospace engineering, and data science (Ulbrich, 2020).

Content knowledge (CK) component of TPACK refers to the knowledge and skills that the teachers need to effectively teach a particular subject matter. In the current study, CK refers to the teachers' knowledge and skills of science, mathematics, and English. This means the teachers in this study have a solid understanding of the key concepts, principles, and practices related to these three subject areas. The teachers in this study were trained on how to map the learning outcomes, knowledge, and skills from the three subject areas and incorporate them into a unit plan (Khine et al., 2017; Mishra & Koehler, 2006). This involves identifying the key concepts, principles, and skills that students need to learn in each subject area and determining how these concepts can be integrated into a coherent unit of instruction. The teachers in this study were also trained to integrate science, mathematics, and English in a meaningful way. This interdisciplinary integration helps students to see the connections between these subject areas and to understand how they are all interconnected, and it refers to pedagogical content knowledge (PCK) in TPACK (Khine et al., 2019; Mishra & Koehler, 2006).

Technological pedagogical knowledge (TPK) component of TPACK in this study refers to teachers' knowledge of teaching and learning strategies of 3D printing technology that can help them design effective learning experiences for their students (Voogt et al., 2013). TPK recognizes that effective technology integration requires a deep understanding of both the technical aspects of the technology and the pedagogical strategies that can be used to implement it effectively (Niess, 2005). Teachers' understanding of 3D printing technology and its pedagogical implications are crucial for effective teaching and learning (Koehler & Mishra, 2009). The teachers in the current study were trained in developing interdisciplinary unit plans to integrate three subjects (science, mathematics, and English) with the integration of 3D printing. The teachers were trained to create interactive and engaging lessons to gauge students understanding. The research team worked closely with the teachers in the development and implementation of the unit plans. The teachers were trained to provide opportunities for collaboration and communication and support student-centered and inquiry-based learning by integrating 3D printing in meaningful ways (Yi et al., 2016).

In conclusion, the current study has explored the integration of 3D printing technology into interdisciplinary STEM education through the lens of TPACK framework.

Another theoretical framework was used to guide this study is unified theory of acceptance and use of technology (UTAUT). It is a theoretical model that helps understand the factors influencing teachers' and students' acceptance of technology. UTAUT incorporates several key constructs to explain technology adoption, including performance expectancy, effort expectancy, social influence, and facilitating conditions (Willimas et al., 2015). In the context of 3D printing integration in education, UTAUT can be applied to understand the factors influencing teachers' and students' perception of this technology. When examining the integration of 3D printing in education, UTAUT offers valuable insights into the factors that shape teachers' and students' perception of this technology (Holzmann et al., 2020). Let's delve into the key constructs of UTAUT and their relevance to the acceptance and adoption of 3D printing:

Performance Expectancy

This construct investigates individuals' belief in the potential of a specific technology, such as 3D printing, to enhance their performance and improve learning outcomes. In an educational context, teachers and students may perceive 3D printing as a tool capable of fostering creativity, problem-solving skills, and engagement. This positive perception influences their acceptance of the technology (Holzmann et al., 2020; Ukobitz, 2020).

Effort Expectancy

Effort expectancy focuses on users' perception of the ease of use associated with a technology. It revolves around how teachers and students perceive the simplicity and user-friendliness of 3D printing technology. When teachers and students find the tools and processes involved in 3D printing easy to understand and operate, their acceptance and adoption of this technology in educational settings are more likely to be encouraged (Holzmann et al., 2020; Ukobitz, 2020).

Social Influence

Social influence encompasses the impact of social factors on individuals' acceptance of technology. Regarding 3D printing in education, social influence can stem from peers, colleagues, or influential figures such as teachers and school administrators. Positive endorsements, support, or recommendations from these influential individuals or groups can motivate teachers and students to perceive 3D printing as a valuable educational tool, thereby increasing their acceptance of it (Holzmann et al., 2020; Ukobitz, 2020).

Facilitating Conditions

Facilitating conditions refer to the presence of essential resources, support, and infrastructure necessary for technology utilization. In the context of 3D printing, facilitating conditions encompass factors such as access to 3D printers, software, technical support, training, and funding. When teachers and students have the necessary resources and support to integrate 3D printing into their educational activities, it positively affects their acceptance and usage of the technology (Holzmann et al., 2020; Ukobitz, 2020).

By considering these constructs within the UTAUT framework, researchers and educators gain a comprehensive understanding of the factors that influence the acceptance and adoption of 3D printing in education. This understanding can guide the development of strategies and interventions aimed at promoting successful integration and maximizing the benefits of 3D printing in educational settings (Wijaya et al., 2022).

LITERATURE REVIEW

The integration of 3D printing in schools has shown positive impact on teaching and learning. Many studies have investigated the impact of implementing 3D printing classrooms. The results of these studies highlighted different outcomes from this integration. Studies have shown that the integration of 3D printing technology in teaching and learning is well-received by both teachers and students. 3D printing provided students with hands-on experiences and allowed for visualization of literary characters and historical landmarks. Students enjoyed using 3D printing technology and believed that it aided in their understanding of complex or abstract concepts (Chen & Cheng, 2021). Previous research has suggested that teachers' attitudes towards integrating technology into the classroom can significantly affect how students use technology (Francom, 2020; Wang, 2021), as well as their cognitive and emotional learning (Kopcha et al., 2020).

Teachers perceived 3D printing as a valuable tool in enhancing students' engagement and motivation. They believed that 3D printing visualize complex concepts to students and bring their ideas to life in a tangible way. However, some teachers were skeptical, citing concerns about cost, accessibility, time, and the need for extensive training (Ali et al., 2020; Novak & Wisdom, 2018). Regardless of teachers' initial perceptions, many teachers who integrated 3D printing into their classrooms reported positive outcomes. They stressed that integrating 3D printing helped their students develop critical and problem-solving skills through an iterative design cycle. Students' perception related to the use of 3D printing technology is similar to their teachers. Students reported that using 3D printing was motivating and engaging in learning about complex concepts in STEM fields. The hands-on learning experiences that are involved in the use of 3D printing helped them to better understand abstract concepts (Aydin-Gunbatar, 2020; Huri & Karpudewan, 2019; Yuceler et al., 2020).

3D Printing and STEM

Since many years ago, the international focus of science education has been centered on achieving proficiency in STEM, particularly, in those nations with a growing need for a workforce with STEM skills (Aydin-Gunbatar, 2020; Huri & Karpudewan, 2019; Li et al., 2020; Tytler, 2020; Yuceler et al., 2020). Nowadays, schools focus on integrating STEM subjects into their formal curricula rather than only teaching science and math due to the need for a knowledgeable workforce in these fields (Ha et al., 2020; Han et al., 2021; Ho et al., 2020; Kelley & Knowles, 2016; Li et al., 2019, 2020; Nugroho et al., 2021; Xu & Ouyang, 2022).

It is crucial to invest in enhancing STEM education in K-12 schools, higher education institutions, and STEM professional development as the need for STEM skills and competencies is on the rise (Ho et al., 2020; Nugroho et al., 2021). The STEM motivation of students is an important requirement for engaging in STEM learning. Students' enthusiasm for STEM subjects correlates strongly with their choice of careers in the future. This has encouraged educators to look for appropriate strategies to promote STEM motivation into their classrooms. Integration of innovative technologies has been noted as a key strategy for improving students' outcomes and increase students' motivation and attitudes towards STEM careers (Li et al., 2019; Xu & Ouyang, 2022; Zuo et al., 2020).

3D printing technology is one of these innovative technologies and has become popular among teachers as an innovative K-12 education tool. Integrating 3D printing in STEM classrooms can boost students' STEM motivation and their involvement and persistence in STEM learning (Cheng et al., 2021; Lee & Kwon, 2023). . 3D printing technology provides students with the opportunity to design and create real-world objects, which helps them to develop their design thinking skills (Kelley et al., 2021; Szymanski et al., 2022; Thibaut et al., 2018; Ukhov & Ryapukhin, 2022). Despite the benefits that 3D printing offers to STEM education, the implementation of 3D printing technology has noted to be quite challenging (Pernaa, 2022). Various challenges have been identified in the literature such as limited budget of schools to adopt 3D printing technology (Evans & McComb, 2022), limited skills and knowledge of teachers (Assante et al., 2020) and student motivation to adopt the technology (Lin et al., 2021). Collaboration between educators, and technologists can improve the productive use of 3D printing in the curriculum. Suggestions for practice and research include teacher training, creating spaces for student work and lesson planning, and other initiatives (Ali et al., 2020; Ukhov & Ryapukhin, 2022).

In summary, integrating 3D printing into teaching and learning is one of the innovative strategies for improving students' outcomes and increasing their motivation and attitudes towards STEM careers.

Teachers' Perceptions

The perceptions and the beliefs of the teachers are crucial to the successful integration of technology since their values guide their pedagogical choices. Teachers' positive beliefs and perceptions related to technology integration into teaching and learning serves the needs of the twenty-first century's teaching and learning (Ucgul & Altiok, 2023). Previous research has shown that teachers' pedagogical ideas significantly impact how they instruct students (Tanak, 2020). Teachers favor using technology in ways consistent with their pedagogical philosophies and core convictions regarding best practices in education. How teachers view the essence of learning in a classroom is strongly correlated with how they use technology (Ningsih et al., 2022).

Research found significant relationship between the amount of 3D printing instruction teachers disclosed in their courses prior to the professional development and the amount they planned to implement after the professional development, confirming the role of change in teachers' perception (Love et al., 2022). In addition, prospective teachers were found more inclined to use 3D printing into teaching-learning activities when they were happy with the course and were sufficiently knowledgeable about the procedures (Ucgul & Altiok, 2023). Teachers confirmed that they will integrate 3D printing when they develop confidence in their digital and 3D printing skills (Antón-Sancho et al., 2022).

Studies found that, teachers' attitudes and beliefs about the usefulness, ease of use of 3D printing technology, and their technical and pedagogical knowledge were significant factors in their decision to integrate the technology into their lessons (Ali et al., 2020). Teachers integrate 3D printing when they perceive it as useful for enhancing student learning outcomes. Teachers' prior experience with technology also influences their intention to use 3D printing. Teachers who have prior experience with 3D printing or similar technologies or received training or support are more likely to have a positive intention towards integrating this technology into their teaching (Holzmann et al., 2020).

According to Novak and Wisdom (2018), teachers perceived 3D printing technology as a useful tool for enhancing students' problem-solving skills and visualization (Song, 2018). Students, on the other hand, perceived 3D printing technology as a tool for improving their spatial reasoning and problem-solving skills (Birt & Cowling, 2016). Overall, the integration of 3D printing technology in teaching and learning is perceived positively by both teachers and students (Carroll & Blauch, 2017; Scalfani & Vaid, 2014; Smiar & Mendez, 2018).

In summary, the successful integration of technology into teaching and learning is influenced by teachers' perceptions and beliefs. Teachers' values guide their pedagogical choices. Teachers' pedagogical ideas significantly impact how they instruct students, and they prefer to use technology in ways consistent with their pedagogical philosophies and core convictions regarding best practices in education. In addition, teachers who perceive 3D printing as useful and easy to use, have prior experience with technology, and have received training or support are more likely to intend to use it in their teaching.

Students' Perceptions

As teachers' perceptions and intentions affect the adoption of 3D printing, students' perceptions are found to affect their motivation to use 3D printing technology in education. Using technology acceptance model (TAM), Habes et al. (2022) found that perceived usefulness and perceived ease of use are important indicators of students' behavioral intentions to accept technology in the classroom. In addition, students' acceptance of 3D printing technology rose due to the experiential learning project (Benham & San, 2020). The integration of 3D printing into teaching and learning affect students positively. Students found the integration of 3D printing engaging, exciting and interests them (Guenther et al., 2021; Szymanski et al., 2022).

A study by Cheng et al. (2020) revealed that the extent of 3D printing integration and teachers' attitudes were significant determinants of students' STEM interests. The integration of 3D printing in STEM related activities increased students' imagination and interest in technical and engineering jobs (Lin et al., 2021). Additionally, it was observed that the stronger integration of 3D printing as a teaching tool made students feel inspired and instrumental in learning STEM skills. This further reinforced the potential of 3D printing in creating an impactful learning experience (Sun & Li, 2018). Studies have shown that students perceive 3D printing as a valuable tool in the classroom, with many reporting increased motivation, engagement, and interest in STEM fields (Davy Tsz et al., 2022; Ford & Minshall, 2019). However, some students found the technology intimidating or difficult to use, leading to potential barriers to learning (Chun, 2021). Therefore, it is important for educators to consider students' perceptions towards 3D printing and address any potential challenges to ensure successful integration into the curriculum.

Additionally, students' attitudes towards STEM and STEM careers can play a significant role in their motivation to engage with 3D printing technology. Research has suggested that incorporating 3D printing into STEM education can improve students' understanding of complex concepts, enhance their problem-solving skills (Abu Khurma et al., 2022), and increase their interest in pursuing STEM careers (Bicer et al., 2017; Chen & Cheng, 2021; Han et al., 2021). Thus, educators should consider the potential impact of 3D printing on students' attitudes towards STEM and STEM careers and use this technology as a means of promoting interest and engagement in these fields.

METHODOLOGY

A mixed method approach was used to collect data for the purpose of this study. The mixed method approach used qualitative and quantitative data collection tools to collect data from the participants and to answer the research questions. This mixed method approach was used to triangulate the data collected and to better comprehend and interpret them (Basit, 2003). The semi-structured interviews and focus groups discussions were considered effective method of data collection in this study to gain a deeper understanding of students' and teachers' perspectives. The survey was used to collect quantitative data from the students related to their perception and their attitude toward STEM career. The survey was used to triangulate the data collected from the focus group discussions and collect data from all the student participants.

Study Participants

In this research study, the targeted population comprises students and teachers work in public schools in Abu Dhabi, the UAE. Two public schools (school A and school B) were selected based on convenient access by the researchers as well as the technological infostructure of the school. The participants of the study were 148 grade 5 students (123 students from school A and, 25 students from school B) and their seven teachers (four teachers from school A and three teachers from school B). Twelve students participated in the focus group discussions (six from each school).

Data Collection Tools

This study focused on the collection of primary data through the use of mixed methods approach as it allows for in-depth exploration of teachers' and students' perceptions and can uncover underlying reasons and attitude toward using the 3D printing. First, the qualitative method selected to provide a more holistic understanding of the teacher's integration of the 3D printing and students' learning. Second, the quantitative method used to collect data from students to collect data from a large sample of students, which can provide a more comprehensive understanding of students' perceptions on the technology. Quantitative data can also be analyzed statistically to identify patterns, trends, and correlations, which can help identify areas that need improvement or further investigation.

Qualitative data was collected from the teachers by using semi-structured interview questions. Survey and focus group discussions were used to collect data from the students. All data collection tools were guided by TAM model, as TAM captures the teachers' and students' perceptions of technology acceptance and integration in teaching and learning. The focus group discussions were aimed to capture information on five areas, which include background information, classroom activity, usefulness, ease of use, and perception. The semi-structured interviews focused on four key elements: background information, planning, implementation, and perceptions of the integration of 3D printing into teaching and learning. On the other hand, students' survey evaluated the students' perceptions on the integration 3D printing technology and interest in STEM careers using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The survey was self-developed by the research team and the content validity was obtained by giving the survey to three experts who reviewed the survey along with the research questions and they give their feedback. All the feedback received from the experts were taken in consideration. The survey consisted of two main variables: students' perception of the perceived usefulness of 3D printing technology (15 statements) with internal consistency reliability of .88, and attitude towards STEM career (six statements) with internal consistency reliability of. 87. The internal consistency reliability was achieved by piloting the survey to a group of 100 students from the same grade level who are not participants in the study.

Implementation Procedures

The study implementation spanned three semesters. In the first semester, a four-step process was followed, starting with 3D printer training for teachers, followed by a mini-training during the implementation phase, training on creating and developing a STEM-based unit plan and the implementation of the unit plan. TPACK model was used to plan the training materials on the technical and pedagogical content, as well as the development of the unit plans (Esposito & Moroney, 2020). In the first semester, the teachers implemented a unit plan that is developed by the research team and fits into the curriculum. The main science topic was

Table 1. Students' descriptive statistics

		School A		School B	
		n	%	n	%
Gender	Male	0	0.0%	12	48.0%
	Female	123	100.0%	13	52.0%
Age	8 years	3	2.4%	1	4.0%
	9 years	66	53.7%	11	44.0%
	10 years	44	35.8%	11	44.0%
	11 years	3	2.4%	1	4.0%
	12 years	0	0.0%	1	4.0%
Access to device	Yes	117	95.1%	24	96.0%
	No	6	4.9%	1	4.0%
Home internet access	Yes	107	87.0%	24	96.0%
	No	15	12.2%	1	4.0%
Use of TinkerCAD before	Yes	51	41.5%	20	80.0%
	No	72	58.5%	5	20.0%
Have seen 3D printer before	Yes	45	36.6%	15	60.0%
	No	78	63.4%	10	40.0%
Participated in all 3D printing activities at school	Yes	55	44.7%	18	72.0%
	No	68	55.3%	7	28.0%
Used TinkerCAD from home before	Yes	53	43.1%	14	56.0%
	No	70	56.9%	11	44.0%

volcanos. The research team mapped learning objectives form science, English and math and developed the unit plan with all related activities and resources. The integration of 3D printing was an essential component of the unit plan. The research team discussed the unit plan with the teachers from the two schools. One researcher was assigned to each of the schools to help and assist in the implementation of the Volcano unit plan and answer teachers' questions. In addition, the researcher helped the teachers with mini-training sessions related to the use of either TinkerCad, the 3D printers or any issue or problem. The unit plan was implemented in six lessons.

The 3D printing and design was mainly related to the students' designing the volcano they were learning about. The students in this activity were asked to search about the closest volcano to Abu Dhabi. The students worked in groups of four to search for the volcano using google earth. Then the students extracted their volcano and imported it into TinkerCad. They modified it, personalized it, and then printed it using 3D printers. The students had to learn about measurement and scales (math) when locating the volcano in the map, and then write facts and the implications of the volcano in Abu Dhabi if it became active (English). By the end of the unit, students presented their findings to the whole class. In the second semester, the research team chose the "fossil" topic from science to be the topic of the second unit plan. Both the researchers and the teachers worked closely to co-develop the Fossil unit plan in both schools.

In the third semester, the teachers in each school had the freedom to choose the topic of the unit plan and the teachers in each school created the unit plan without the help of the researchers. School A's teachers chose the "adaptation" as the topic of their unit plan and school B's teachers chose "electricity" as the topic for their unit plan. All the created unit plans were interdisciplinary unit plans with the integration of science, math, and English using 3D printing technology.

Overall, the study approach involved a gradual transition from researcher-supported implementation to teacher-led implementation, demonstrating potential for sustainable integration of 3D printing in STEM education.

RESULTS

Survey data was collected from two schools in Abu Dhabi, comprising only female students in school A, whereas school B had 52% female students and 48% male students. The highest age group (53%) was nine years in school A, whereas it was nine years and 10 years (44% each) in school B as seen in **Table 1**. When asked if the students had used TinkerCad software before, a mixed response was observed in school A students, whereas, in school B, 80% of the students indicated to have used it before. 63% of school A students identified not seeing a 3D printer before, while 60% of school B students confirmed in affirmative. Upon being

Table 1. Relationship between interdisciplinary integration of 3D printing & students' STEM perceptions

Model		Unstandardized coefficients		Standardized coefficients	T	Sig.
		B	Standard error	Beta		
1	(Constant)	31.993	4.061		7.879	.000
2	Students perception 3D	1.764	.152	.692	11.587	.000

asked if the students participated in all 3D printing activities held at school, only 44% of school A students confirmed, while it was 72% of school B students.

Relationship Between Interdisciplinary Integration of 3D Printing & Students' Perceptions Toward STEM Careers

Simple linear regression analysis was conducted to examine the relationship between students' attitude towards STEM careers and the interdisciplinary integration of 3D printing into teaching and learning. The linear regression analysis revealed a strong positive correlation between students' attitude towards STEM careers and the integration of 3D printing technology in teaching and learning. As illustrated in **Table 2**, the overall regression was statistically significant (R2=0.475, F(1, 146)=134.259, p=0.000). It was found that (students' perception of the interdisciplinary integration of 3D priming) significantly predicted (students' attitude toward STEM career).

The results of students' survey that measured the correlation between the following set of statements (students' perception of the interdisciplinary integration of 3D printing technology in teaching and learning, and students' attitude toward STEM careers) were confirmed by the students' focus group interviews. The focus group discussion focused on the students' experience with 3D printing and their learning in STEM subjects. The results from the focus group discussions show how the interdisciplinary integration helped students to better understand the concepts presented in the lessons. The students were enthusiastic about 3D printing and believed that it could enhance their learning experience in STEM. One student said, "With having the printed model in hand, I was able to see and touch what I was learning about in class, it made concepts easier to understand and remember." Another student confirmed, "using 3D printing in our project made us see the connections between different STEM subjects, like how math and science work together." In addition, a student confirmed that "3D printing is a really nice way to learn science and math, it is much better than learning from a picture or a drawing." Students demonstrated some understanding of STEM concepts, such as volcanoes and their properties. They were also familiar with various activities and projects that they had completed in science and English classes. One student mentioned, "the 3D printing project helped me understand the concept of scale in a really hands-on way." Students enjoyed these activities and found them engaging, one student said, "it is a nice activity … it is fun". Another student added, "I think 3D printing made me interested in STEM subjects because it is fun, and it is different from other methods of learning." Students suggested that creating 3D printed models was helpful in reinforcing what they had learned in class. A student confirmed that by saying "we had the chance in our group to test our ideas and see if they work."

3D printing technology integration made the students think about their future careers and some of the students mentioned engineering and architecture. One student stated, "designing 3D models helped me think about future careers that use technology and design." The hands-on activities helped the students to gain practical experience on how technology and design can be applied in STEM careers. Furthermore, the integration of 3D printing helped students to understand the importance of technology in solving real-world problems. One student mentioned "working with 3D printing has shown me how knowledge and skills from different subjects can be applied in creative ways to solve problems." Another student added, "using 3D printing in school has shown me how important technology and how it can help solve real-world problems."

In summary, the focus group interviews with students confirmed that using 3D printing technology in teaching and learning can enhance students' learning experience in STEM subjects. The students were enthusiastic about 3D printing, finding it engaging and motivating. They also believed that creating 3D printed models was helpful in reinforcing what they had learned in class. Students demonstrated an understanding of STEM concepts, and the interdisciplinary integration of 3D printing helped them to connect subjects and ideas. They found that 3D printing provides a way to test their ideas and see the connections between different STEM subjects.

Teachers' Perception of Interdisciplinary Integration of 3D Printing

The interview data from the teachers revealed that the teachers had positive perception of the integration of 3D printing technology in teaching and learning. The teachers found that using 3D printing positively impacted students' attitudes towards STEM. A teacher said, "using 3D printing helped students to see the real-world implementation of what they learn in class, and this might encourage them to have STEM as a career in the future." Another teacher added, "exposing students to 3D printing is a good approach to develop their skills and prepare them to the future." Furthermore, the teachers perceived 3D printing as a useful tool for teaching and learning and teacher acknowledged the capability of 3D printing in motivating students. A teacher stated that "using 3D printing make learning exciting and motivating for the students." Another teacher noted, "it is a great tool to use in teaching STEM subjects. It is hands-on and interactive, and helps students visualize concepts and ideas." A teacher added, "I was a bit intimidated at the beginning to use 3D printing technology, but after some training and practice, I found it to be a really effective tool to boost students' engagement."

Most of the teachers revealed that the interdisciplinary integration of 3D printing technology was effectively imparted the concepts to the students and made the learning interesting. One teacher stated that, "my girls enjoyed it … and they found it very interesting … There's no volcanoes here, so that's just something they read about or see pictures of, but for them to realize it is real and to see that it has got different aspects, that there is something inside it, it was good." Another teacher identified group work in the interdisciplinary integration as a very effective way of engaging the students, she added, "the children talk, share, and work in groups. Whether it is math, English, or science, it was really amazing. For all the 23 years I have been teaching, I think this semester was my best with the integration of 3D printing." The excitement of the students that comes from having the actual prototype printed is another factor that motivated students and enhanced their excitement about learning. One teacher said, "They are very excited about it, being able to use things like that. The thought that they were going to make something, really got them interested in the work that they were doing."

In summary, teachers showed positive attitudes towards the integration of 3D printing technology in teaching and learning. Teachers perceived 3D printing as a useful tool for teaching and learning and has the potential to motivate the students. Most of the teachers found that the interdisciplinary integration in the unit plan was effectively communicated concepts to the students and made the learning interesting. Additionally, the excitement of the students that came from having the actual prototype printed is another factor that motivated students and enhanced their excitement about learning.

Challenges Faced During Implementation

Regardless of the teachers' positive perception of the interdisciplinary integration of 3D printing technology in teaching and learning, the teachers identified some challenges with this integration. One of the major issues identified was the lack of time. One teacher confirmed that, "what we were doing in the unit plans and how we covered it was very interesting, however, we always ran out of time". Another teacher quoted "well, for me, personally, I struggled, I do not know about my colleagues, but for me it is always time management." Another issue identified was to make the student learn the actual context of the concept. One teacher quoted that "one of the questions I got asked was, "is it really this small?"" no, it is not that small. A lot of people asked me, "Teacher, is the dinosaur really this small?" I said, "no, it is much bigger. Can not bring a real one, they're too big." Another challenge identified was integrating science, English, and mathematics. Majority of teacher revealed difficulty in integrating mathematics with English and science. One teacher noted that, "you know what challenge there is, it is okay when it comes to the English and the science because you can integrate it, but our outcomes in grade five is really a lot. Especially with the math, because with the math you can integrate certain things but other things that you cannot."

DISCUSSION

The study examined the interdisciplinary integration of 3D printing technology in teaching and learning within elementary schools in the UAE. This study explored how students and teachers perceived this interdisciplinary integration within the UAE elementary schools. Additionally, it examined the relationship between students' perception of the interdisciplinary integration and students' attitudes toward STEM careers.

Consistent with the finding of previous research (Habes et al., 2022), the results of the current study indicated that teachers and students positively perceived the interdisciplinary integration of 3D printing in teaching and learning.

Students Attitudes

Students perceived 3D printers and 3D printing software as easy and thought themselves capable of learning the technology and would like to use it more in class. The perceived utility and reported simplicity of use are significant predictors of students' behavioral intentions to utilize technology in the classroom. This finding aligns with TAM's central constructs, such as perceived usefulness and perceived ease of use, as students perceived 3D printing as beneficial for their learning experience in STEM subjects. They found it helpful for understanding and visualizing concepts, problem-solving, and acquiring new computer skills. These perceived benefits likely contributed to their positive attitude towards STEM careers (Cheng et al., 2021)

In addition, students found that the use of 3D printing is motivating, exciting, easy, and useful. This finding is supported by Benham and San (2020) who argue that experiential learning project increased students' understanding of 3D printing technology, which changed their perceptions and motivated them to learn. In addition, the study revealed significant relationship between students' perceptions of the interdisciplinary integration and their attitude toward STEM career. The findings of the current study are in line with earlier studies (Yoon & Strobel, 2017). Students who participated in a 3D printing program showed interest in STEM fields and improved understanding of STEM ideas. It offers students the chance to actively design their own models and become involved in the designing and printing process, which can stimulate their interest in STEM (Novak & Wisdom, 2020). Designing and printing 3D objects using TinkerCad provided students with experiential learning opportunities, allowing them to actively participate in the learning activities, which is supported by experiential learning theory (Szijarto, 2021). By manipulating the 3D models and observing their creations, students were able to make connections between different STEM subjects and deepen their understanding of the learned concepts. This hands-on and reflective learning experience likely contributed to their positive perceptions of STEM careers (Coskun et al., 2022).

The reasons behind this association might be because of the following reasons: the use of TinkerCad to design 3D objects gave students the opportunity to express their creativity and imagination in a concrete way, which might contributed to students' motivation and gave them the chance to see the relevance of STEM concepts to their lives. This relationship between 3D printing integration and students' perceptions toward STEM careers can be explained using the self-efficacy theory. According to Bandura's self-efficacy theory, individuals' beliefs about their ability to perform a specific task influence their motivation and career aspirations (Lunenburg, 2011). The hands-on experience of designing and printing 3D objects using TinkerCad likely boosted students' self-efficacy in STEM-related activities. By successfully engaging in 3D printing and experiencing tangible outcomes, students gained confidence in their ability to apply STEM concepts and skills. This increased self-efficacy likely influenced their interest and intentions towards pursuing STEM careers (Ali et al., 2019). In addition, when students design their own 3D models and print them, they get confidence in their abilities and gain a sense of success, which might contribute to their attitudes toward STEM subjects. Students can see and touch objects, which can aid in their understanding of complex STEM concepts. The interdisciplinary integration of 3D printing promoted teamwork and communication skills. By giving the students the opportunity to work together to solve problems and communicate with their peers, they developed social and emotional skills that are imperative to their life. Additionally, 3D printing inspired students to pursue STEM careers by exposing them to real-world applications of the technology.

Teachers' Perspectives

Teachers also showed a positive perception toward the interdisciplinary integration of 3D printing technology in teaching and learning. The teachers found to be keen on learning the technology and spending time mastering it for better integration into the lessons. One reason for this is that teachers found the integration of 3D printing congruent with their pedagogical philosophies and fundamental beliefs regarding best practices in education (Ningsih et al., 2022). In other words, how teachers use technology is significantly connected with how they perceive the fundamentals of classroom learning. The positive attitudes of teachers towards 3D printing technology integration can be attributed to several factors. Firstly, 3D printing provided an exciting innovative approach to teach STEM subjects as discussed by Anand and Dogan (2021), which contributed to the improvement in students' engagement and motivation. Secondly, 3D printing allowed students to visualize and manipulate complex concepts and ideas in a 3D format, which contributed to the teachers' perception of the usefulness of 3D printing (Cheng et al., 2020; Medina Herrera et al., 2019). This finding also supports TAM in acknowledging the importance of usefulness in technology adoption.

The positive teachers' perception toward the integration of 3D printing might be related to the following reasons: when teachers use 3D printing in their lessons, they gain experience and skills that can be useful and valuable for their own career development. This can help keep teachers motivated and engaged in their profession and continue to develop their teaching strategies. This finding is supported by Davy Tsz et al. (2022) and Ford and Minshall (2019) who argue that teachers and students motivation get positively impacted by the use of the 3D printing technology. 3D printing can help teachers enhance their teaching effectiveness by providing students with hands-on activities that can help them to better understand complex concepts. This finding supports experiential learning theory, which focuses on learning by doing and having experiences. This might give teachers a sense of accomplishment when they see their students engaged in their learning. In addition, teachers can create personalized learning experiences for their students that can meet their individual learning needs. This can be especially beneficial for students who may struggle with traditional teaching methods or have special needs (Backhouse et al. .2019).

Various issues and challenges are found in the integration of 3D printing into lessons, such as limited time, lack of teachers' skills, and lack of knowledge related to the integration of math with other subjects and that is aligned with the results of Holzmann et al. (2020). Teachers were found to be restricted with limited time and skills and sought more detailed training on 3D printing. A significant number of teachers mentioned lack of time as a major challenge in integrating 3D printing into lessons. Similar finding is corroborated with other studies such as Assante et al. (2020) and Bower et al., (2020) who argue that challenges related to 3D printing involve lack of teachers' skills. Teachers' intentions of integrating 3D printing into their lessons was found to be linked with their skills to use 3D printing and the availability of more time (Song, 2018). Previous literature also note that teachers expressed skepticism, noting concerns about the need for substantial training, cost, accessibility, and time (Ali et al., 2020; Novak & Wisdom, 2018).

Implications for Practice

The following recommendations for practice are made based on the study's findings.

Recommendations for schools

1. Schools must train their teachers on the necessary technical (such as operating the 3D printers, changing filament, etc.) and pedagogical skills and knowledge (such as the interdisciplinary integration) related to the integration of 3D printing into teaching and learning. In addition, continuous support (such as IT personnel support) must be given to the teachers to ensure the sustainability of such integration.
2. Train teachers on how to align the 3D printing projects with learning objectives, and standards in STEM subject areas for effective and meaningful integration of this technology.
3. School leaders should invest in the necessary equipment, human and physical resources to assist teachers in incorporating 3D printing into their lessons.
4. Schools should celebrate innovative practices that incorporate 3D printing and provide incentives for teachers to explore and integrate new technologies into their lessons.

Efforts should be made to partnership with the local community and industries to introduce students to real-world 3D printing applications and STEM professions.

Recommendations for teachers

1. Teachers should provide students with ample opportunities to experiment with a wide range of 3D printing software (such as TinkerCad and Thingverse) and hardware to help students get a

comprehensive awareness of the capabilities and limitations of various technologies and prepare them for STEM-related employment in the future.

2. Teachers should encourage their students to take risks and learn from their mistakes through fostering a culture of experimentation and iteration in their 3D printing projects.
3. Teachers should do action research when integrating 3D printing in their lessons to continue assessing the impact of 3D printing integration on student learning, motivation, and engagement. The findings of this action research should be used to inform future adoption and enhancements. This can help guarantee that 3D printing is utilized in a relevant and effective way to support STEM learning.

Future Research

Further research studies could investigate different approaches of integrating 3D printing into teaching and learning and its relationship to student engagement, and the extent to which it inspires students to pursue STEM careers. Other research studies could investigate the impact of integrating 3D printing on different areas of learning. In addition, comparative studies between public and private schools in the UAE should be undertaken to reveal points of similarity and difference between two types of schools. The study is limited to two schools in the UAE with a limited sample size. It is recommended that further schools should be investigated as part of the study and their teachers and students should be probed before and after providing them with the opportunity to learn 3D printing through a planned project. Moreover, comparing schools in all the seven emirates could be insightful since it would lead to knowing the differences and similarities in the teachers' and students' perceptions regarding adopting 3D printing in STEM curriculum.

CONCLUSIONS

This study highlights the positive impact of integrating 3D printing technology into elementary school education in the UAE. Students perceive 3D printing as motivating and useful, which positively influences their attitudes towards STEM careers. Teachers also have a favorable attitude towards 3D printing integration. However, the study identifies challenges such as limited time and lack of teacher skills that need to be addressed for effective integration.

The findings emphasize the potential benefits of interdisciplinary 3D printing integration and provide valuable insights for educators and policymakers interested in promoting STEM education. This study confirms a strong correlation between students' attitudes towards STEM careers and 3D printing integration, as it helps them understand technology's real-world applications and positively reinforces their learning. It has significant implications for education policymakers, administrators, and teachers, emphasizing the importance of teacher training and support. By addressing challenges, schools can maximize the benefits of 3D printing in education, fostering student engagement and improving attitudes towards STEM careers. Overall, this study contributes to the existing literature and highlights the transformative potential of 3D printing technology in elementary school STEM education.

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