Article type

Full paper, double-blind peer review.

Publication history

Received: 26 January 2021. Revised: 27 February 2021.
Accepted: 28 February 2021. Published: 13 April 2021.

Cover image

loktov
via Pixabay.

Special issue Technology enhanced learning in the MENA region | **More at** <https://doi.org/10.21428/8c225f6e.1fd869f8>

High school students' experience of a 3D printing station at a bilingual school makerspace in Kuwait

Sayed M. Eldebeky

Department of Educational Research, Lancaster University, Lancaster, United Kingdom

Keywords

3D printing; makerspaces; maker movement

Citation

Eldebeky, S. M. (2021). High school students' experience of a 3D printing station at a bilingual school makerspace in Kuwait.

Studies in Technology Enhanced Learning, 1(2), 371-385.

<https://doi.org/10.21428/8c225f6e.5c7a27a0>

Abstract

In recent years, three-dimensional (3D) printing has become more accessible to school makerspaces (places for making projects using different tools), as prices are dropping and more schools are becoming able to afford 3D printers. Schools in Kuwait need evidence that 3D printing aids education in order to justify purchasing more 3D printers and provide teachers with training to find ways to integrate it into their curricula. This qualitative case study examines 3D printing and the users of this technology so as to better understand 3D printing's impact on education. It presents the results of a survey asking high school students about the skills they developed during 3D printing projects and field notes collected in a 3D printing station in a school makerspace. I employed two theoretical models to frame this study and enrich the discussion: a 21st-century learning framework and the Dynamic Decision-Making Model. Participants reported that they developed a number of skills during their 3D projects, such as collaboration, communication and technology. Moreover, the author also found a lack of connection between this kind of technology and its instructional value. The issue which was found in this research is that many users of the above-mentioned technology face problems with it because it is still under development.

1. 3D Printing as a New Technology in Schools

3D printing technology is gaining momentum all over the world in different sectors. Several countries in the Middle East have started to look for ways to integrate this technology to meet the needs of the future. For Example, Sheikh Mohammed bin Rashid Al Maktoum, Vice President and Prime Minister of UAE and Ruler of Dubai, launched the Dubai 3D printing strategy to utilise this technology 'for the service of humanity and promote the status of the UAE and Dubai as a leading hub of 3D printing technology by the year 2030' (The promise of 3D printing, 2018, p.1). The first makerspace, the *Sabah Al-Ahmad Centre for Giftedness and Creativity* (SACGC), was created in Kuwait in 2010 to support talented and gifted people. This makerspace contains a 3D printing lab to support inventors to implement their ideas.

The use of 3D objects in education offers many possibilities for understanding and exploring concepts (Liziero & Basniak, 2019). For example, 3D printing can enhance successful learning experiences and bring lessons to life for kinaesthetic and visual learning (Ford & Minshall, 2019). Furthermore, 3D printing has the potential to support learning by providing exciting experiences. This study investigates how 3D printing can help a K-12 curriculum meet the needs of today's 21st-century learners and help them prepare them for the future.

Following the introduction of low-cost 3D printers, many educators argued about the efficacy of integrating this technology into education. 3D printing shows promise, but educators need to find value in using it (Steed, 2019) and the value should not be just about printing a model, as opposed to acquiring skills. The integration of 3D printing in education has raised hopes and concerns about how it can be utilised as a tool for learning (Trust & Maloy, 2017). As stated by Novak (2019), evidence suggests that although administrators push the integration of 3D printing in schools, there is a risk that it will be resisted due to many constraints. Consequently, research is required to help educators find ways to integrate 3D printing into education, as there is scarce research in this area (Loy, 2018).

During my work as a makerspace specialist at a bilingual school in Kuwait, I was asked to create a plan to integrate 3D printing into projects that were conducted in the makerspace. After reading prior research and consulting with friends, I chose to buy six XYZ 3D printers: four small printers, one big printer, and a full-colour 3D printer. The teachers were happy with the outcomes as they did not

believe initially that they could make anything with this tool. Having a 3D printer was like having a small factory in the school to enable students to achieve their dream through building anything.

While 3D printers can help reshape learning in classroom settings, educators should weigh the costs and challenges of using this new tool (Trust & Maloy, 2017). Cano (2015) found that many teachers do not see the value of 3D printing in education, an attitude shared by some of the faculty at my school. Moreover, students may waste their time by downloading any model and printing it without learning any skills (Hoy, 2013).

This study was born out of my passion as a head of makerspace to expand my makerspace role in teaching and learning. This study can be helpful for teachers and administrators to integrate 3D printing into teaching and learning. Moreover, it can aid makerspace staff in introducing 3D printing labs in their makerspaces.

1.1 Purpose of the Study

As 3D printers have decreased in cost and increased in availability, they have grown more common in some schools in Kuwait as ways to support Science, Technology, Engineering and Mathematics (STEAM) or design technology. Thus, educators need to find ways to utilise 3D printers effectively for education (Flowers, 2019). The purpose of this qualitative study is to investigate whether students using 3D printing in their projects show a significant improvement in 21st-century skills and what problems they might face during 3D printing projects.

1.2 Research Questions

To start examining its role in education, we need to first understand students' perceptions of 3D printing. Limited research has been conducted on how students perceive 3D printing stations in makerspaces. To address this deficit, the present paper attempts to evaluate a particular 3D printing station in a school makerspace by asking the following question:

- 'How do high school students perceive a 3D printing station in a makerspace?'

Sub-questions of the study include the following:

1. What skills can students learn when they use a 3D printing station in a makerspace?
2. What are the challenges related to using a 3D printing station in a makerspace?

3. How can teachers encourage students to participate in using a 3D printing station?

2. Literature Review

This literature review was conducted to ensure a thorough examination of research on 3D printing in education, since the issue is new to schools in Kuwait. The first topic of research is the Maker Movement and makerspaces. The second topic is 3D printing in schools and how educators can use it to prepare students for the future. Finally, the third topic includes previous studies on 3D printing. Using the Qatar National Library database, peer-reviewed scholarly journal articles published between the years 2008 and 2019 have been selected. Recently published books have also been selected. I used the following search terms in various combinations: 3D printing in schools, 3D printing in makerspaces and 3D printing in education.

2.1 The Maker Movement, Makerspaces and Design Thinking

3D printing is connected with the Maker Movement, makerspaces and designing thinking. While makerspaces are the physical places for 3D printing, design thinking is the method for making 3D printing projects. The Swiss psychologist Jean Piaget combined many ideas of Dewey, Montessori, Froebel and Pestalozzi with his theory of *constructivism*. Learners construct knowledge inside their heads based on their experience using an internal process of sense-making. Seymour Papert, who is considered to be the father of the Maker Movement, developed Piaget's theory to form another theory called *constructionism* (Martinez & Stager, 2013). Papert's theory of constructionism expands Piaget's constructivism to include learning in a physical activity that ends in a shareable final product or 'model' (Martinez & Stage, 2013). Papert's theory of constructionism, which focuses on constructing knowledge through the act of making, paved the way for the Maker Movement.

The Maker Movement started with digital software and technologies and online communities intending to change the way people engaged in traditional hobbies and artistic endeavours such as arts, crafts, woodworking, tinkering, metalworking, and electronics (Martin, 2015). It began after the publication of *Make* magazine in 2005 and the first Maker Faire in 2006 (Hatch, 2014). As the movement has grown, makers have been creating physical locations called fab labs or makerspaces in learning environments such as universities, libraries, museums, art studios, tech shops, and K-12 classrooms. Research on making as a learning process for design-based approaches in subjects such as science,

technology, engineering, art and music (STEAM) education is growing every month (Lacy, 2016).

2.2 3D Printing as a Way of Preparing Students for the Future

According to Papert (1993), learning is the construction or transformation of internal representations. Designing 3D models is an example of this construction model to transform students' ideas into physical objects via 3D printing. 3D printing presents many opportunities across many subjects and is quickly being integrated into schools (Schwab, 2017, as cited in Novak, 2019). Students in schools will, in a very few years, be starting careers which have not yet taken shape. Gross et al. (2014) suggests that 3D printing is a means by which future endeavours will begin (as cited in Flowers, 2019).

2.3 Previous Studies

In a study by Trust and Maloy (2017), participants mentioned that their students developed a number of skills while working on 3D printing projects. These included proficiency with 3D modelling, creativity, technology literacy, problem-solving, self-directed learning, critical thinking and perseverance. In their study, the authors mentioned a number of challenges that teachers face when using 3D printers in their classrooms. Despite their promising findings, the authors suggested that more in-depth research, such as interviews, should be conducted in order to validate the results.

Furthermore, a study by Sampaio and Martin (2013, as cited in Formiga, De Araujo, & Santos, 2019) was conducted with eight elementary students. The students worked in groups to create chains using Tinkercad software to import ready-designed 3D models. Findings suggested that the students found the software easy and fun to use but teachers found it difficult to understand. Other studies revealed that teachers and students need training in 3D designing and 3D printing. In the same vein, Posch and Fitpatrick (2012) showed that some of the students faced difficulties while engaging in 3D printing activities.

In another study by Novak and Wisdom (2018), which examined the effects of 3D printing project-based learning on preservice elementary teachers' science attitudes, the authors engaged teachers in a 3D printing science project on why things float or sink, demonstrated using 3D printed boats. The authors explored how collaborative 3D printing inquiry-based learning experiences affected preservice teachers' science teaching self-efficacy beliefs, anxiety

towards teaching science and interest in science. Novak and Wisdom's (2018) findings stress the importance of preparing teachers prior to implementing 3D printing in schools. In summary, limited research has been conducted in schools. Moreover, previous research (Miyasaka & Fabrício, 2015, as cited in Formiga, De Araujo, & Santos, 2019) focused on the use of 3D printing in learning and the role of 3D printing as an accessible tool for learners in making 3D models (Loy, 2018).

2.4 The Need for This Study

Although educational researchers have posited that the maker movement could contribute positively to education (Bevan et al., 2020), a close examination of learning through making is necessary for integrating it into a given school system (Halverson & Sheridan, 2014). Aside from a few 3D printing studies from other countries (Schnedeker, 2015; Kostakis, Niaros, & Giotitsas, 2015), no previous research has been done to explore the impact of the 3D printing on learning in Kuwait or other Middle Eastern countries. Consequently, I intend to fill this literature gap by performing a qualitative study that differs from previous studies in two ways: first, listening to students' voices, which are sometimes overlooked in research, and second, using multiple tools for data collection.

3. Conceptual Models

3.1 21st-Century Learning Framework

This qualitative case study used a 21st-century learning framework to guide the discussion. 21st-century learning largely refers to deeper learning competencies such as innovation, digital literacy and problem-solving, which are necessary to prepare learners for the future. This means that students must also be competent communicators, creators, critical thinkers, and collaborators (the four Cs) (Battelle for Kids, 2020).

In 2002, the Partnership for 21st Century Learning, a non-profit organization of business leaders, educational leaders, and policymakers created a framework for 21st century teaching and learning (Battelle for Kids, 2020). The Partnership for 21st Century Learning (P21) joined the Battelle for Kids (BFK) family in 2018. The Framework for 21st Century Learning includes interdisciplinary themes for content knowledge instruction, namely Global Awareness, Financial, Economic, Business and Entrepreneurial Literacy, Civic Literacy, Health Literacy, and Environmental Literacy. 3D printing technologies can support different skills to

educate learners of the 21st Century (Formiga, De Araujo, & Santos, 2019).

Figure 1. Framework for 21st-century learning (2021)

The framework for 21st-century learning has been chosen to frame my discussion because the Partnership for 21st Century Learning recommended including 21st-century themes and the four Cs in education in teaching and learning. Including these themes and the four Cs can help students develop a global cultural understanding and skills competencies for the future. In addition, the four Cs can distinguish students who are prepared for future jobs from those who are not (Bridge, 2019).

3.2 Dynamic Decision-Making Model

Researchers and scholars have put forth a number of models to explain technology integration such as the Substitution Augmentation Modification Redefinition (SAMR) model (Puentedura, 2014). One model of technology integration is the Dynamic Decision-Making Model (see Figure 2) which was developed to aid teachers in making informed decisions about integrating 3D printing. Furthermore, it was developed to support educators in using technology for the intent of learning rather than for technology's sake (Steed, 2019). This model was chosen because it is one of the effective models for integrating 3D printing into instruction and it emphasises effective decisions, in terms of how to utilise 3D printing in learning.

Educators are encouraged to match the following while considering decision-making points:

- The conceptions of 3D printing with the instructional outcomes
- The 3D printing pragmatic constraints with activity-pragmatic constraints

Figure 2. Dynamic Decision-Making Model (Steed, 2019)

- Product constraints with 3D modelling features
- Activity product constraints with 3D affordances
- Sidebar learning with 3D printing contextual benefits
- 3D printing approaches and assessment

The connection between the two conceptual models is clear when the conceptions of 3D printing are linked with the instructional outcomes. The four Cs in the framework for 21st-century learning can be used as a guide for the instructional outcomes to determine the instructional value of 3D printers in education.

4. Methodology

This study used qualitative research to explore how high

school students perceive 3D printing in a school makerspace. Creswell (2009) described qualitative methods as an approach for investigating and understanding the meaning that individuals associate with social or human problems. This case study design helped me to examine the practices of high school students at a bilingual school on a deeper level through analysing data obtained from high school students in Kuwait. In addition, the use of a case study methodology is important to this study in that the primary aim was to understand the possible contributions that 3D printing has or could have on teaching and learning.

4.1 Site Description

The study was conducted at a bilingual school in Kuwait City. The campus serves more than 2,100 students and has four buildings: one high school, one middle school, one

Figure 3. A 3D layout of the makerspace at the author's school

elementary school and one preschool. The school offers a bilingual programme in which Arabic and English carry equal emphasis and status. The majority of students are Kuwaiti. The school has a makerspace (see Figure 3) which contains the following stations:

1. 3D Printing
2. Robotics and Coding
3. Science and Engineering
4. Electronics and Tinkering
5. Arts and Crafts
6. Augmented Reality
7. Green Screen
8. Woodwork
9. Laser Cutters and CNC routers

4.2 Research Methods

I applied qualitative research methods to gain insight into students' beliefs and experience. Using a qualitative case study approach, I utilised two methods of data collection: surveys and fieldwork notes. The use of surveys has been reported to be a useful qualitative approach by other researchers. The purposive sampling principle for participants was used as it allows for effective data triangulation, thus enhancing validity (Ritchie & Lewis, 2013). The survey involved qualitative questions in order to allow me to delve deeper into the required data to examine the perceptions of students using 3D printing in projects. I observed students during seven 3D projects in a makerspace and made field notes on each project (see Appendix A).

4.3 Participants

The participants of this study were selected from high school students in a bilingual school in Kuwait from grades 11 and 12. Their ages ranged from 16 to 18. Participants were selected through purposive sampling. Purposive sampling allowed for the identification of high school students with certain criteria (Patton, 1980). Furthermore, high school students were used as a purposeful sample due to their participation in 3D printing projects in the makerspace.

4.4 Equipment

The da Vinci Colour printer (see Figure 4) was used in this study. It is the world's first full-colour 3D printer which utilises inkjet technology to produce quality full-colour 3D prints. Moreover, the printer has a 3D print bed volume of 7.9 by 7.9 by 5.8 inches. It was chosen for several reasons: it saves work in case the power goes off, students can change the filament during the printing so they can use different colours in the model and students can colour what they print. Also, there is a free 3D gallery which contains many 3D models.

Figure 4. The da Vinci Colour printer

4.5 Data Analysis

The focus of this analysis was to understand and describe the participants' experience while working on 3D printing projects. I analysed two types of data separately: survey results and field notes. Concerning the analysis of the online survey, phase 1 of data analysis included collecting survey response data. I was able to access the returned survey data in a Google Sheets format, which showed responses by date. After the codes were grouped, data were organised as related among respondents. The online survey was analysed using open coding with Charmaz's (2006) grounded methodology.

4.6 Ethical Considerations

To ensure the rights of the students, each participant's anonymity was guaranteed. Any request to withdraw from the study at any time would have been honoured. The name of the school was anonymous; however, the school requested that the researcher present a summary to the director.

5. Findings and Discussion

5.1 Survey Results

5.1.1 Observations from Question 1

1. Describe the 3D printing project you did in the makerspace.

The majority of students' 3D printed models were items such as a key chain, an iPhone case or a tower. Other students printed a large, coloured brain using the big colour 3D printer. Many students were interested in 3D printing items that were very large. Students used only two types of software: Tinkercad and Sketchup (see Appendix 1). Three students described their project as 'fun'.

5.1.2 Observations from Question 2 and Question 3

2. Choose the skills you have developed while working on 3D printing projects.
3. Write other skills.

Out of 32 participants who answered this question, 27 mentioned that they had developed technology skills while 26 participants said they had developed their creativity (see Figure 5). Nearly 70% of participants chose collaboration. A small number of participants chose decision making and critical thinking. Some students reported that they learnt

how to work better in groups, and they found the maker-space environment fun.

Figure 5. Analysis of question 2

5.1.3 Observations from Question 4

4. Have you faced any problems while working on 3D printing projects?

Eighteen participants, which is 56 % of the whole sample, stated that they faced problems during the 3D printing projects (see Figure 6). On the other hand, 14 participants stated they did not face any problems in their 3D printing projects.

Figure 6. Analysis of question 4

5.1.4 Observations from Question 5

5. Write the problems if your answer to the previous was yes or skip the question.

Students mentioned three main problems while they were working on their projects. Firstly, they need help and training. Secondly, they need a big 3D printer to print big models. Thirdly, they need more time to complete their work. The following list summarises their answers:

1. Students need to learn how to colour a model.
2. Students spent too much time on fixing their model.
3. Students need to 3D print a large model.

4. Students could not print successfully on their first attempt.
5. Students need more training to support them during 3D printing projects.
6. Students need help to make the correct measurements for their models.
7. 3D colour printers are not feasible printers.

5.1.5 Observations from Questions 6 and 7

6. How can we improve the 3D printing station in our makerspace?
7. Write other comments.

Students suggested that their 3D printing station should be more organised by having more space for collaboration. In addition, they suggested that more choices for filaments, computers and colours should be added. Furthermore, they mentioned that they needed more training in 3D printing. Only one participant stated that it was perfect, and it does not need any improvement.

5.2 Findings of the 3D Printing Projects Analysis

As mentioned in the field notes (see Appendix 1), I noticed that many students faced problems during their 3D printing colour projects, and they could not print successfully during their first attempt due to some mistakes in their designs or technical issues with the 3D printers. Additionally, more features should be added to the software of 3D printers as it takes too much time to prepare the file for printing. Finally, teachers should always have a plan B in case something happens with the printers, and the makerspace staff should have an extra extruder to use in case the filament is jammed. Although students faced problems, said students were also happy and enthusiastic about working on 3D projects.

5.2.1 Conceptions of 3D Printing with Regard to Instructional Outcomes

3D printing has the potential to offer exciting learning experiences (Bull, Haj-Hariri, Atkins, & Moran, 2015). Moreover, 3D printers offer a new approach that educators can use to engage students in critical thinking and problem-solving, and to bring lesson plans to life (Fettig, 2017). For example, during a lesson on the brain (see Figure 11), students were excited and motivated to learn 3D modelling; this also enabled them to understand the new concepts that they were learning. Furthermore, the main purpose of using 3D printing should not be building a model rather than

gaining learning value (Flowers, 2019). For example, during the house project, students practiced their spatial ability by identifying the distance between the walls (see Appendix 1).

Participants indicated that they acquired 21st-century skills such as collaboration, communication and creativity (see Figure 5). A small number of participants mentioned that 3D printing developed critical thinking skills. Critical thinking can be developed when students start designing from scratch and creating complex models. However, in this study few students designed their models from scratch (see Appendix 1). Scot (2015) states that the research evidence is conclusive: enquiry, design and collaborative approaches to learning build a powerful combination of content understanding, basic skills and applied 21st-century skills. 'Research findings are clear, 3D modelling and printing can address the sort of STEM skills that many educators and policymakers consider most important to productivity in the 21st century' (Cano, 2015, p. 2).

The findings of this study are different from the findings produced by Trust and Maloy (2017) as around 75% of the participants felt they developed critical thinking skills while building and printing 3D models. I believe that the difference in the findings is because participants in this study were students, but the other study's participants were teachers. Moreover, participants in Trust and Maloy's study indicated that the 3D model requires critical thinking skills to design the 3D models. Loy (2019) states that 3D printing provides a starting point for students engaging with complex problems crossing traditional subject boundaries and this can help them to practice critical thinking skills. For example, a high school student looked for ways to help students during the pandemic in 2019. He found a practical solution in the form of 3D printed hands-free door openers (see Figure 7) designed to make it possible to open doors using arms or, in some cases feet instead of hands, thus decreasing the chance of spreading Covid 19 (About Us, 2019).

5.2.2 Pragmatic and Technical Constraints on 3D Printing

There are some constraints that teachers need to consider when using 3D printers (Steed, 2019) for example, teachers need to match the pragmatic instructional requirements with the pragmatic issues of using 3D printing. Participants have indicated that it takes too much time to print, and so teachers had to extend the assignment for two weeks to enable students to finish printing their models. Moreover, they stated that it took much time to prepare the model for printing in the software and some students were not happy about waiting for more than 15 minutes (see Figure 8). Understanding the constraints of 3D printing can impact the

way in which it can be integrated into projects in a makerspace. Additionally, it can help teachers and students to find creative ways to work around these barriers so that 3D printing can be used to empower student enquiry (Flowers, 2019).

Figure 7. The door openers

Figure 8. Errors in the settings

Although students enjoy adopting 3D printing in schools, teachers should have a back-up plan in case something does not work as planned (Novak, 2019). During the brain project, students tried to use the flexible filament, but they could not do so due to certain technical problems. Instead, teachers advised them to use the normal filament (see Appendix A).

One of the challenges in 3D printing is the effective use or the educational value of the outcomes. Teachers should not use technology for technology's sake rather than with the intent of learning. 'Without more advanced learning opportunities, academics will struggle to place digital technologies such as 3D printing at the centre of educational learning instead they remain supplementary to it' (Loy, 2019, p.100). Although printing 3D models might not require creativity from the user, the real value comes out of the process of 3D designing the model and connecting the 3D model to solve a problem.

5.2.3 Product Constraints with 3D Modelling Features

There are many 3D modelling applications with different features. Teachers need to suggest one that is user-friendly and does not take up too much of students' time. For example, in the house project (see Figure 9), students used SketchUp, but they could not continue because it was too complicated and advanced for them. Instead, they were advised to use Tinkercad as it had the features they needed. In this study, the students were confused by having many kinds of slicing software, a free software used in of 3D printing processes for the conversion of a 3D object model to specific instructions for the printer. For example, there were three slicing programs for XYZ 3D printers.

5.2.4 Activity Product Constraints with 3D Affordances

Knowing about 3D printing affordances can help teachers design suitable 3D activities for their students. There are many 3D affordances that can affect instructional activities, such as rapid prototype, scalability, complexity, uniqueness, and variable density (Steed, 2019). Many instructional problems can be decreased if teachers and students are aware of 3D affordances such as infill density.

Infill features relate to the amount of filament inside or between the layers and they can be found in many 3D printers with different options. Students should be aware of their project requirements in terms of infill so as to obtain the desired effect. Participants of the house project failed to 3D print the house more than three times because they had to choose the correct settings in the infill options (see Figure

10). Another affordance that helped my participants in their projects was replicability – making many copies of the same model at the same time. This feature could be found only in small 3D printers (see Figure 11).

Figure 9. The house project

Figure 10. Failed project

5.2.5 Learning with 3D Printing's Contextual Benefits

Although 3D printers are available to fulfil objectives for teaching and learning, the real objectives of these materials sometimes do not meet the students' needs (Santos, 2007). 3D printing is not about making a model only, as the process involves learning other skills through the design and printing models. Rather, using design thinking as an approach to guide the process can be helpful, as students need to follow several steps, such as identifying the problem, materialising and testing. During the process, students might fail to 3D print successfully due to mistakes in designing, and so they may decide to start again (see Figure 12).

Figure 11. Copy models

Figure 12. Jammed filament

There are many learning opportunities to be had from unforeseen equipment errors (Kerestes, 2019) and the process of overcoming these errors can help students to embrace mistakes as a method of learning. In the course of working on the house project, the model became corrupted. During the analysis of this 3D printing error, students realised that the ground of the house was 2D and the walls were very thin. However, they could print successfully after they adjusted their design. Engaging in the design of a 3D object can aid enquiry-based learning for students as they learn the new features in the software and try to solve the problems of their design (Flowers, 2019). Failed attempts at printing models can open up new learning opportunities if they are analysed as students help other students to engage in experimentation and investigation.

5.2.6 3D Printing Approaches and Activity Learning

In 3D designing lessons, students can design through three approaches: by downloading a ready-made model from the internet and customising it later, by scanning an object with a 3D scanner or by designing from scratch. In this study, the majority of designs were downloaded from the internet, but a few projects started from scratch when students were familiar with 3D designing. Some students chose to use a ready-made model because they did not have enough time and they had not been trained how to design 3D models.

Despite increasing focus through programmes such as STEAM, there is little support offered to schools and teachers to learn 3D printing and associated skills such as 3D scanning. New methods of training must be implemented by schools to ensure that teachers and students know how to use 3D printing (Novak, 2019). 3D printing has expanded over the last few years as teachers have explored its potential as a learning tool in many subjects. “Thoughtful integration and professional development are required for teachers and students to support them on how to use this technology” (Bull et al., 2015, p. 14).

6. Limitations

These findings should be read with the following limitations in mind. In this study, I observed only a few 3D printing projects in a school makerspace. Certainly, observing other school makerspaces and increasing the number of participants would make this study more robust. Furthermore, the researcher’s choice of employing a case study methodology limits the scope of this study in terms of population size, demographic data, and other aspects.

However, it is still believed that this study provides useful insights and groundwork for future research.

7. Conclusion

While the rapid growth of technological advancements such as 3D printing offers many opportunities to learn numerous skills for the future, educators need to find ways to integrate this technology into the curriculum. Findings of this study revealed that students learnt many skills. However, there were many constraints of using 3D printing which have been highlighted in the discussion of the findings through the Dynamic Decision-Making Model. Over time, these constraints might be reduced due to predicated technological advances in 3D printing. While 3D printing can help to engage students in many skills and in different subjects, 3D printing should be purposeful, and facilities should be focused on learning rather than making a model. In this study, the first key finding is that educators should plan well before using 3D printing as they might face many problems. The second key findings suggests that teachers should not focus on the process of 3D printing. Rather, they should focus on the process of designing and on helping students to embrace making mistakes as a method of learning.

While these findings are tentative and invite further in-depth research due to the study’s limitations, the study contributes to the scarce body of knowledge on how 3D printing technology can enhance a curriculum and describes students’ experience during 3D projects. Practitioners can find the study useful when they want to establish 3D printing laboratories or expand their existing stations. It is recommended that when schools buy 3D printers that they purchase printers that are upgradable, so that the school can grow with the latest developments rather than the machine becoming outdated in this rapidly changing innovative world. Finally, schools should provide teachers with professional development to learn how to use this modern tool effectively.

References

- About Us. (2019). Retrieved from <https://www.hands-free.health/>
- Bevan, B., Ryoo, J. J., Vanderwerff, A., Wilkinson, K., & Petrich, M. (2020). “I See Students Differently”: Following the Lead of Maker Educators in Defining What Counts as Learning. *Frontiers in Education* 5: 121. doi: 10.3389/feduc.2020.00121

- Bodgan, R. C., & Biklen, S. K. (2003). *Qualitative research for education: An introduction to theory and methods* (2nd ed.). Needham Heights, MA: Allyn & Bacon.
- Bridge, C. L. (2019). *Examining the Effectiveness of Middle School Students Using iPad Devices for Improving 21st-Century Skills With and Without Four Cs Specific Instruction* (Doctoral dissertation, Northcentral University).
- Bull, G., Haj-Hariri, H., Atkins, R., & Moran, P. (2015). An educational framework for digital manufacturing in schools. *3D Printing and Additive Manufacturing*, 2(2), 42-49.
- Charmaz, K. (2006). *Constructing grounded theory; a practical guide through qualitative analysis* (1st ed.). California: Sage.
- Creswell, J. W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Boston, M.A.: Pearson.
- Creswell, J. W. (2013). *Qualitative inquiry and research design: choosing among five approaches* (3rd ed.). Los Angeles, C.A.: SAGE Publications.
- DiCicco-Bloom, B., & Crabtree, B. F. (2006). *The qualitative research interviews*.
- Durant, K. M. (2016). The maker movement and 3D printing: a critique (Doctoral dissertation, Arts and Letters).
- Flowers, J. (2019). Using 3D Printers to Engage Students in Research. In *Interdisciplinary and International Perspectives on 3D Printing in Education* (pp. 50-69). IGI Global.
- Framework for 21st Century Learning. (2021). The Battle for Kids. Retrieved from http://static.battelleforkids.org/documents/p21/P21_Framework_Brief.pdf
- Ford, S., & Minshall, T. (2019). *Where and how 3D printing is used in teaching and education*.
- Formiga, M. M. M., De Araujo, M. M., & Santos, I. M. (2019). Case Illustrations of 3D Printing in Brazilian Schools and Community. In *Interdisciplinary and International Perspectives on 3D Printing in Education* (pp. 158-175). IGI Global.
- Hatch, M. (2014). *The maker movement manifesto*. New York, NY: McGraw-Hill.
- Horton, K. L. (2017). *In Their Eyes: A Case Study Describing the Contributions of Making on Teaching and Learning in a Designated Middle School Makerspace* (Doctoral dissertation, Drexel University).
- Huang, T.-C., & Lin, C.-Y. (2017). From 3D modeling to 3D printing: Development of a differentiated spatial ability teaching model. *Telematics and Informatics*, 34(2), 604-613. doi: <https://doi.org/10.1016/j.tele.2016.10.005>
- Johnson, L., Adams Becker, S., Estrada, V., & Freeman, A. (2015). *NMC horizon report: 2015 K*.
- Kerestes, J. F. (2019). 3D Printed Glitches: Learning From Manufactured Errors. In *Interdisciplinary and International Perspectives on 3D Printing in Education* (pp. 70-93). IGI Global.
- Kostakis, V., Niaros, V., & Giotitsas, C. (2015). Open source 3D printing as a means of learning: An educational experiment in two high schools in Greece. *Telematics and informatics*, 32(1), 118-128.
- Lacy, J. E. (2016). *A case study of a high school fab lab*. The University of Wisconsin-Madison.
- Liziero, A. R., & Basniak, M. I. (2019). Using OpenSCAD for Teaching Mathematics: Building an Educational Model for 3D Printing. In *Interdisciplinary and International Perspectives on 3D Printing in Education* (pp. 111-133). IGI Global.
- Loy, J. (2018). Understanding the Scope for a Product Design Education Discourse on Additive Manufacturing. *Archives of Design Research*.
- Loy, J. (2019). 3D Printing Interdisciplinary Learning for Complex Problems. In *Interdisciplinary and International Perspectives on 3D Printing in Education* (pp. 94-109). IGI Global.
- Martin, L. (2015). The promise of the Maker Movement for education. *Journal of Pre-College Engineering Education Research (J-PEER)*, 5(1), 4.
- Martinez, S. L., & Stager, G. S. (2013). Invent to learn: Makers in the classroom. *The Education Digest*, 79(4), 11.
- Novak, J. I. (2019). Re-educating the Educators: Collaborative 3D Printing Education. In *Interdisciplinary and International Perspectives on 3D Printing in Education* (pp. 28-49). IGI Global.

- Patton, M. Q. (1980). *Qualitative evaluation methods*. Beverly Hills, CA: Sage Publications.
- Posch, I., & Fitzpatrick, G. (2012, November). First steps in the FabLab: experiences engaging children. In *Proceedings of the 24th Australian Computer-Human Interaction Conference* (pp. 497-500). ACM.
- Puentedura, R. R. (2014). SAMR: A contextualized introduction. *Lecture at Pine Cobble School*. Retrieved March, 13, 2014.
- Ritchie, J., Lewis, J., Nicholls, C. M., & Ormston, R. (Eds.). (2013). *Qualitative research practice: A guide for social science students and researchers*. Sage.
- Schnedeker, M. (2015). *An Exploration of Introductory Training Experiences in 3D Design and 3D Printing* (Doctoral dissertation, Tufts University).
- Steed, M. B. (2019). Dynamic Decision-Making Model: Integrating 3D Printing in Education. In *Interdisciplinary and International Perspectives on 3D Printing in Education*. IGI Global.
- The promise of 3D printing. (2018). Retrieved from <https://www.marmoremena.com/the-promise-of-3d-printing/>
- Trust, T., & Maloy, R. W. (2017). Why 3D print? The 21st-century skills students develop while engaging in 3D printing projects. *Computers in the Schools*, 34(4), 253-266.

About the author

Sayed Mahmoud Eldebeky is currently a Makerspace specialist at a school in Kuwait, where he leads on STEAM, project-based learning and maker-centred learning. He is a Google Certified Trainer, Google Certified Administrator, Apple Certified Teacher and Makerspace leader. Sayed teaches 3D printing, coding, laser cutting and CNC routing and supports teachers in exploring how they can integrate Makerspaces into their courses. He has two master's degrees from University College London, in Digital Learning and Library Sciences, has attended Design Technology training at Eton College, London, and has worked or trained in Turkey, KSA, UAE, Qatar, Finland, India and Kuwait. Sayed's current research includes examining learning in school makerspaces, 3D printing and maker-centred learning in K-12 schools.

✉ Email: s.ali20@lancaster.ac.uk

ORCID: [0000-0002-2917-3488](https://orcid.org/0000-0002-2917-3488)

🐦 Twitter: [@SayedEldebeky](https://twitter.com/SayedEldebeky)

Open Access (CC BY 4.0)

© 2020 The Authors. This article is distributed under Creative Commons Attribution 4.0 International licence.

You are free to

- Share — copy and redistribute the material in any medium or format
- Adapt — remix, transform, and build upon the material for any purpose, even commercially.

Under the following terms:

- Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.
- No additional restrictions — You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

The full licence conditions are available at: <https://creativecommons.org/licenses/by/4.0/>

Appendix A. Field notes

Projects	Notes	General Notes
Building a house	<p>Students failed to 3D 3 times</p> <p>They used the wrong type of Filament</p> <p>The door that is designed was very thin.</p>	<p>Students prefer to download ready-made objects from the internet.</p> <p>Chipped filament is available by the company, so people are forced to buy filament from the same company.</p> <p>Flexible filament did not work with the 3d printers.</p> <p>It is recommended to have extra extruder to replace it with the extruder when it is jammed with the filament.</p> <p>The majority of students are eager to solve their 3D problems</p> <p>It took too much time to 3D print some projects</p> <p>I was told that one should always monitor 3D printers by the technical support, but this is not feasible</p> <p>It is recommended to buy 3D printers that can be up-graded because this technology is under-development.</p> <p>The small type of 3D printers is the most feasible one.</p>
The mobile case	They failed because they used the mix 3D printer but when they tried to another printer, they printed successfully.	
Forest fire	They failed to 3D print from the first time but when they decrease the size of the model, they printed it successfully.	
Glasses	It is printed successfully	
Cone	<p>Students needed to copy the model, but they could not find it in the up-dated version of the software.</p> <p>Cancelling printing the projects took much time.</p> <p>Much time for preparing the model.</p>	
The colour 3D printer	This is still a new technology. It is still in its infancy.	
The brain	<p>Students could 3D print many parts of the brain using the small printers</p> <p>After several attempts, they could print a colour model using the colour 3d printer but in a small size</p> <p>Students could 3D print a brain using a Super printer and they painted it</p> <p>Students liked the model that they painted rather than the small one of the colour 3D printer.</p>	