3D printing in education – a way to foster learners' activity and improve their creativity and design skills

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Abstract: *3D printing is one of the new technologies increasingly involved in training at different stages - from schools to universities. Although devices and supplies are still quite expensive and not all educational institutions can afford them, the benefits of their application have been proven over the recent years. Many authors present their experience and describe the possibilities for active learning by creating 3D models of complex systems, anatomical body parts, and machine parts that make learners go deeper into acquiring mathematical concepts. 3D printing in training engages learners and improves their practical skills; they become creators, not just passive information consumers. Even when learning is online, it is possible to set collective tasks for the preparation of 3D models, and then they will be combined and implemented by the teacher. These models can be used as a teaching tool in various disciplines and can also be sold. This improves learners' teamwork skills and develops their communication and entrepreneurial abilities. The main purpose of this paper is to provide an overview of 3D technology, its areas of application, and the benefits of its successful application in education so that new digital learners are prepared for the challenges of tomorrow.*

Keywords: 3D printing, Education, 3D models, Active learning.

1. Introduction

Undoubtedly, 3D printing is one of the technologies that are becoming more and more popular and applicable in various fields - from creating small figurines and toys just for fun, to large 3D designs of buildings, anatomical organs and implants in medicine, in engineering to create spare car parts, and even in culinary to print shapes from food on the plate (Anandharamakrishnan, et al., 2022). To prepare people who can work with 3D printers, create 3D models, and know how to apply this technology, it is necessary to introduce it at each level of training.

The new generation of learners is digitally literate, different devices surround them, and each new technology provokes their curiosity and interest, making them more active and creative. Many STEAM (science, technology, engineering, arts, and mathematics) centers are equipped with 3D printers and through 3D printing, cross-curricular connections are made between different sciences, models of anatomical parts are created, models that reveal the structure of

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atoms, chemical bonding, models of geographical and historical objects, etc. 3D printing is becoming increasingly accessible, even for personal use at home. There are free and easy-to-use software and platforms with available 3D models that users can download and use for free or at a low price.

To reveal this technology's potential for successful implementation in education, it is necessary to consider its essential functionalities, how it works, the types of 3D printers, and the materials used.

The main purpose of this paper is to provide a short overview of 3D technology, its areas of application, and the benefits of its successful application in education so that the new digital learners are prepared for the challenges of tomorrow.

Some of the research questions are identified as follows:

- What are the main functionalities and capabilities of 3D printing technology?
- What is the potential of implementing 3D printing in education?
- What are the challenges and benefits of integrating 3D printing in education?
- What pedagogical approaches could be used when adopting 3D printing in education?
- What are the future research areas in 3D printing research in education?

1.1 3D printing technologies

Historically, 3D printing has existed since the 1980s, but its popularity and use began two decades later. It is known as additive printing because the object is built up layer by layer from specific material (polymer, metal, and ceramic). It differs from the so-called subtractive-based ones, in which material is removed, such as grinding or milling (Schneider & Kumar, 2020) or under the influence of various factors such as temperature, pressure, etc. (Saptarshi & Zhou, 2019)

Regardless of the technology used, printing a 3D model goes through several stages (Figure 1). It starts with conceptualization, i.e., determining the part to be printed.

Figure 1. Stages of 3D printing technology

A 3D design is created and exported using specialized software to a Stereolithographic (.STL) file format. It is also possible to download a ready-made

3D model from platforms offering rich collections. To print the model, it is necessary to transform this file into a set of commands (GCode) that the 3D printer can understand and execute. The model is divided into layers by special software called a "slicer, " usually built into most 3D printers. This software is suitable and can be used for almost all FDM printers. (Tully & Meloni, 2020)

Different 3D technologies depend on how the 3D objects are built: Fused Deposition Modeling (FDM), Poly Jet model, Selective Laser Sintering (SLS), Stereo Lithography (SLA), Laminated Object Manufacturing (LOM). (Top, Şahin & Gökçe, 2019).

1.2 3D printers

As mentioned above, many 3D printers differ in size and the materials they use for printing.

They can be conditionally divided into two main categories: desktop 3D printers, which are widely used for teaching purposes, personal needs at home, and the production of small parts. These 3D printers are smaller, easy to use, and relatively cheaper.

The other category is for industrial purposes. They are used to manufacture various components in the automotive industry, aerospace and defence, healthcare, power and energy, etc. These printers are larger, perform more specific tasks, and use different materials (metal, ceramics, bio-products, fabrics, etc.) (Grand View Research, 2023; UltiMaker, 2023).

Tully and Meloni (2020) provide recommendations and guidelines on what printer to use, depending on the project's goals, the objects to be printed, and the planned costs. They describe the main features of the 3D printer, the materials that are used, and the stages that are gone through. When choosing a suitable printer, the authors advise researchers that it is necessary to consider the present and future use well, to balance between the financial side and time, benefits, and constraints. According to them, there are several **benefits** of 3D printing compared with traditional manufacturing:

- 3D printing reduces the need for external services and specialists, and creating some parts in-house is possible;
- Shorter production time for various items needed by the end user;
- Independence and freedom from the need for other machines, typically a 3D printer is sufficient to produce a complete end product.

3D printing reduces waste and creates individual spare parts that are hard to find and buy because they are out of use and do not require maintenance.

As a **challenge** and **disadvantage,** they pointed out that these new technologies could overwhelm new users with less experience.

1.3 3D printing software

Creating 3D designs requires specialized computer-aided design (CAD) software, which is mainly used in architecture, interior design, engineering projects, and computer games. Some programs are for professionals, while others are suitable for beginners in this field. Most are free, open-source, or browser-based, and some allow the transformation of a 2D image into a 3D object. The main criteria for choosing the best CAD software should be the user's experience level (Sculpteo, 2023).

Some of the best known and recommended for this purpose are Autodesk Fusion 360, Autodesk Tinkercad, OpenSCAD, Blender, NanoCAD, 3D Builder, 3D Slash, 3D Crafter, LibreCAD, etc.

Some CAD software programs are appropriate for educational purposes and suitable for kids, like LeoCAD, which uses Lego bricks to create 3D objects. Another one is BlocksCAD, which uses block commands and helps kids learn coding concepts and computational thinking.

Plenty of available 3D models can be downloaded for free or at an affordable price and modified to support educators and learners. This builds communities of people who share common interests.

Some of these platforms are **Cults** (Cults, 2023), **All3DP** (All3DP, 2023), **and Free3D (Free3D, 2023), which offer a wide** variety of 3D models in different categories.

UltiMaker Thingiverse (2023) has a rich collection of 3D models, divided by subject, including some designed for blind people.

Sketchfab (Sketchfab, 2023) is a leading web platform for 3D and AR, but most models are paid.

3DFindit (3DFindit, 2023) is a visual search engine for 3D CAD, CAE and BIM models using different filters. Users can upload their files and search for similar ones.

NIH 3D (NIH 3D, 2023) is an open, community-driven portal for downloading, sharing, and creating scientific and medical 3D models for 3D printing and interactive 3D visualization, including virtual and augmented reality.

NASA 3D resources (NASA 3D resources, 2023) has a collection of 3D models of lunar and planetary terrains, small space bodies, and a library of physical objects accessible to the visually impaired people. These models serve as a tool for introducing space sciences to the learners (Horowitz & Schultz, 2014).

1.4 Implementation of 3D printing

The development of the 4th industrial revolution and its associated concepts and technologies, such as robotics, IoT, machine learning, and others, contributes

to the increasing adoption and integration of 3D printing in various fields. For a long time, the aerospace, automotive industry, and healthcare have been applying 3D printing for prototyping and creating different parts of aircraft and cars, especially for the interiors because customization is possible.

According to statistical analyses and studies, 3D printing for prototyping has the highest relative share, followed by manufacturing and proof of concept. As the most used material is Fused Deposition Modelling (FDM), there is also an increase in Direct Metal Laser Sintering (DMLS) for creating metal components and Selective Laser Sintering (SLS) for the sector of consumers' goods (Fortune Business Insights, 2023).

The increase in the use of metal and ceramics for 3D printing is also justified by reducing the use of plastics to protect the environment.

Many food industry by-products need to be reused to reduce costs and environmental damage, leading to the increasing popularity of food printing. Some authors explore extrusion-based 3D food printing systems with in situ gelation and mixing. They find that these systems provide greater control over the final properties of the printed products (Álvarez-Castillo et al., 2021).

The widespread adoption of this technology in various areas also requires specialists in this field, because, according to the data, about 71% of companies do not feel sufficiently prepared and trained to use 3D printing effectively (Joshi, 2023).

The presented statistical data reveals the need for a good understanding of this technology to foster innovation and the ability to transform and grow businesses.

2. Adopting 3D printing in education

New technologies surround the latest generation of learners, and many are curious to explore and use them. This implies updating the teaching facilities, curricula and programs, acquiring new skills and enhancing the teachers' competencies. Applying active learning methods (learning by doing, problem-based learning, personalized and adaptive learning, project-based and inquiry-based learning, maker education and STEAM education, and online and blended learning) increases learners' motivation and enhances interest in the discipline. Many schools and universities have purchased 3D printers and equipped STEAM classrooms and centers.

Based on the research by (Alhamad et.al., 2019) and their experience and continuous practice, it could be assumed that students become more excited and enthusiastic when given the freedom to use 3D printing technologies in their coursework. This innovative process has generated much interest among students, who are thrilled to be involved in this area. They believe a specific 3D printing and scanning course should be assigned for different educational areas and specialties, especially mechanical engineering education.

According to (Ford & Minshall, 2019) and their study of possible ways to apply 3D printing in different educational institutions (schools, universities, libraries, and special education settings), six categories of implementing 3D printing have been identified: (1) to teach students about 3D printing; (2) to teach educators about 3D printing; (3) as a support technology during teaching; (4) to produce artifacts that aid learning; (5) to create assistive technologies; and (6) to support outreach activities.

Because this is a relatively new technology and is still limited, educational institutions have 3D printers. Many teachers are unfamiliar with it and need to be trained to introduce it to their students. If the teachers feel confident when using it, they will be able to implement it in their subjects appropriately. Their scoping review (Kit Ng et al., 2022) outlined pedagogical approaches that could be incorporated in mathematical education alongside 3D printing, such as project/ problem-based learning, collaborative learning, and maker / design-based learning.

3D printers are being used to enrich STEM education through a variety of learning techniques and experiences. Reports of 3D-printed models for improved visualization of chemical phenomena, as well as the educational use of 3D-printed laboratory devices, are rapidly increasing (Pinger, Geiger & Spence, 2020).

Gitnux (2023) reported that 66% of education and research institutes use in-house 3D printers. This indicates that they know the need to incorporate this technology into teaching and learning in various disciplines.

One advantage of using 3D printing in education is that developing the creativity and practical skills to use this technology will prepare learners for the job market (LeapFrog, 2023).

Furthermore, acquiring new skills and integrating this technology with various disciplines, including medicine, architecture, art, design, engineering, and others is essential. Creating 3D anatomical models (Mamo et al., 2023), works of art, geographical objects, complex structures, and objects from different subject areas requires in-depth knowledge of the specific field.

3D printing is beneficial for blind people. Through 3D models, they can visualize and interpret content in graphical form. An organization and website, See3D, has been set up to organize the process of requesting, printing, and delivering 3D printed models for visually impaired people (blind people) (Karbowski, 2020). Creating tactile media and resources for blind people is of regional and national importance, and these assistive technologies will provide training for blind or visually impaired youth (Brulé & Bailly, 2021).

Another research study among students with blindness in a biology classroom in a primary school in Montenegro showed that students have a positive attitude towards 3D modeling and that this pedagogical approach through practical activities helped them acquire knowledge and their ability to describe cell parts and organelles. It increased their visualization of learning content, communication, and feeling of equality in participation. (Anđić et al., 2022).

The development of this technology and its applications in various fields has led to exploring the possible benefits and outcomes of integrating it into education, which has been evident in the last few years. Many authors present and share their experiences of applying 3D printing in different disciplines and possible ways to connect with other subjects, which are analyzed and summarized by (Novak et al., 2021). The authors present five significant guidelines and recommendations for a multidisciplinary approach for learning 3D printing:

(1) Prepare a new generation of engineers. Developing a new generation of engineers is crucial because 3D printing can create complex structures and innovative items that are difficult to make using other techniques. Because of its widespread use in engineering fields, the automobile industry, and the aerospace sector, proficiency in 3D modeling and printing processes is required

(2) Democratize additive manufacturing technology and production. Developments in this area help to democratize additive manufacturing production and technology. 3D printing is becoming increasingly integrated into many aspects of modern life due to the expanding availability of 3D printers and related materials and a significant drop in the price and time needed to create 3D models.

(3) Support learning using low-cost 3D-printed learning aids. The availability of free 3D modeling software and platforms for shared 3D models and resources provides opportunities for quick and easy prototyping and 3D printing of educational materials.

(4) Produce assistive technologies. 3D printing has enormous potential for creating assistive devices for humans and animals, such as prostheses and orthoses specifically adapted to the individual's needs, devices for people with visual impairments, and products for everyday use.

(5) Promote creativity and innovation. Students can create their projects, see the results, and print them using various materials. They are more enthusiastic and motivated when they can freely use 3D printing in their work.

3. Conclusions

Contemporary education requires updating the curriculum content and creating cross-curricular links, which is one of the main ideas and goals in STEAM education. Augmented and virtual reality, 3D modelling, and printing contribute to making learning content more accessible, immersive, and interactive. Increasingly accessible 3D desktop printers that can be used at home encourage creativity and learner activity. Creating a 3D model requires new skills and knowledge in different subject areas, making learning more effective.

The free software available to create 3D models, and the ability to download them from platforms with similar content supports teachers and learners alike. The flipped classroom learning model can be used, where learners prepare

independently at home on a topic and only discuss the main points they find difficult or need more explanation in class. Also, 3D printing is suitable for applying PBL (project-based learning), from researching and studying an object or phenomenon to creating and printing the 3D model. This builds teamwork skills, responsibility, and discipline.

Experts from different sciences (biological, life sciences, and others) must work together and learn from each other to adapt the learning content and curriculum to engage and motivate learners and teachers to be creators (Hansen et al., 2020).

A step forward in improving the curriculum in the Faculty of Veterinary Medicine at Trakia University, Stara Zagora, is to incorporate 3D printing in the elective subject "Informatics" and teach students how to benefit from this technology professionally.

Developing and applying 3D printing in education will be one of educational institutions' leading goals and objectives. It will also influence and be one of the key competencies in the era of the 4th industrial revolution (Chun, 2021).

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