Evaluation of 3D Design Applications in STEM Education

Mustafa Tevfik Hebebci
Necmettin Erbakan University, Turkey, https://orcid.org/0000-0002-2337-5345

Güleser Maya Hebebci
Ministry of Education, Turkey

Abstract: The three-dimensional design and production technologies are today widely used in many fields. Automotive, health, art and education, and especially architecture and engineering are among the prominent examples. The three-dimensional design technology can be categorized into two dimensions: design and production. The first of these dimensions, three-dimensional design applications and software, is software that can practically transform ideas into realistic and three-dimensional models. The production part, which is the second dimension, covers the processes of physicalizing the designed model with various 3D printers. To this end, this research examines and provides information about three-dimensional design applications and software that can be used in STEM education. In this context, five different basic, intermediate, and advanced applications and software that do not have access problems are included in the research. The examined applications and software are analyzed from various aspects such as ease of use, file format, operating environment, language and platform support, and supported operating system.

Keywords: 3D design applications, STEM education, review

Introduction

STEM education, which is regarded as one of the current and innovative approaches in the education field, is a contemporary approach that emphasizes interdisciplinary work, and it is described as the most important educational movement of recent years by some circles (Berlin & Lee, 2005; Kuenzi, 2008; Reiss & Holmen, 2007). The number of studies on STEM education, which has attracted the attention of researchers since the beginning of the turn of the century, is increasing day by day (Brown, 2012; Chomphuphra et al., 2019; Ha et al., 2020; Li et al., 2020; Mizell & Brown, 2017). In this regard, it is of strategic importance for countries that want to have a say in international competition (Corlu et al., 2014).

The literature review on this topic suggests that some tools and materials are generally used in studies on STEM education. These tools include simple tools and equipment (paper, rope etc.), programmable electronic cards

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(Arduino, Raspberry Pi, etc.), various experimental sets, coding, three-dimensional (3D) design software, and 3D printers (Altan et al., 2016; Baran et al., 2015; Khanlari, 2013). Due to its nature, the use of engineering and technology in STEM education has a crucial significance. 3D design and production is one of the important technological developments developed in this sense.

The human mind is structured to learn to perceive within the 3D universe. Hence, the existence of 3D objects in education reveals that they can contribute to quality and effective learning. Individuals understand and perceive the ball, which has a concrete structure and the object itself, more easily than the circle, an abstract concept (Allen, 1978). In this context, 3D design applications are thought to have a significant role in education.

3D design software, which was developed only for experts in the past, is now being developed at a level and variety that can appeal to all segments. Hence, it is sufficient to have only basic computer skills to use some applications. Considering the benefits of these programs, it has become inevitable to be used in the educational environment. However, the increase in existing applications and software day by day creates a big problem for educators and researchers.

This research aims to evaluate 3D design applications used in STEM education. In this direction, five applications and software determined by the researchers are examined and analyzed from various perspectives. In determining the applications and software, basic factors such as up-to-datedness, widespread use, suitability for the educational environment, and ease of use are considered. Herein the following applications and software are examined:

1. Tinkercad
2. SketchUp
3. Vectary
4. 3D Slash
5. FreeCad

Tinkercad

Tinkercad is a free, easy-to-use web-based application that equips designers and engineers with essential skills to innovate in 3D design, electronics, and coding (Team Tinkercad, 2021). The software was developed by former Google engineers Kai Backman and Mikko Mononen. The company, which moved its headquarters to San Francisco in 2012, has been operating under the umbrella of Autodesk, a US company that has developed professional software for industrial use since 2013. It is home to nearly 40 million designers and more than 300 million designs as of the end of 2021 (Gewirtz, 2019). Tinkercad is generally preferred in educational environments to create 3D and 2D printing models and in introductory solid geometry education (Dahl, 2012).

Thanks to its user-friendly interface, numerous designs can be made using simple geometric shapes such as cubes, cylinders, and spheres through Tinkercad. On Tinkercad, models are created with simplified constructive

solid geometry. The basic shape logic in Tinkercad consists of “solid” and “hole” structures. These structures can be combined to form new shapes (Griffey, 2014).

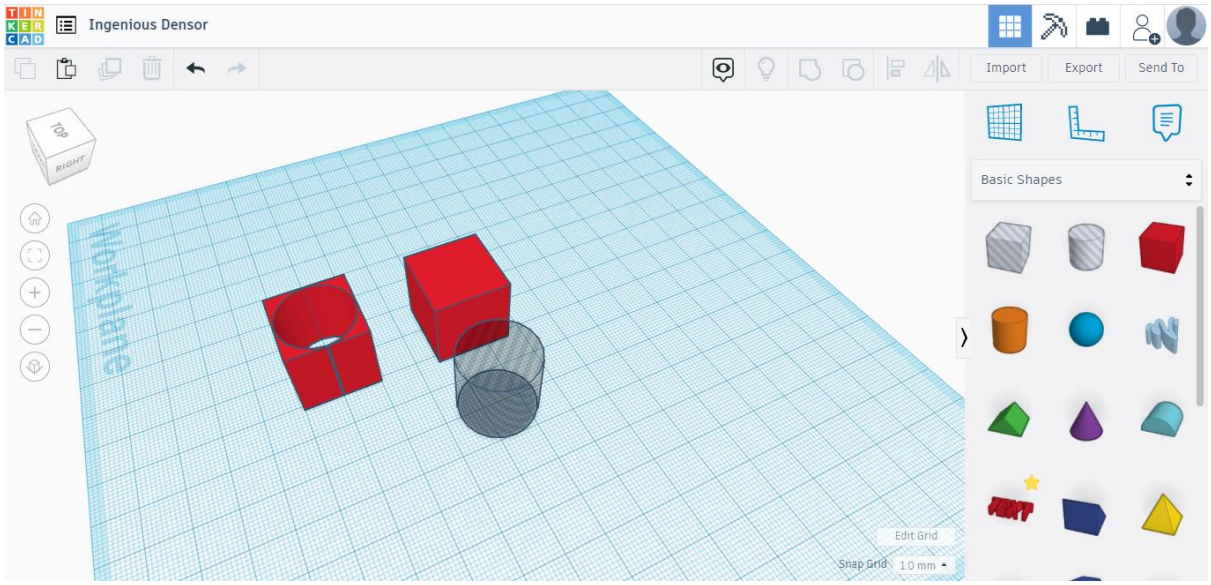

Figure 1. Solid, Hole, and Combined Structures in the Tinkercad Workspace

Tinkercad has a gallery of 3D designs. This section contains 3D designs made by other users. Users can make arrangements by transferring the 3D designs here to their designs.

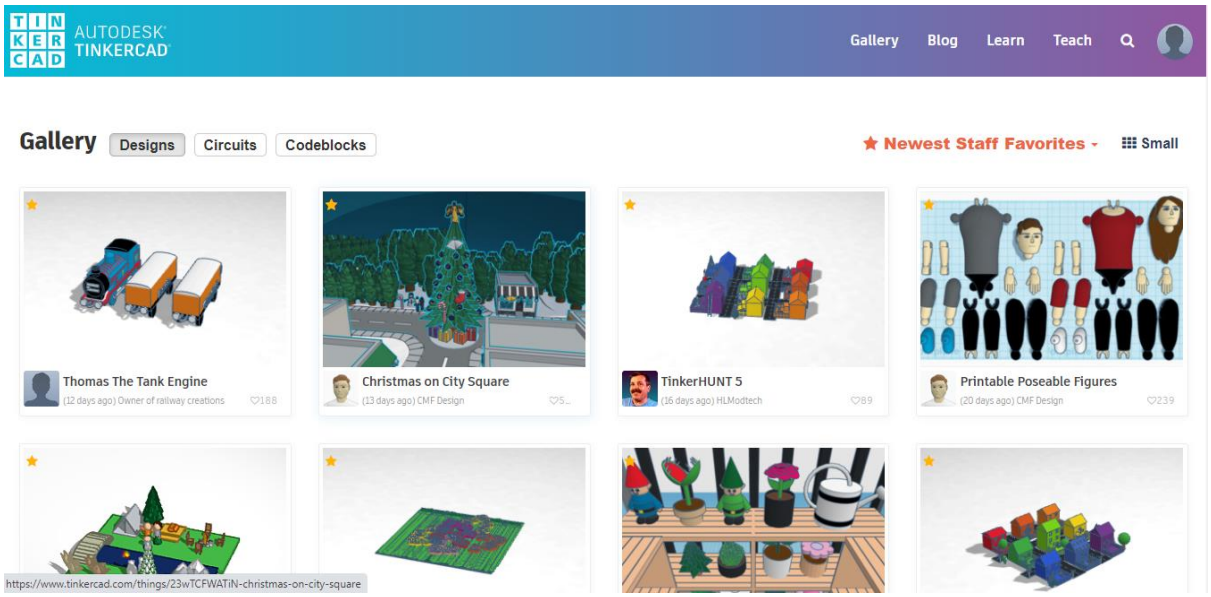

Figure 2. Tinkercad Gallery Section

3D designs prepared on Tinkercad can be physicalized by 3D printers or laser cutting machines (Ali et al., 2019; Alimisis & Loukatos, 2018; Angelopoulos et al., 2020; Bhaduri et al., 2021; Chun, 2021; Chou & Shih, 2020; Jung, & Lee, 2017; Ng, 2017; Özdemir et al., 2017). In this context, Tinkercad prepared two and three-

dimensional designs for 3D printers as .obj, .stl, and .glb, and for laser cutting machines, it can also convert to .svg format. These file extensions are recognized by many 3D printers and laser cutting machines on the market. Besides, Tinkercad does not apply any fees or watermarks for the design outputs it provides.

Tinkercad is a popular tool in educational environments and scientific research due to some of the features it offers. It is noteworthy that the software is often preferred in the application dimension of the studies, especially when it comes to 3D modeling (Doğan & Uluay, 2020; Morimitsu, 2021; Tosun, 2020). Developing day by day, Tinkercad has sections for not only 3D design but also block coding exercises and electronic circuit programming.

Tinkercad has the following advantages in general terms (SketchUp, 2021):

1. Free and easy to use
2. Web-based design
3. Support for different platforms (Windows, Android, IOS etc.)
4. Large user base
5. Rich and executable library
6. Required file outputs for 3D printing
7. Language support

SketchUp

SketchUp is 3D design software developed for users interested in 3D drawing from different domains. The software, which was first on the market in 2001, was launched in 2006 by Google, and then it was acquired by Trimble in 2012. The latest version of the software is SketchUp 2021. The version for professionals has many advanced features. SketchUp has basic features such as texture, 2D and 3D models, layer management, lighting effects, and animation.

SketchUp offers three basic usage packages: a free version for individual and professional use, a 30-day free enhanced web and desktop trial version, and the paid SketchUp Pro. Although the free versions have very limited features, they can be adequate for beginners. The designs that users can create using SketchUp are listed as follows (Sketchup, 2021b):

1. Creating a 3D model
2. Customizing the SketchUp interface for the way users make designs
3. Sharing 3D models as step-by-step animations, scenes, or printouts with realistic light and shadows
4. Printing the developed models through a 3D printer
5. Importing the existing 3D drawing files from other 3D modeling software
6. Exporting SketchUp file for use with other modeling software

3D Warehouse is a website of 3D models developed with SketchUp. It is a useful resource and online

community for anyone who creates or uses 3D models.

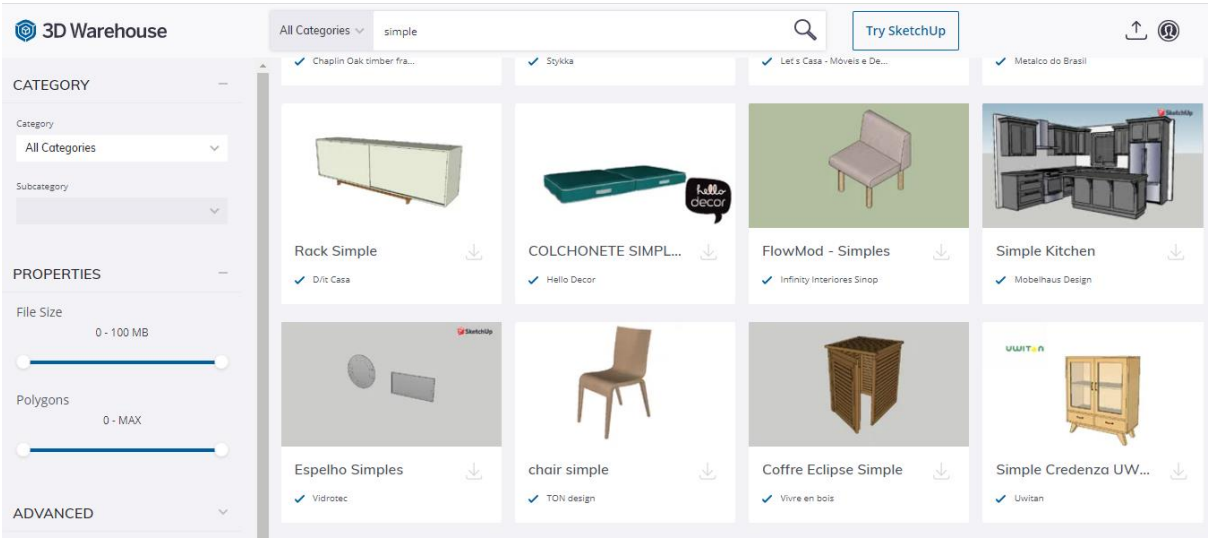

Figure 4. SketchUp 3D Warehouse

Using 3D Warehouse, users can do the following (Vectary, 2021):

1. Download previously designed models and include them in personal projects
2. Save the models as favorites to find them easily later
3. Organize public model or material collections and save private folders
4. Upload the models created on 3D Warehouse to share them with others and get their feedback.
5. Connect and collaborate with other 3D Warehouse users.

SketchUp is one of the 3D design tools that attract the attention of educators and researchers. In this context, it has been used in many studies in the literature. Research results generally show that the use of SketchUp has a positive effect on education. In respect to this, Fleron (2009) reported that SketchUp in education is a cardinal technological tool in developing spatial skills. Similarly, La Ferla et al. (2009) asserted that SketchUp could be used in curriculum designs to improve students' spatial skills. Similar results were also obtained in another study by Dorta, Saorin, & Contero (2008).

Vectary

Vectary is a web-based 3D design application developed for beginner users on which images are processed in real-time. It has a similar structure to Tinkercad. It does not require any software installation and coding skills. Users can create new designs using the library Vectary has or make their personal drawings. Operations such as drag-drop, enlargement, and reduction can be done easily on the added objects (Vectary, 2021b).

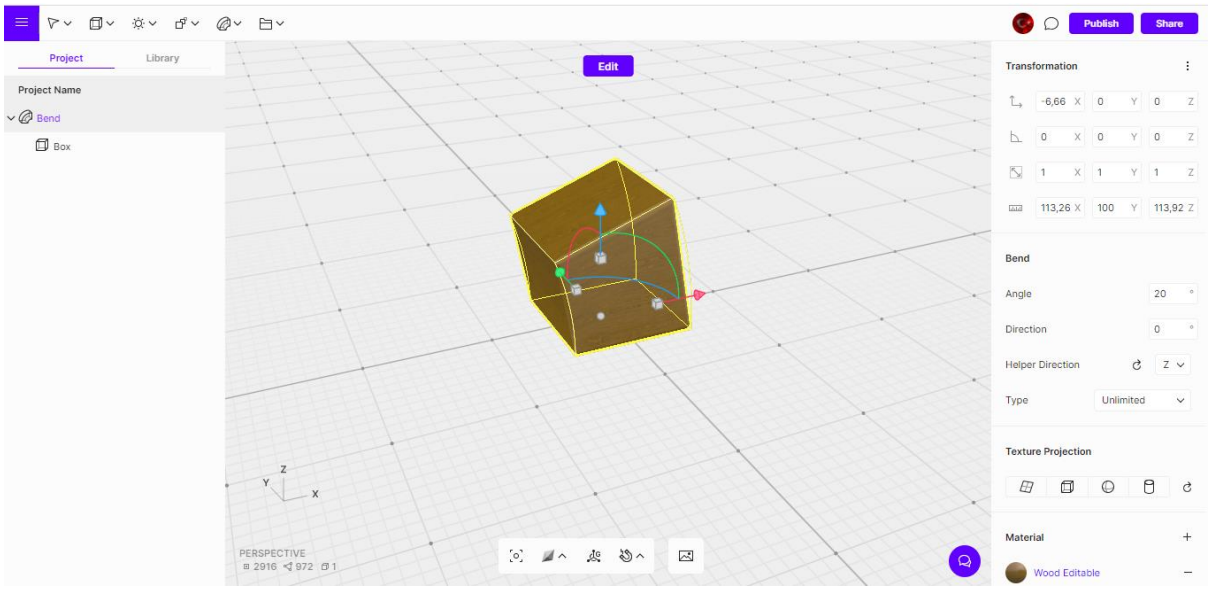

Figure 5. Vectary Design Screen

Developed by a group of software developers based in Slovakia, Vectary allows existing 3D models to be rearranged with various settings. There are two different versions of the application, namely free and paid. The free version naturally has more limited features than the paid version. Features of the free version involve the following:

1. Vectary studio (Full access)
2. Up to a maximum of 25 projects
3. WebAR (Preview only)
4. .obj and. stl output format
5. Free library of 3D objects, materials, and icons
6. Community support
7. Figma & Sketch plugin
8. Photorealistic rendering

One of the fundamental features that distinguish Vectary from other applications is its WebAR plugin. WebAR is a technology that allows visitors to experience augmented reality on the web without having to download an external application. The Vectary WebAR viewer supports it on both IOS and Android operating systems (3D Slash, 2021).

3D Slash

It is a web-based 3D design application for beginner-level users. Unlike other applications, it allows designing without registering as a member. The platform has a simple structure for 3D design beginners and children. The app has four different user plans: free, premium, for schools, and professionals (3D Slash, 2021b). Many designs can be created using the free version. The features of the application can be listed as (FreeCad, 2021):

1. Simple interface
2. Start designing and having an output as .stl or .obj file
3. Practical copy-paste, move, resize, flip, and merge operations
4. Coloring of objects
5. Projecting images or text on the object
6. Creating teacher-controlled classrooms
7. Reviewing files created by students in real-time
8. VR view support

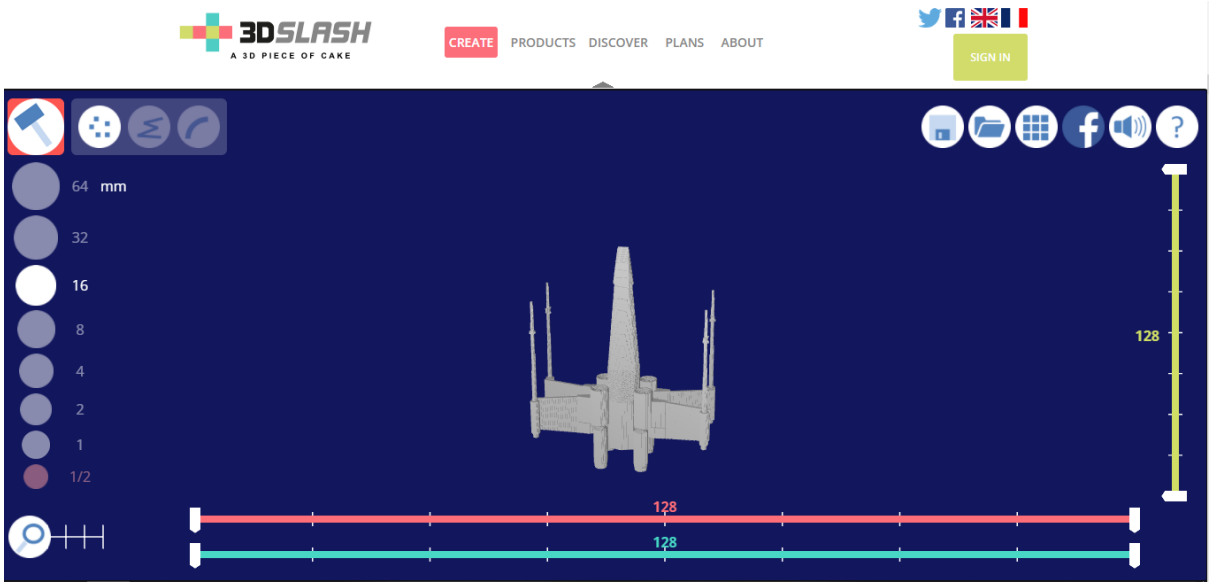

Figure 6. 3D Slash Design Screen

When 3D Slash is examined in general, it can be said that it is simpler and more basic than other 3D applications. In the gallery section, there are previously designed objects. Users can make adjustments to existing designs by using this button. The app also has VR support and classroom creation features.

FreeCad

FreeCad is open-source parametric modeling software for designing real-life objects. Parametric modeling is a technique that allows users to access the history of the object designed and easily modify it with various adjustments (FreeCad, 2021). It was first introduced freely available in 2002 by Jürgen Riegel, Werner Mayer, and Yorik van Havre and licensed as free and open source. Due to the nature of free software, it is developed day by day by volunteers and users.

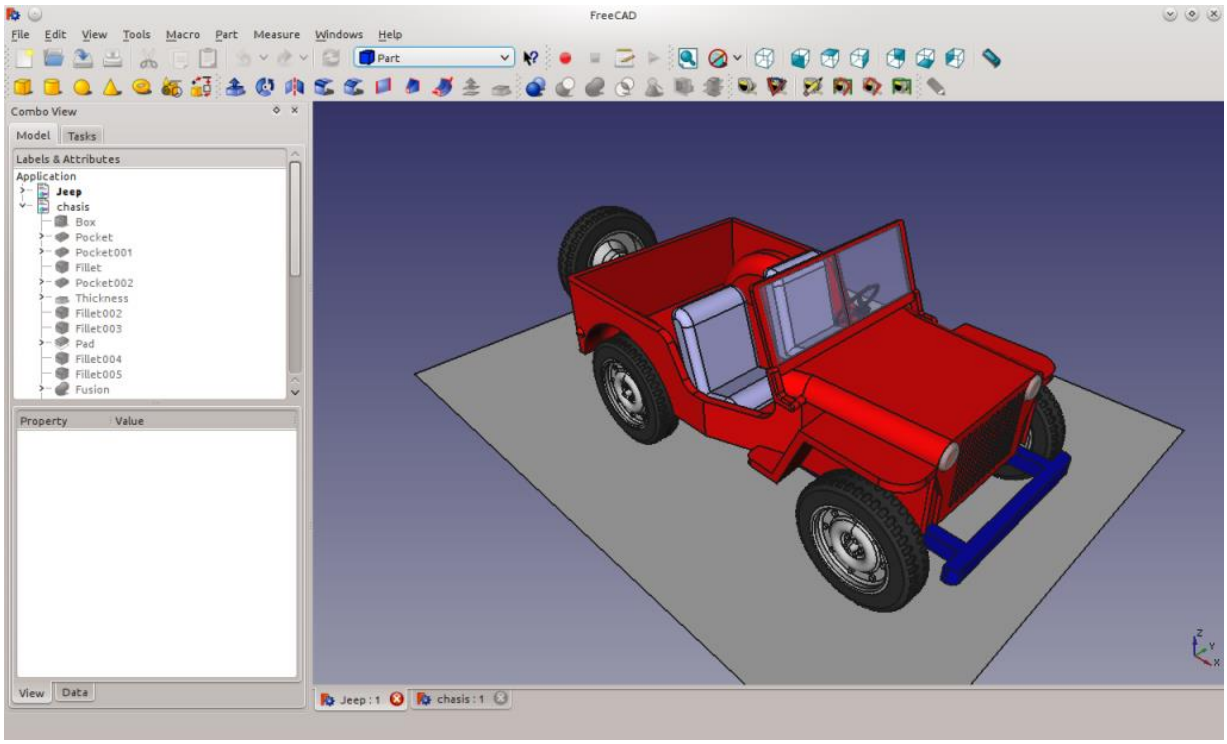

Figure 7. FreeCad Workspace

FreeCAD is multiplatform (Windows, Mac, and Linux), highly customizable, and extensible 3D design software. It reads and writes many open file formats such as STEP, IGES, STL, SVG, DXF, OBJ, IFC, and DAE (FreeCad, 2021). Although FreeCad is aimed at engineering, it can serve a wide range of users. FreeCad requires installation, and the latest version released is 0.19.3. The version suitable for the operating system can be downloaded from the web page.

FreeCAD has a complex structure for beginners. Therefore, it is important to understand the nature of 3D design by working with simpler and more perceptible applications beforehand.

Conclusion

There has been a rapid development in software and hardware for 3D design and production processes with the developing technology. This situation has affected many closely related fields, especially architecture, health, and education (Gartner, 2015). Today, 3D design software is developed in different varieties and levels that appeal to everyone. As a matter of fact, the number of software for the needs of a primary school child or an architect who makes 3D designs for commercial works is quite high. Thanks to the hardware and operating system support provided by these software applications, 3D design has emerged even on mobile devices.

In this research, some 3D design applications and software used in STEM education were examined. The use of 3D technology in STEM education is among the current issues addressed by researchers in recent years

(Schelly, 2015; Sun, 2018; Tillman et al., 2019). Many studies conclude that 3D design and production applications in the educational environment positively affect important 21st-century skills such as scientific creativity, critical thinking, spatial thinking skills, and problem-solving (Hebebci, 2019; La Ferla et al., 2009; Lin & Chen, 2016). To this end, the fact that students transfer an object of their dreams to the virtual environment through 3D drawing software and get the output of it with 3D printers enables many abstract concepts to become concrete. This case also enables students to gain an important experience (Brown, 2015).

Within the scope of the research, 3D design software apps have been discussed in terms of various features. In this context, the comparison table for the five-software discussed is given below.

Table 1. Comparison of 3D Design Applications and Software

	Tinkercad	**SketchUp**	**Vectary**	**3D Slash**	**FreeCad**
Open Source	No	No	No	No	Yes
Library	Yes	Yes	Yes	Yes	Yes
Price	Free	Free/Pro	Free /Pro	Free /Pro	Free
Platform support	Yes	Yes	Yes	Yes	Yes
Setup	No	Yes/No	No	No	Evet
Level	Beginner	Intermediate - Advanced	Beginner	Beginner	Intermediate - Advanced
Membership	Yes	Yes	Yes	No	No
File format	.obj, .stl, .glb	.obj, . stl, .skp	.obj, .stl	.obj, .stl	.stl, .dxf, etc.
Multi language	Yes	Yes	No	No	Yes
Classroom	Yes	No	No	Yes	No
Community	Yes	Yes	Yes	No	Yes

Consequently, the software included in the research can be effectively used in STEM education. However, in the selection of this software, variables such as time, fee, and internet infrastructure are of great importance. So much so that Tinkercad, which has been very popular among these applications in recent years, needs internet access as a prerequisite because it works only on a browser-based basis. Considering the fees for these services, all of such software has a free version. Free software with all features available are only Tinkercad and FreeCad. Hence, Tinkercad, Vectary, and 3D Slash can be more effective in situations that require learning and practice in a limited time. Nevertheless, SketchUp and FreeCad require more experience and professionalism than other applications.

Recommendations

Advanced and different applications and programs can be evaluated. The effects of these programs in educational environments can be examined.

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