

# Integrating 3D Printing Technology in Education: Insights from a Makerspace Case Study in Kuwait

<sup>1</sup>Sayed M. Eldebeky <sup>2</sup>Ganka Ivanova <sup>3</sup>Michael Nii Laryeafio <sup>4</sup>Samuel Ayertey <sup>5</sup>Derick Nyame, <sup>6</sup>Nahla Moussa

<sup>1</sup>Zayed University, Dubai-UAE (0000-0002-2917-3488)

<sup>2</sup>College of Interdisciplinary Studies, Zayed University, UAE (0000-0001-5847-3087)

<sup>3</sup>Arden University (0000-0003-1257-8398)

<sup>4</sup>Arden University (ORCID: 0000-0003-0834-8741)

<sup>5</sup>University of Wolverhampton (0009-0007-7517-9585)

<sup>6</sup>Associate Prof., College of Humanities, Arts and Applied Sciences, Amity University, Dubai, UAE, (0000-0003-1342-8201)

<sup>1</sup>sayed.mahmoud@zu.ac.ae <sup>2</sup>ganka.ivanova@zu.ac.ae <sup>3</sup>m.niilaryeafio@gmail.com <sup>4</sup>sbayerter@yaho.com

<sup>5</sup>derick2702@hotmail.com <sup>6</sup>nmoussa@amityuniversity.ae

**Abstract** -The development of 3D printing has created an opportunity for educators to utilise such technology in teaching and learning. However, lack of training and other challenges can stop schools from using this technology effectively. This study presents an overview of current 3D printing technology usage in a makerspace at a school in Kuwait. Twenty-seven teachers participated in this study, primarily recruited and selected based on their prior experience using a 3D printing station in the makerspace. This paper is a case study that uses two data sources: observations and questionnaires. The integration of 3D printing is being analysed through the lens of the High Possibility Classrooms (HPC) model, providing a theoretical framework for the study. The results indicated that using 3D printing was effective for education, but there were specific areas that required improvement. Several insights emerged: 3D printing prepares students for the future, promotes student-centred learning, and accommodates various subjects and contexts. This study fills a gap in research, especially about Kuwaiti schools. Furthermore, the findings can inform administrators who are considering the adoption of 3D printing devices in their schools, providing valuable guidance for successful implementation to help students develop soft and engineering skills.

**Keywords** - 3D printing, Makerspace, soft skills, engineering skills

## I. INTRODUCTION

Makerspaces are inclusive spaces that foster collaborative activities, including crafting, fabrication, and technological innovation, bringing various disciplines together (Zhao, 2021). Makerspaces have been established due to the increasing demand for places that accommodate students while making models and artefacts. These spaces are often located in libraries or separate dedicated areas and contain many stations, such as 3D Printing, coding, and robotics (see Figure 1). Within the educational context, "3D printing is directly connected with two other emerging educational

concepts: makerspaces and design-based thinking" (Maloy, Kommers, Malinowski, & LaRoche, 2017, p. 232).



Fig. 1. A 3D layout of the makerspace.

Three-dimensional printers – "3D printers" – provide students with innovative opportunities previously unavailable in schools (Eldebeky, 2021). Harnessing the technology of 3D printing "can revolutionise the way things are made, allowing anyone to make any object" (Petrikowski, 2014, p. 5). In education, there are many possibilities for the use of 3D Printing. For example, it can be used to create customised parts of a game, going beyond teaching students about 3D Printing itself (Kelley & Knowles, 2016).

According to the 2015 K-12 Horizon Report, as cited in Trust and Maloy (2017), one key benefit of 3D Printing in schools is that it allows for a more authentic exploration of objects and concepts that may have been inaccessible to schools. Using 3D printers can help students become involved in solving real problems (Eldebeky, 2023). Additionally, it allows educators to help students acquire different learning experiences, such as making models connected to the school subjects. This shift from textbook-based learning helps prepare students with future-ready skills (Marco, 2017).

Despite the numerous benefits of 3D Printing in education, prior research on the topic is limited to its integration into kindergarten to 12th-grade (K-12) curricula (Santos, Ali, &

Areepattamanni, 2018). While some studies explore its role in STEAM, there is little research on practical applications of 3D Printing in non-technical subjects like English and math. Moreover, there is limited research on 3D printing stations in makerspaces. Consequently, there is a need for comprehensive and user-friendly guidelines that outline various methods for incorporating 3D Printing into teaching. To fill this gap, the current study evaluates a 3D printing station in a Kuwaiti school makerspace to explore its benefits for students.

This study originated from the researcher's desire, who works as a makerspace specialist, and his aspiration to enhance the impact of makerspaces on teaching and learning. The researcher hopes this study can assist teachers in supporting students' knowledge and harnessing their excitement for the 3D printing station (see Figure 2).



Fig. 2. Students demonstrating enthusiasm during a 3D printing activity

This study can assist schools by informing policy development related to the use of 3D printing stations. With the increasing number of schools in Kuwait planning to establish makerspaces or introduce 3D printers into their libraries, there is a clear need for academic research to guide the effective implementation of such projects. Moreover, it can help school leaders who plan to create 3D printing stations in their schools.

Guided by the High Possibility Classrooms (HPC) model, the researcher examined 3D printer use in a school makerspace, documented teachers' experiences, and analysed the findings. It provided a lens through which the integration of 3D Printing was analysed and evaluated in the school's teaching and learning practices. This paper begins with an introduction outlining the research problem, questions, and objectives. The second part is the literature review, which covers the benefits and challenges of 3D Printing and the maker movement. Part three describes the methodology and data collection methods used in the study. Finally, the fourth section presents the study's findings and conclusions, followed by the bibliography.

### A. Purpose of the Study

3D Printing is an emerging field for many people, including those in education. This study aims to evaluate the current status of 3D Printing in a bilingual school in Kuwait and explore its impact on teaching and learning. To achieve this, an online survey examined how 3D printing stations are used in school makerspaces. The implications of such a study may establish a baseline for understanding the implementation of 3D Printing in other makerspaces. Additionally, this research can assist in decision-making processes related to expanding makerspaces and acquiring additional equipment. By providing evidence on the value and benefits of 3D technology, this study can help school administrators weigh the costs and benefits associated with investing in 3D printing technology in the context of our school. This research aims to contribute to the broader understanding of 3D printing integration in educational settings and provide insights to inform future developments in this field.

### B. Research Questions

While 3D Printing has been implemented in some schools, limited research has explored its specific benefits in the context of makerspaces. As a result, this study was designed to address the need to understand how a 3D printing station can enhance teaching and learning in a makerspace. To achieve this goal, this paper evaluates a 3D printing station in a makerspace by posing the following questions:

RQ1: What are teachers' perceptions about 3D printing stations?

RQ2: What skills, if any, do teachers believe that students develop when they use 3D printers?

By investigating these research questions, this paper aims to provide valuable insights into the perceptions and beliefs of teachers regarding the integration of 3D printing technology in school makerspaces. The findings will contribute to the existing knowledge base and illuminate the potential benefits and skill development associated with 3D Printing in educational settings.

## II. LITERATURE REVIEW

This section summarises the literature on using 3D Printing in education. Considering the ever-evolving nature of the 3D printing domain, this literature review was conducted to ensure a comprehensive examination of the topic. The review focuses on three key areas relevant to 3D Printing. The first topic is the maker movement, as it is one of the typical topics of interest in 3D Printing. The second topic focuses on 3D Printing in schools, and the third topic encompasses prior research on 3D Printing. The review includes literature published between 2007 and 2023, which was selected from the Lancaster

University library databases, including One-Search, Eric, and Google Scholar. Search terms such as "3D printing in education," "3D printing in makerspaces", and "3D printing in teaching and learning" were used in various combinations.

### A. The Maker Movement

In 1971, Seymour Papert and Cynthia Solomon introduced computer-based projects for children involving music, movie-making, and puppeteering (Papert, 1991). Their work encouraged educators to support learners in having authentic experiences rather than teaching content. According to Martinez and Stager (2013), Papert expanded the constructionism theory, highlighting that students learn by creating things that can be shared with others. This influential theory laid the foundation for the emergence of the maker movement, inspiring educators to embrace hands-on learning and empower students as active creators.

The maker movement emerged in 2005 when Make magazine was established, and it accelerated in 2006 with the inaugural Maker Faire, as indicated by Dougherty (2012). Since then, this movement has spread worldwide, and many countries host an annual Maker Faire, which brings together enthusiasts of the movement from around the world (Pepler & Bender, 2013). Extensive research highlighted the substantial educational benefits of making, illustrating its potential to improve student learning experiences significantly.

Papavlasopoulou, Giannakos, and Jaccheri (2016) emphasised the noteworthy impact of the maker movement on education, characterising it as a technological and creative evolution that provides boundless opportunities. This movement gained traction in schools, public libraries, and makerspaces, offering opportunities for experiential learning across a diverse range of activities such as 3D Printing, tinkering, electronics, coding, and woodworking. Making is student-centred learning, while schooling or traditional teaching is teacher-centric (see Figure 3). In the researcher's school, makerspaces are uniquely positioned and equipped with diverse advanced tools, enabling them to deliver comprehensive 3D printing projects across various subjects.

Traditional Schooling (as per current "reform" strategies)	Making
Teacher-centric	Student-centered
Instructionism	Constructionism
Overvalues learning with one's head	Learning with head, heart & hands equally valued
Race to the Top	Flow
My time	Our time
Standardized	Unique
Backward design	Serendipity
Teach to control, monitor & deliver content	Teach to liberate and amplify
Reproduce	Create
Differentiated instruction	Intimate learning
Raise achievement	Empower

Fig. 3. Schooling vs. Making (Horton, 2017, p. 4).

The literature review conducted by Papavlasopoulou et al. (2016) provided valuable insights into the state of research.

They examined empirical studies on the maker movement and identified an increasing need for it in many countries. The authors reviewed 43 studies and articles about maker movement or makerspaces. Among the 43 peer-reviewed articles analysed, only two papers focused on exploring the educational benefits of 3D Printing within makerspace activities. Furthermore, these studies highlighted the scarcity of empirical research concerning makerspace and 3D Printing. Consequently, the paper by Papavlasopoulou et al. (2016) represents a robust contribution, providing crucial clarity regarding the current research landscape surrounding 3D Printing.

### B. 3D Printing in Schools

Although 3D Printing is a relatively recent tool, it was identified as one of the emerging technologies that will most impact STEAM education as per the New Media Consortium (NMC) report 2013. Since then, the accessibility of 3D Printing has improved, leading to its widespread adoption in educational institutions. Schools have quickly recognised their value, acquiring 3D printers for various purposes. Some schools started adopting it as part of design technology or ICT courses. Other schools purchase it as part of a makerspace, innovation, or engineering laboratory (Cano, 2015). As a result, 3D Printing is expanding, reshaping the educational landscape and empowering students with new possibilities for design, creation, and innovation (Eldebeky, 2023).

As student learning needs continue to evolve, it becomes imperative for educators to explore innovative approaches to meet these changing demands. In this context, 3D Printing can enable teachers to transform lessons and learning (Kozinova, 2018), as it can bring life to many subjects and help students act as content creators rather than consumers. To adapt to the digital revolution, the teaching and learning methods in the 21st century need to be redefined. 3D Printing presents a valuable chance for interdisciplinary learning, allowing learners to engage with real-world challenges in today's world, as Loy (2019) emphasised. Additionally, 3D Printing facilitates small-scale production, providing students with hands-on experiences and practical applications of their ideas.

### C. Previous Studies

Numerous studies have demonstrated the growing popularity of 3D Printing as a valuable tool for teaching robotics and other subjects, effectively illustrating its potential to foster innovation and problem-solving skills among students (Fettig, 2017). A notable example of this is the ability to utilise 3D printers to produce various robot parts at a relatively low cost, so students moved from using a robot to making their own robot (Gonzalez-Gomez, Valero-Gomez, Prieto-Moreno, & Abderrahim, 2012). Moreover, research emphasised the role of 3D Printing in supporting project-based learning, allowing students to engage in hands-on, experiential activities that enhance their understanding of various subjects (Serdar, 2016).

Despite the advantages of 3D Printing that many studies have highlighted, there are challenges when integrating 3D

Printing into teaching and learning (Cano, 2015). Numerous studies found that 3D Printing implemented in schools had many issues: it requires time to learn 3D modelling, and Printing as it is a process; some students may print dangerous tools such as guns; and intellectual property concerns when students download or share the printed object (Chastain, 2014). Furthermore, some schools face difficulties finding effective ways to integrate technology into the curriculum. However, access to school technology has dramatically improved (Herman, 2002, as cited in Rayna, Striukova, & Darlington, 2015). Acknowledging and addressing these challenges is crucial for successfully integrating 3D Printing in educational settings.

In a study by Buehler, Easley, McDonald, Comrie, and Hurst (2015) on the effect of 3D Printing in education in Pakistan, the findings highlighted that teachers and students are motivated and convinced that 3D Printing can offer multiple advantages to Pakistan's education system. Similarly, Loy (2014) conducted a study at Griffith University's Product Design Studio, revealing three distinct advantages of 3D Printing: the promotion of student-centred learning and improvement in student work, the transformation of the relationship between students and lecturers, and the incorporation of ethical responsibilities into the learning process. Both studies indicated the importance of 3D Printing in establishing a positive learning environment. It is worth noting that while a considerable volume of research is available on the utilisation of 3D Printing in higher education, limited attention has been given to its application in K-12 school settings.

In a case study conducted in a makerspace in a public library in the United States, Sullivan, Lantz, and Adams (2019) investigated the use of 3D Printing by observing the experiences of two female students. The researchers used Guernsey's framework (2007) to understand how the two girls interacted with 3D Printing in a makerspace. They analysed what the girls said, and did, and how they behaved to study their thoughts about the content, environment, and themselves. This study allows other researchers to examine how the girls reacted, talked, and engaged with 3D Printing. Although the study's results demonstrate that engaging girls with technology can be achieved successfully by implementing 3D printing activities, the findings could be strengthened if the teachers who trained the students were the real teachers of the students, not makerspace specialists who are experts in 3D Printing. By taking this approach, the study could have provided more profound insights into integrating 3D Printing across various subjects and instructional contexts, enriching our understanding of its impact on student engagement and learning outcomes.

A noteworthy publication is the literature review conducted by Ford and Minshall (2016) that examines the diverse applications of 3D Printing in education. This review discussed using 3D Printing in different settings, such as schools, universities, libraries, and makerspaces. The results indicated that 3D Printing is utilised for educational purposes in various ways. It educates students and teachers on the subject, enhances 3D printing skills, fosters creative design abilities, and produces artefacts that can serve as learning tools or assistive

technologies in special education. However, it is essential to note that the review did not identify specific information regarding the application of 3D Printing in different subject areas.

In general, the available literature indicates that 3D Printing has beneficial effects. It highlights the educational benefits that students can gain from 3D Printing, the effective teaching of design skills, and the potential for supporting teaching and learning by creating 3D models. However, a significant research gap exists regarding the evaluation methods for 3D printing resources. Developing evaluation methods like rubrics would allow educators to fully leverage these resources in their teaching and learning practices (Novak & Wisdom, 2018).

Further research is necessary to address the increasing demand for integrating 3D printers in makerspaces within K-12 environments. At present, research is scarce regarding the incorporation of 3D printing technology within school makerspace environments. Therefore, there is a pressing need for empirical research that focuses on 3D Printing in makerspaces. This paper can serve as a guide for other schools seeking to establish these stations and can also evaluate the impact of such integration on education.

### III. THEORETICAL FRAMEWORK

The High Possibility Classrooms (HPC) is a pedagogical framework developed to support educators who "teach various stages of schooling to take 'pedagogical steps' in their practice with technology" (Hunter, 2015, p. 2). This conceptual framework originated from research conducted on exceptional teachers' understanding of integrating technology in the classrooms of Australian students aged 6 to 16 years (Hunter, 2017). Teachers in the original study developed their knowledge of technology integration through the framework, which included theory, creativity, public learning, life preparation, and contextual adaptations as the key. It emerged from the research and analysis of data taken from teachers' practices in technology integration, including 3D Printing, in both Australian and international contexts. Also, it emphasises pedagogy rather than technology through students' learning processes. The five conceptions of this model will frame the discussion of this study.

Each conception in this model is supported by themes of pedagogical strategies and students' learning processes. Firstly, the theory conception refers to how teachers' technology philosophy in the classroom affects practice. Secondly, the creativity conception includes five themes: enhancing learning through technology, creating opportunities for production, unleashing playful moments, supporting the teachers' values and enabling differentiation of learning and enabling differentiation of learning. Thirdly, in the public learning conception, technology scaffolds the performance of students' work in front of peers. Fourthly, the concept of life preparation is supported by technological tools that help give students a voice and denote ownership and responsibility. Finally, the concept of contextual accommodations refers to nurturing the

community of learners in their classrooms and using technology to define the game of effective teaching (Hunter, 2015). As outlined in the HPC model (Hunter, 2015), these five conceptions provide a comprehensive framework that integrates pedagogical strategies and student-centred learning processes with the effective use of technology in the classroom.

The High Possibility Classrooms (HPC) model serves as the framework for framing the discussion in this study. It offers a conceptual lens to explore the pedagogical strategies and students' learning processes associated with technology integration. It also provides a structure for organising the analysis of the research findings, examining how teachers' technology philosophies, creativity, public learning, life preparation, and contextual accommodations shape instructional practices and student outcomes. By employing the HPC model, this study acknowledges the importance of considering the broader educational context and pedagogical approaches when examining the impact of technology integration, thereby providing valuable insights and implications for enhancing teaching and learning in the digital age.

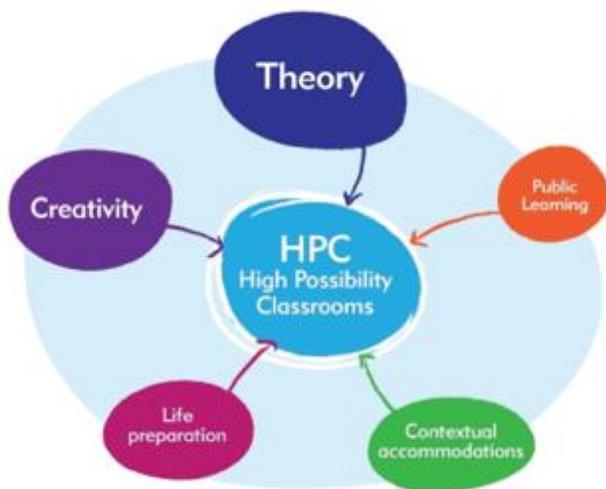


Fig. 4. Five Conceptions of the HPC Framework (Hunter, 2015, p.176).

#### IV. RESEARCH METHODOLOGY

In this case study, the 3D printing station was evaluated by examining teachers' experiences utilising it. According to Yin (2009), a case study is a research approach that empirically investigates a present-day phenomenon in its authentic context. Case studies are typically based on multiple data sources, including interviews, surveys, and other sources, to describe a specific practice or phenomenon. According to Creswell (2012), this methodology involves utilising observations, interviews, documents, and audio-visual materials as data collection methods. According to Stebbins (2001), a case study

design is suitable for exploring the changes in a school environment due to the use of new technology (as cited in Corey, 2016). This approach is suited for descriptive and exploratory studies because it focuses on 'how' and 'why' questions (Patton, 2002). The research site is a school in Kuwait with a makerspace with twelve 3D printers.

To validate the research, two data sources were used for data collection. Qualitative studies are generally subjective to the researcher. The concept of triangulation, as described by Cohen and Manion (1994), entails employing multiple data sources to ensure the validity of research. It gave the researcher confidence that the collected data is accurate. The findings in this paper were triangulated using surveys and observations.

##### A. Research Participants

Twenty-seven teachers participated in this study. Participants were mainly recruited from a school in Kuwait and were selected because they had prior experience using a 3D printing station in the makerspace. They taught various subjects, including English, Mathematics, Science, and Psychology. They also represent different nationalities, such as American, Canadian, Egyptian, Lebanese, and Kuwaiti. This study included male and female participants aged 28–61.

##### B. Research Methods

Multiple data collection methods were employed using a qualitative case study approach. First, the researcher examined data from a case study in which 27 teachers from different disciplines, grade levels and schools were asked to complete an online survey. The second set of data was obtained through observations. Through observations, the researcher captured and described detailed field notes taken during 3D printing lessons, enabling later coding and analysis, and facilitating the identification of themes.

Surveys were conducted to collect viewpoints, beliefs, or perceptions related to a present-day phenomenon, as stated by Gay, Airasian, and Mills (2011). This method was chosen for its effectiveness in gathering extensive information while ensuring anonymous responses and confidentiality. Hence, the utilisation of an online survey proved valuable in achieving the objectives of this study, which involved gathering opinions regarding the evaluation of a 3D printing station within a makerspace. The questions were developed to align with the participants' experience and knowledge, and the final version of the online survey instrument was created using the QuestionPro software.

### C. Equipment Description

The equipment used in this study was the da Vinci Super 3D printer (see Figure 5). The da Vinci Super is a large-format printer specifically designed for school use. It offered support for third-party filaments, allowing students to explore various materials.



Fig. 5 Caption: XYZ 3D Printer.

Fig. 5 Alt Text: A colour photo of the XYZ 3D printer on a wooden table.

### Ethical Considerations

Ensuring privacy and maintaining a respectful approach are critical ethical considerations in educational research (Cohen & Manion, 1994). In this study, strict measures were taken to protect the confidentiality of participants. All data were securely stored, with survey responses and other information being password-protected and accessible solely to the researcher's computer, ensuring privacy and data protection. Throughout the study, a strong emphasis was placed on respecting all participants and ensuring their confidentiality. Individuals who chose not to participate were also extended the same level of confidentiality and respect. Implementing these ethical safeguards ensured the protection of the rights and privacy of all participants involved in the study.

### Data

Data analysis serves the fundamental purpose of deriving meaningful insights from collected data (Hunter, 2017). In this study, the researcher employed two primary methods of data analysis: survey results analysis and observation analysis. Each data type was treated as a distinct entity throughout the analysis process. The first phase of the online survey analysis involved collecting survey response data. The researcher obtained responses in spreadsheet format, enabling the examination of responses chronologically. Subsequently, using the process of open coding in the grounded theory method, the researcher grouped codes and organised the data based on relational patterns among respondents.

### Analysis

## V. RESEARCH FINDINGS

### A. The Online Survey Findings

#### Question 1: How would you rate the makerspace regarding 3D Printing?

Of the 27 participants who answered the first question, nine stated that 3D Printing is highly effective, and 13 indicated it is effective. Only three out of 27 participants stated that it is somewhat ineffective, and two stated it is ineffective (see Figure 6).

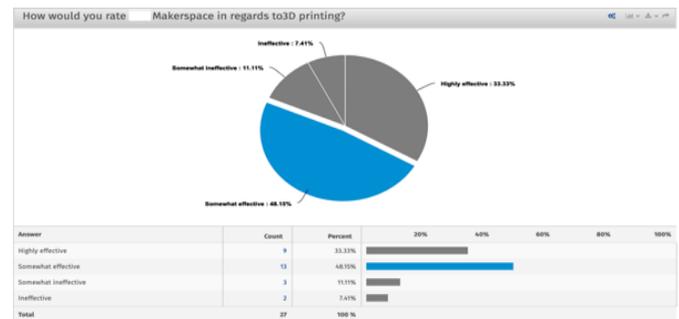


Fig. 6. Responses to Question 1.

#### Question 2: What are your goals when you use/will use 3D Printing?

Participants indicated that their goals for the lessons were to have students synthesise their learning and demonstrate their understanding in a creative and novel way. Additionally, participants aimed to show depth of analysis when learning to use the 3D printer to create, rather than merely printing an object. They also expressed the goal of helping students bring their vision to life and enabling them to see the physical product of their 3D design work on the computer. Furthermore, two participants mentioned that their students used 3D Printing as part of a project and printed tools to assist them in a play (see Figure 7).

What are your goals when you use/will use 3D printing ?	
03/16/2019	4121681A To have students synthesize their learning and demonstrate their understanding in a creative and novel way while at the same time showing depth of analysis, instead of merely printing an object.
03/18/2019	4121465A
03/18/2019	41194039
03/17/2019	41182988 The goal was for the students to learn to use the 3-D printer to create.
03/17/2019	41182317
03/17/2019	41182276 Help students create their vision
03/13/2019	41124297 تطوير النمط التقليدي في التدريس
03/12/2019	41098282 actually there are different goals,such as relating it to the curriculum I teach.
03/12/2019	41076065 I have never tried to use a 3D printer.
03/11/2019	41075605 The goal for the 3D printer should be aligned to the goal of the unit. If the printer is a feasible option for the students to demonstrate their final product of learning then it should be an option for the students to use.

Fig. 7. Goals of participants using 3D Printing.

**Question 3: Which skills and knowledge do you feel your students have developed/will develop by engaging in a 3D printing project?**

23.08% of the participants indicated that their students developed technology skills using 3D Printing. 21.54% of the participants mentioned that their students developed creativity, and 20% of participants selected 3D modelling as a skill that their students developed. 15.38% chose problem-solving, and 12.31% chose critical thinking. Only 7.69% reported that students can learn soft skills using 3D Printing (see Figure 8).

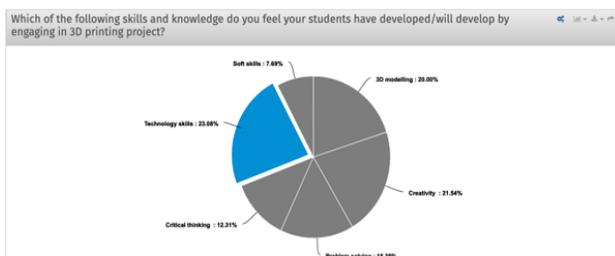


Fig. 8. Skills developed in 3D projects.

*Please describe how your students demonstrated/can demonstrate one or more skills and knowledge listed above during a 3D printing project.*

Most participants indicated that students could develop creativity, technology, and critical thinking skills by replicating a symbol, creating a logo, and designing original artwork (see Figure 9). Interestingly, one participant mentioned that students could not develop skills due to a lack of resources and feedback. Samples of the responses include the following:

"Students replicate a symbol from a poem or story, students could create their symbol, and after printing, add further value with colour, distressing, etc."

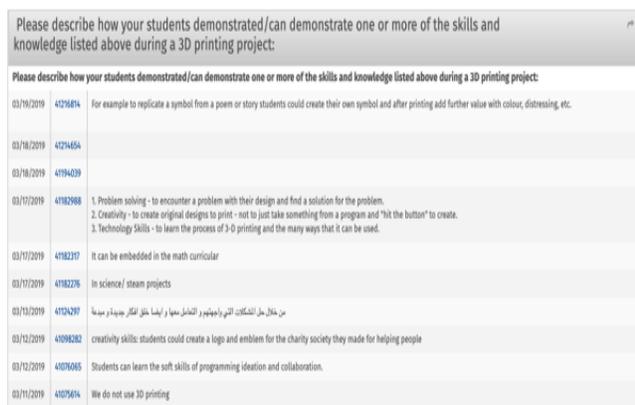


Fig. 9. Ways to develop skills during 3D lessons.

**Observations from Question 4**

*What suggestions do you have for improving the 3D printing station?*

Participants indicated additional training for students and teachers is needed (see Figure 10). They also suggested purchasing advanced 3D printers, such as colour 3D printers. Unfortunately, some samples of the responses were not provided. Samples of the responses include the following:

*"More in-depth workshop for teachers and students. Perhaps an after-school or recess club".*



Fig. 10. Suggestions to improve 3D printing stations.

**Findings of the 3D Printing Projects Analysis**

Findings of the 3D Printing projects analysis in this section, the findings of the 3D printing projects analysis will be presented, as documented in the field notes.

- 1- Skill Acquisition: While working on the projects, students demonstrated proficiency in 3D Printing, successfully producing a wide range of intricate models. These endeavours showcased their ability to translate concepts into tangible objects and underscored their acquisition of diverse technical skills associated with 3D printing technology.
- 2- Student Engagement and Enthusiasm: One of the observations was the enthusiasm and engagement exhibited by students when working on their 3D projects. Their eagerness to explore the technology, experiment with designs, and bring their ideas to life underscores the appeal and educational value of hands-on 3D printing experiences.
- 3- Challenges and Learning Opportunities: Among the undertaken projects, one specific challenge emerged during the brain model project. It was observed that students encountered difficulties due to the complexity of the model, which required additional time and materials. This experience offered a valuable learning opportunity, emphasising the importance of project planning, resource allocation, and problem-solving skills within a real-world context.
- 4- Collaborative Learning: The findings highlighted that the 3D printing projects fostered a sense of collaboration among students. Participants enhanced

their technical skills through joint efforts and knowledge exchange and contributed to the printed objects' overall value. This collaborative aspect of the projects mirrors the collaborative nature of 3D printing projects in makerspaces.

In conclusion, the analysis of the 3D printing projects showcased multifaceted outcomes, ranging from technical proficiency and student engagement to challenges that drive learning and collaborative learning. These insights underscore the educational significance of integrating hands-on 3D printing experiences into the curriculum of school makerspace projects.



Fig. 11. Printed Models.

## VI. RESEARCH DISCUSSION

The foundational themes of the five conceptions within the HPC framework will inform the discussion of the results, particularly concerning integrating 3D Printing into teaching and learning processes (see Figure 12). These principal themes will now be examined in depth.

Theory-driven technology	Creativity for learning through technology	Public learning through technology	Life preparation using technology	Contextual accommodations using technology
<ul style="list-style-type: none"> <li>• Technology drives construction of learning</li> <li>• Technology enhances purposeful teaching</li> <li>• Technology focuses planning</li> <li>• Technology enriches subject matter</li> <li>• Technology promotes reflective learning</li> <li>• Technology shifts conversation and thinking</li> <li>• Technology engages students in authentic ways</li> </ul>	<ul style="list-style-type: none"> <li>• Technology boosts creativity</li> <li>• Technology creates opportunities for production</li> <li>• Technology unleashes playful moments</li> <li>• Technology supports values</li> <li>• Technology differentiates learning</li> </ul>	<ul style="list-style-type: none"> <li>• Technology scaffolds performance</li> <li>• Technology enhances outcomes</li> </ul>	<ul style="list-style-type: none"> <li>• Technology operationalises the real world</li> <li>• Technology gives voice</li> <li>• Technology means ownership and possibility</li> <li>• Technology reveals effectiveness</li> </ul>	<ul style="list-style-type: none"> <li>• Technology remains personal and professional</li> <li>• Technology changes time</li> <li>• Technology nurtures community</li> <li>• Technology defines the game</li> </ul>

Fig. 12. Themes that underpin the HPC conceptions.

### A. Theory-Driven Technology Practice

The main idea in constructionism is constructing knowledge via experiences. 3D printers assist students in understanding new concepts and building a meaning of what they designed. 3D printing projects in the makerspace align with the constructionist perspective on learning as they allow students to construct knowledge through hands-on experiences, rather than relying solely on transmitting information from teachers to learners, as Papert (1991) stated.

One key challenge in this process is the occurrence of failed prints. From the researcher's observation, when students needed to print the sun in a big size (see Figure 11), they tried and failed many times. The researcher found that when students encounter difficulties with 3D Printing, it is an excellent catalyst to stimulate their interest in learning and inspire them to innovate. Students can acquire skills such as analysis and testing before they get their final product. 3D printers are valuable tools for learning through failure (Fettig, 2017). Nowlan's (2015) study indicated that 3D printing requires trial, error, and experience to print successfully. 3D printers can be the vehicle that enables both teachers and students to make meaning of their world. For example, students learned about the solar system via 3D Printing of the different planets, and they learnt science and engineering concepts. Consequently, technology can enhance purposeful teaching (Hunter, 2013).

Not only does 3D Printing enrich subjects, such as the psychology lesson where students learnt about psychology content, but it also introduces an element of enjoyment and excitement. 3D Printing can create an environment of excitement for students (Cano, 2015). The researcher noticed that students did not want to leave the makerspace until they collected their model. Many schools reported that after building a makerspace, they experienced improved student attendance

and engagement: "I told my mother, I needed to come to school because I wanted to 3D print my robot today" (Cano, 2015).

Furthermore, it has been noticed that some students could not complete their projects due to the time needed to print their work, more than seven days. Teachers and students should be informed of the constraints of 3D Printing. This matches a previous study by Schmidt and Ratto (2013), who found that people did not understand the constraints of 3D printers. During this, the researcher observed a teacher expressing frustration when their students repeatedly visited the makerspace with unsuccessful attempts at 3D Printing. To address this issue, the study suggests that teachers should adopt a contingency (B) plan, as Barlex and Stevens (2012) recommended.

### *B. Creativity For Learning Through Learning*

Educational researchers agree that 3D Printing supports creativity in learning (Kostakis, Niaros, & Giotitsas, 2015). 21.54% of the participants said their students developed creativity (see Figure 8)—moreover, students who can transform their ideas into tangible objects through 3D printing experience the creative process. Additionally, Cano (2015) highlighted that the trial-and-error process can foster creativity. 3D Printing can spark the students' interest in generating many designs to solve a problem because it is a multi-layered process that contains many steps, such as defining a problem, brainstorming, evaluating, and finding a solution. Using the design thinking approach during the 3D designing and printing process provides an excellent opportunity to cultivate critical thinking and problem-solving skills.

3D printers can help students learn spatial intelligence when visualising and manipulating 3D shapes and images. Engaging in 3D Printing and modelling provides an excellent opportunity to practice spatial reasoning. According to Wai, Lubinski, and Benbow (2009), spatial ability predicts the development of new knowledge, particularly in STEM fields, fostering innovation. For example, in the solar system project (see Figure 11), students learnt the distance between the planets.

### *C. Public Learning*

Not only can students learn 3D designing skills, but they can also develop an understanding of copyright of the 3D models. Furthermore, students can grasp various concepts without explicit instruction and acquire multiple technology skills, including digital citizenship skills. For example, in the broken heart lesson, students learnt how to cite resources; this aligns with Kolitsky (2014), who stated that students and teachers can utilise 3D Printing as a technology tool to not only learn how to use this technology but also how to use 3D objects for learning within other subjects.

One of the problems indicated by participants which prevented them from working effectively with 3D printers was a lack of training. Multiple studies and reports examining 3D Printing cautioned that the absence of proper training in this field can pose a significant obstacle to its widespread adoption (Ford & Minshall, 2016). For example, Fettig (2017) stated that 3D Printing can facilitate learning and increase student engagement, but achieving success requires an effective professional development plan to train teachers. Access to technology is not limited to providing tools alone; it includes teacher professional development and teachers' experience with technology (Becker, 2000). One participant indicated, "More in-depth workshops for teachers and students. Perhaps an after-school or recess club".

### *D. Life Preparation Using Technology*

According to the findings, 9% of participants indicated that students developed soft skills (see Figure 8). 3D printing stations provide dedicated spaces for cultivating soft skills and help students acquire soft skills such as collaboration, critical thinking and problem-solving (Cano, 2015). These spaces allow students to express their perspectives, explore multiple solutions to a single problem in their learning, as they can choose a myriad of solutions to solve a problem. Additionally, students actively engage with their local communities to address real-world issues relevant to their communities. So, 3D Printing can change the environment of teaching to student-centred learning. This echoes the results of Loy (2014), as mentioned in the literature review, who indicated that 3D Printing promotes student-centred learning and improves students' work by altering how students and teachers interact and connecting learning to ethical responsibilities. Also, students become responsible for their learning as they must finish on time and present a final product.

Loy (2014) argues that student-centred learning involves a shift in power from the teacher to the student, stating that "Student-centred learning involves the balance of power within the learning experience shifting from the lecturer to the student" (p. 3). According to Loy (2014), due to the novelty of 3D printing technology, internet resources tend to be more accurate and up-to-date compared to the limited availability of publications specifically focused on 3D Printing. Loy (2014) additionally highlighted that students can act as teachers by sharing new information about the expansion of technology in the classroom. The researcher has reservations about Loy's (2014) argument for several reasons. First, internet resources contain accurate and inaccurate information on 3D printing topics, and sometimes some websites may market some fake information in favour of specific models of 3D printers. Second, students can gain theoretical knowledge of 3D Printing. However, practical knowledge is gained by physically working with machines.

Not only can a 3D printer facilitate engaging and enjoyable learning experiences, but it can also be integrated into different subjects in a manner that fuels students' curiosity and sparks their interest to innovate. Educators should prepare students for jobs not even been created due to technology's exponential growth. Research revealed that teaching with 3D Printing enables students to acquire creativity, problem-solving, critical thinking skills, and the ability to collaborate and communicate globally (Horowitz & Schultz, 2014). Teaching 3D modelling and Printing can prepare students for the future by teaching 21st-century skills that engage and inspire students.

### E. Contextual Accommodation

3D Printing spans various subjects and contexts, including science, mathematics, and history. For example, in the English project (see Figure 11), students were required to learn history, English, and design skills. This approach facilitated the simultaneous learning of multiple concepts for students and teachers.

3D Printing nurtures the community of learning and changes it from instructions to making, where students work and learn collectively. As 3D Printing involves many skills, such as designing and 3D modelling, students do not need to master every concept; instead, they can seek support from peers, community members, or parents who volunteer to assist with design skills (Cano, 2015). For example, in the solar system lesson (see Figure 11), students were required to learn about science; so, a science teacher was invited to help them.

To sum up, the previous section explored the theory-driven practice of using 3D printers in education. It emphasises the constructionist perspective, where students construct knowledge through hands-on projects. Although challenges such as failed prints occur, these setbacks enhance student engagement and facilitate learning through trial and error. 3D Printing can enrich subjects, foster creativity, and help students develop critical thinking and problem-solving skills. It also supports public learning by teaching skills like copyright understanding and digital citizenship. However, lack of training and time constraints were identified as obstacles. Overall, 3D Printing prepares students for the future, promotes student-centred learning, and accommodates various subjects and contexts, fostering a community of learning and collaboration.

## VII. RESEARCH LIMITATIONS

This study involved a limited number of 27 participants, constraining how the findings can be generalised to other educational settings. Additionally, this research focused on using 3D Printing within makerspaces to support the curriculum, excluding applications of 3D printers in computer laboratories or science classrooms. Despite these limitations, it is still believed that this study provides valuable insights for future research and administrators who plan to integrate 3D printers in makerspaces.

## CONCLUSION

While integrating 3D Printing into the curriculum presents students with abundant chances to grow, collaborate, learn, and explore, there are many challenges that educators and policymakers should be aware of when expanding 3D stations in schools (Eldebeky, 2021). This study explored teachers' perceptions of the skills students can develop while working on a 3D printing station in a makerspace. Furthermore, analysing the reflections of students' projects offered valuable insights into their collaborative experiences with 3D modelling design. The findings revealed that students can develop various skills, including creativity, spatial intelligence, and collaboration. However, some challenges have been reported, such as the need to train teachers in the practicalities of 3D Printing. While these findings are preliminary and invite further in-depth research due to the study's limitations, the study contributes to the limited existing knowledge regarding the impact of 3D printing technology on teaching and learning. This study will be valuable for educators and administrators who plan to add or expand 3D printing stations in schools, and can be valuable in writing a policy for using 3D printers in makerspaces.

The analysis of 3D printing projects revealed that students succeeded in printing various models and acquired valuable skills. The insights from the analysis aligned with the conceptions of the High Possibility Classrooms (HPC) framework, including theory-driven technology practice, creativity for learning through learning, public learning, life preparation using technology, and contextual accommodation.

Answers to the following research questions discuss the study's conclusions:

*RQ1: What are teachers' perceptions regarding 3D printing stations?*

Most participants (22 out of 27) rated 3D Printing as highly effective or practical, while only a small number considered it somewhat ineffective or ineffective.

*RQ2: What skills, if any, do teachers believe that students develop when they use 3D printers?*

The participants identified technology skills, creativity, 3D modelling, problem-solving, critical thinking, and soft skills as the main areas of development.

## RESEARCH IMPLICATIONS

This research offers implications for students, teachers, and school leaders.

Firstly, it encourages schools to incorporate 3D printers in school makerspaces. Secondly, it emphasises aligning the school curriculum with 3D printing projects. Thirdly, it recommends that schools provide professional development opportunities for teachers to stay updated on the latest trends in 3D Printing and acquire additional resources, such as colour 3D printers.

## RECOMMENDATIONS FOR FUTURE RESEARCH

To expand the knowledge and understanding of 3D Printing in school makerspaces, future research may focus on the impact of 3D Printing on teaching and learning outcomes. Additionally, exploring the alignment of the curriculum with 3D printing projects in different contexts will be valuable. Furthermore, investigating the value of integrating other advanced 3D printing technologies, such as Makerbot, which can be managed remotely using a mobile app, would be worthwhile. Lastly, exploring the potential of integrating the emerging trend of 4D Printing could also prove beneficial.

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