International Journal of Technology and Design Education (2022) 32:1553–1581
https://doi.org/10.1007/s10798-021-09660-y

The contribution of 3D computer modeling education to twenty-first century skills: self-assessment of secondary school students

Tuğra Karademir Coşkun[1] · Gül Fidan Deniz[2]

Accepted: 17 February 2021 / Published online: 6 March 2021

Abstract
In this study, the contribution of the 3D computer modeling to the twenty-first century's common competencies was evaluated from the perspective of secondary school students. The one-group post-test only design was used in the study. The instruments of the data collection process were an achievement test and a questionnaire developed by the researchers. The t-test and single sample chi-square test for related samples were performed to analyze the gathered data. The results of the study presented that secondary school students thought that 3D computer modeling education contributes to the lectures as mathematics, geometry, technological information, and design. Moreover, it supports the development of design, communication, collaboration, creativity, and problem-solving skills positively.

Keywords 3D computer modeling · Twenty-first century skill · Secondary school students

Introduction

There is a rapid change in skills and competencies expected from the twenty-first century's students, and in line with this rapid change, learning environments change (Karademir, 2018). The twenty-first century's profile is not the person who receives and uses information. It focuses on educating individuals by developing the skills of critical thinking, problem-solving, collaborative learning, openness to innovation, creativity, productivity, and entrepreneurship (ISTE, 2016; NAE, 2010; P21-The Partnership for 21st Century Skills, 2009). Therefore, it can be said that traditional education approaches are insufficient for individuals to acquire these features. The objectives can be achieved by contemporary education, which is based on knowledge generation in contrast to memorization. The rapidly developing ICT should affect all areas of education, and fundamental changes

✉ Tuğra Karademir Coşkun
tkarademir@sinop.edu.tr

Gül Fidan Deniz
gulfidantulum@hotmail.com

1 Distance Education Center, Sinop University, Sinop, Turkey

2 Osmancık Atatürk Secondary School, Çorum, Turkey

in educational approaches are compulsory (Turkish Education Association, 2007 cited: Haşlaman et al., 2007). Moreover, new learning environments focused on competencies is obligatory because of this change. From this point of view, new technologies are the solutions for educational sciences.

It can be said that, in recent years, 3D printers are one of the most popular technologies which contribute to educational environments and sectors such as military, commerce, and health. 3D printers have become necessary resource providers, especially in the manufacturing industry. The discussions about 3D modeling skills have increased in educational settings because of the rapid development of 3D printers and their functionality.

In this context, the research has focused on the search for an alternative way to improve the twenty-first century skills of the students. Contribution of 3D computer modelling education to the twenty-first century common competencies as an alternative method has been evaluated from the perspective of middle school students. Critical thinking, problem-solving, communication, collaboration, entrepreneurship, information and digital skills have been determined as twenty-first century common themes and has been included in the study.

3D modeling education

Three-dimensional (3D) modeling of an object can be seen as a complete process that starts from data acquisition and ends with a 3D virtual model that is visually interactive on a computer (Remondino & El-Hakim, 2006). 3D modeling has been widely used in areas including computer graphics, architecture, mathematics, the military, virtual reality, and communication, and there is more and more demand for 3D content for tissue engineering and heritage protection (Luan et al., 2008).

3D modeling supports educational environments in two ways. The first one is to provide real-world experiences to students by the virtual world used as learning materials. In other words, it is a process of learning from 3D technologies. The cost-effective and realistic 3D education environments make students qualified and lower the costs in vocational and technical education (Yaman et al., 2015). Because visualizations and graphical displays have an essential role in enhancing students' learning experiences (Frank, 2005). For example, in the study conducted by Yaman et al. (2015), the effect of "Stereoscopic 3D Imaging Technology" on students' learning satisfaction and motivation was examined. The results of this study determined that 3D animations caused an increase in students' learning satisfaction and motivation. Parallel to this, Emre et al. (2018) applied the primary "congenital disease model" which was designed and printed with 3D modeling to the fifth grade students at medical faculty. It was found that the use of these models in internship training for pediatric surgery contributes positively to satisfaction. Vidaurre et al. (2019) evaluated the use of 3D models as a teaching tool for medical students in their study. The results of this study concluded that congenital heart disease models designed with 3D are applicable and useful for the processes of diagnosis and treatment. Akıllı and Seven (2014) stated that for better understanding and solving different complexities, 3D computer model presentations are the best materials, and these models are an effective and scientific way to instantiate some intangible concepts. Another study conducted by Chekrouni et al. (2020) analyzed the effect of 3D models on students, and the results showed that the 3D Atlas significantly improves students' understanding of human embryology, reflected in significant higher test scores for new students.

Second contribution of 3D modeling to education is "to learn 3D modeling" and developing different skills by this learning process. It is known that today's children develop their thinking and comprehension skills through 3D materials very quickly (Prensky, 2001). Besides, it is claimed that students can develop their imagination by designing 3D models and by instantiating these models with 3D printers; moreover, students can mentally create new designs to find solutions for the problems they face (Kuzu Demir et al., 2016). Kostakis et al. (2015) examined the extent of the technological capabilities of open-source 3D printing that could serve as a means of learning and communication in two high schools in Ioannina, Greece. They found that 3D printing and design can electrify various literacies and creative capacities by the spirit of the interconnected, information-based world. However, at this point, it is also necessary to mention the disadvantages of 3d printers. These disadvantages include some competency requirements to be able to create 3D modeling (Despeisse et al., 2016), the high raw material costs (Kuzu Demir et al., 2016), the high initial investment cost (Kostakis et al., 2015; Thornburg et al., 2014), the effects of harmful gases that may occur as a result of high heat (Azimi et al., 2016). It is impossible to print the large models with home type 3D printers (Sönmez et al., 2018). In addition, it is time-consuming to prepare education programs suitable for using 3D printers (Schelly et al., 2015).

Moreover, 3D modeling can improve students' spatial ability (Brown, 2015). Kell et al. (2013) emphasized that the development of students' spatial ability at secondary school level may increase the individual's chance of success in creative and scientific achievements. Similarly, different studies found that such applications performed via computer affect spatial thinking ability (Arıcı, 2013; Özabacı & Olgun, 2011; Yıldız & Tüzün, 2011). Akıllı and Seven (2014) concluded that 3D models increase students' academic achievement, three-dimensional thinking, and spatial animation skills. Chang et al. (2019) examined the effects of three-dimensional computer-aided design on the creative self-efficacy and performance of high school students. As a result of the research, it was found that there is a moderate positive correlation between students' total scores of creative self-efficacy, individual creativity items, and innovative performances. Also, the use of three-dimensional computer-aided design has significantly increased students' creativity. Liaw et al. (2019) described the development of a 3D-VE and evaluated healthcare students' experiences of their collaborative learning in the environment. As a result, it was reported that the participants are positive about the usability, feasibility, and perceived sense of the presence of the 3D-VE in supporting collaborative learning. Watching and seeing 3D computer models is considered as a possible way to develop and modify students' incomplete mental models (Wu & Shah, 2004). 3D computer-aided design (3D-CAD) enables accurate and scalable presentations and realistic images to visualize ideas (Hatchuel et al., 2018; Lee & Yan, 2016).

In general, it can be said that the effects of 3D modeling and 3D printing technology on education are positive in terms of developing different cognitive and affective skills. In the literature, it is possible to find positive reflections such as an increase in motivation, cooperation, creativity, problem-solving, spatial intelligence, and satisfaction. From this point of view, the question is whether the 3D computer modeling in classroom environments can be an alternative method to develop the twenty-first century competencies or not.

The definitions of twenty-first century skills

A competence allows individuals to solve tasks autonomously and to adapt to different environments and situations (Pantic & Wubbels, 2010). The changing production needs of the twenty-first century have an impact on competencies and the schools as the training institutions. Nowadays, individuals change to active producers from passive workers. In line with this, the routine, repetitive, and easily automated tasks are performed by robots, while people perform interactive and idea-based tasks. In this context, policymakers emphasize education to acquire twenty-first century skills (Gretter & Yadav, 2016).

The related literature shows that different institutions focused on different competencies for twenty-first century skills according to the changing conditions and needs. Table 1 summarized some of the twenty-first century skills defined by the institutions below.

Table 1 presented that there are different types of skills defined by organizations concerning twenty-first century skills. For example, Binkley et al. (2012) identified twenty-first Century skills in four groups included ten skills. The first category as the “Ways of Thinking” emphasized higher-order thinking skills, and subsumed more straightforward skills such as recall, and drawing inferences. The second category, “Ways of Working”, focused on communication and teamwork. At the same time, "Tools for Working” included the skills of information literacy and ICT literacy, which are the future and mark a significant shift that is likely to be as important as the invention of the printing press. The last category is “Living in the World”. This category emphasized that "people should learn to live not only in their cities or countries but also throughout the world". That’s why they have identified and grouped Citizenship, Life and Career, and Personal and Social Responsibility as twenty-first-century skills. There is another description by Wagner (2008) in his book named "The Global Achievement Gap: Why even our best schools don’t teach the new survival skills our children need and what we can do about it". It is the “Seven Survival Skills for the 21st Century," which defines seven skills to prepare all students for the twenty-first century and make them a global citizen. Wagner (2008) described these seven areas of competence. Also, he criticized parents and policymakers because of considering test scores as the most reliable measures and criteria of an excellent school system. He stated that they would lose their competitive advantage in the global economy unless they can teach new survival skills. Another organization that has been working on the definitions of 21st Century skills is Partnership for 21st Century Learning. “The P21 Framework for 21st Century Learning” was developed with input from educators, education experts, and business leaders to define and illustrate the skills, knowledge, expertise, and support systems that students need to succeed in work, life, and citizenship.” In this framework, there are four main skill categories as “Key Subjects and 21st Century Themes”, “Learning and Innovation Skills”, “Information, Media and Technology Skills”, and “Life and Career Skills”. Another definition was developed by the National Education Association-NEA (2010) to introduce the concept of Four Cs and emphasize its importance to educators, and to have twenty-first century education in the classroom practices. The NEA (2010), defining the four main themes, also supported the importance of these skills by the results of “The AMA 2010 Critical Skills Survey” conducted by the American Management Association in 2010. According to the managers who participated in the study, the skills of reading, writing, and arithmetic are not sufficient if the employees cannot think critically, solve problems, cooperate, or communicate effectively. So according to NEA, “It is clear that the “Four Cs” needs to be fully integrated into classrooms, schools, and districts around the country to produce citizens and employees adequately prepared for the twenty-first century." In line with this, ISTE (International Society for Technology in Education, 2016) designed new student standards to empower students’ voice and ensure that learning is a student-driven process. Besides, as shown in Table 1, it is seen that there are many definitions of twenty-first century skills made by many different institutions.

In addition to those mentioned above, there are many other definitions of twenty-first century skills made by different organizations in the literature. These definitions show how

Table 1 twenty-first century skills defined by different institutions

Assessment and teaching of twenty-first century skills (Binkley et al., 2012, p. 17)	Seven survival skills for the twenty-first century (Wagner, 2008)	P21 framework for twenty-first century learning (P21, 2009)
Ways of thinking	1. Critical thinking and problem solving	*Core Subjects and 21st Century themes*
1. Creativity and innovation	2. Collaboration across networks and leading by influence	1. Global awareness
2. Critical thinking, problem-solving, decision making	3. Agility and adaptability	2. Financial, economic, business and entrepreneurial literacy
3. Learning to learn, metacognition	4. Initiative and entrepreneurialism	3. Civic literacy
Ways of working	5. Effective oral and written communication	4. Health literacy
4. Communication	6. Accessing and analyzing information	5. Environmental literacy
5. Collaboration (teamwork) tools for working	7. Curiosity and imagination	*Learning and innovation skills*
6. Information literacy		1. Creativity and innovation
7. ICT literacy		2. Critical thinking and problem solving
Living in the world		3. Communication
8. Citizenship—local and global		4. Collaboration
9. Life and career		*Information, media and technology skills*
10. Personal and social responsibility—including cultural awareness and competence		1. Information literacy
		2. Media literacy
		3. ICT (Information, Communications, and Technology) literacy
		Life and career skills
		1.Flexibility and adaptability
		2. Initiative and self-direction
		3. Social and cross-cultural skills
		4. Productivity and accountability
		5. Leadership and responsibility

Table 1 (continued)

Four Cs (National Education Association, 2010)	Twenty-first century competencies (Singapore Ministry of education, 2018)	ACER's preparing twenty-first century learners (Lonsdale & Anderson, 2012)
1. Creativity	1. Civic Literacy, Global Awareness and Cross-Cultural Skills	1. Critical thinking and problem-solving skills
2. Critical thinking	2. Critical and Inventive Thinking	2. Communication
3. Communication	3. Communication, Collaboration and Information Skills	3. Teamwork
4. Collaboration		4. Information and media literacy
The 3 × 3 model of Twenty-first learning (Kereluik et al., 2013)	Twenty-first century competencies (Asia Society-GCEN, 2013)	ISTE Standards for Students (International Society for Technology in Education, 2016)
Foundational knowledge (to know)	1. Cognitive competencies	1. Empowered learner
1. Core disciplinary knowledge	2. Academic mastery	2. Digital citizen
2. Cross-disciplinary knowledge	3. Critical thinking	3. Knowledge constructor
3. Digital/ICT literacy	4. Creativity	4. Innovative designer
Metaknowledge (to act)	5. Interpersonal competencies communication and collaboration leadership global awareness	5. Computational thinker
1. Creativity and innovation	6. Intrapersonal competencies growth mindset learning how to learn intrinsic motivation grit	6. Creative communicator
2. Problem-solving/ critical thinking		7. Global collaborator
3. Communication/collaboration		
Humanistic knowledge (to values)		
1. Life/job skills		
2. Ethical/emotional awareness		
3. Cultural competence		

much the twenty-first century skills are essential and also indicates that there is no common framework. When these definitions made by the most reputable and known institutions are compared, it can be seen that there are specific themes in common. These themes include critical thinking, problem-solving, communication, collaboration, entrepreneurship, information, and digital skills.

Similarly, a study conducted by Van Laar et al. (2017) also analyzed the twenty-first century digital skills. It concluded that the themes were subjected to the skills of knowledge, communication, collaboration, critical thinking, creativity, and problem-solving. In their following study, Vaan Laar et al. (2019) studied with a group of employees (N = 1222). They tried to determine the levels of the common themes of information, communication, collaboration, critical thinking, creativity, and problem-solving, which are considered essential skills in the twenty-first century. The results showed that the level of twenty-first century digital skills varies considerably. From this point of view, this research focused on critical thinking, problem-solving, communication, collaboration, entrepreneurship, information, and digital skills.

Research questions

The importance of the twenty-first century skills for productive human resources for the future is clear from the definitions of various institutions. In this context, studies argue that "there is a need within a reinvention of the way that classrooms and schools are constructed that respond to the necessary twenty-first century skills" (Campbell et al., 2013). Therefore, the need for new methods of alternative innovative learning environments and achievements is compulsory, which means to support twenty-first century skills while teaching knowledge. In other words, it is interdisciplinary learning. The subject of this research is the 3D computer modeling. Conducting project-oriented studies for 3D computer modeling is very important for production, and it is known that problem-based learning environments contribute to the development of twenty-first century skills (Bell, 2010; Ravitz et al., 2012). To develop twenty-first century skills, such as critical thinking, communication, inquiry, and collaboration, 3D printing may be a way of renovating classrooms while providing students with playful and experiential learning experiences (Becker et al., 2018; Figg et al., 2018). 3D modeling and printing are useful tools to develop twenty-first century skills of the students (Cano, 2015).

From this point of view, the contribution of the 3D computer modeling education (3DCM) to the twenty-first century skills was evaluated from the perspective of secondary school students. In this context, the aim of the study is not to determine a learning method, but rather to present the contribution of a computer-based competency to the twenty-first century skills. In light of the main purpose of the study, the sub-questions were listed below.

1. Is there any significant difference between the achievement scores of pre-test and post-test of the secondary school students?
2. What is the direction of the effect of 3D modeling on students' knowledge and technology skills in the other courses (like Painting, Science, Mathematics-Geometry etc.)?
3. What is the direction of the effect of 3D modeling education on students' designing skills?

4. What is the direction of the effect of 3D modeling education on students' collaboration and communication skills?
5. What is the direction of the effect of 3D modeling education on students' creative thinking and problem-solving skills?
6. What is the direction of the effect of 3D modeling education on students' entrepreneurship skills?

Methods

Research model

The one-group post-test only design was used for this research. In a one-group post-test only design, treatment is implemented (or an independent variable is manipulated); and a dependent variable is measured after the implementation of this treatment (Price et al., 2017). The model of the research is demonstrated below.

G_1	X	$O_{1.2}$
Pre-achievement test	The 14-week 3D Modelling Education	Post-achievement test
Paired samples according to achievement levels 5th–6th–7th grades		Twenty-first century skills test

As stated in the demonstration of the model, in the study designed as a single group, firstly, the pre-achievement test was conducted to the paired groups created according to the pre-achievement levels. Secondly, the post-achievement test was conducted after completing the 14-week 3DCM education. Lastly, the twenty-first century skills test was performed. The aim of this research is not to analyze a relational pattern between pre and post-tests. In this study, it is aimed to determine the effect of 3D modelling education on twenty-first century competencies from the perspective of the student through structured questionnaires. Since the data obtained after 3D modelling education is important in this study, one-group post-test only design is suitable and sufficient for the research. Besides, it is very difficult for researchers to match the students for the experimental design at three different grade levels (5th, 6th, 7th) and reach the desired sample size. Therefore, it was decided that the most appropriate method was the one-group posttest only design.

The study group

The research was carried out with ninety-nine middle school students who studied at 5th, 6th, and 7th grades at two different public schools in Turkey. The distribution of the students, according to their degree, is shown in Table 2.

Table 2 illustrates that 43.4% of students who participated in the research were studying in 5th grade, 40% were studying in 6th grade, and 16.2% were studying in 7th grade. In this study, criterion sampling, one of the purposeful sampling methods, was used for the

Table 2 The distribution of the students according to their grade

Grade	f	%
5.0	43	43,4
6.0	40	40,4
7.0	16	16,2
Total	99	100,0

Table 3 The results of ANOVA

	Sum of squares	df	mean square	F	Sig
Between groups	374,550	2	187,275	1554	217
Within groups	11,566,359	96	120,483		
Total	11,940,909	98			

selection of secondary school students. Criterion Sampling involves searching for cases or individuals who meet a specific criterion, like having a certain disease or having a particular life experience (Palys, 2008). The first criterion taken into consideration when selecting the students for the study group is not to take a course on the 3D design before. The second criterion is that there is not to have a significant difference between the 3D design achievement scores of the groups; in other words, the groups should have equal pre-achievement scores in terms of the skills. Therefore, to equalize the groups in terms of achievement scores, eight students who showed extreme values in the sample were excluded from the group. After the extraction, ANOVA test was performed to determine whether the difference between the achievement scores of the groups (5th, 6th, 7th grade) was significant or not; and the results are given in Table 3.

The test results (Table 3) are non-significant ($p > 0.05$); in other words, there was not any significant difference between the groups in terms of achievement scores. So, it can be said that the study group is suitable for this research.

Data gathering tools

3D Modeling education is provided by using the Tinkercad platform. Tinkercad is a free platform that allows individuals to make 3D drawings. There are several reasons for choosing this platform. These reasons were gathered according to the opinions of eleven computer teachers who had previously provided this education in secondary school. These are,

1. Not to require high-level computer skills,
2. Not to require high-level drawing skills
3. To have a tool and interface that is easy to understand
4. Easy to reach and free of charge
5. Providing storage for models
6. Accessibility in different environments outside the school.

Data collection tools were developed in accordance with the Tinkercad platform used. In this context, the data were gathered by the "3D Modeling Achievement Test” and “Contribution of 3D Computer Modeling Education” questionnaire.

3D Modeling Achievement Test The test, developed by the researchers, aims to measure students' knowledge about 3D modeling. The development process was started by preparing a table of specifications included the learning outcomes. The table of specifications prepared is given in Table 4.

When the table of specifications in Table 4 is examined, it is seen that there are attainments in different learning levels. Considering this table, teachers who teach in secondary school about Tinkercad were asked to write test questions. To teach about Tinkercad previously in secondary school was prioritized for writing qualified items. The 36 questions were written by the teachers, including the learning outcomes in the table of specification (The projects measured the learning outcomes of the analysis and synthesis step). A group of secondary school students reads the questions firstly for language fluency, and some items were revised according to the feedback. Then, the test was applied to the group educated for Tinkercad, and the item scores matrix was formed with the obtained data. The significance of the difference between the item scores was examined by defining the upper and lower 27% percentiles. In the next step, item discrimination indexes were calculated. It is accepted that the test can include the item discrimination indexes higher than 0.30 show the right discrimination level and these items. Therefore, to establish a well-constructed achievement test, ten questions with an item discrimination index of less than 0.30 were excluded from the analysis. Item difficulty indexes of the remaining twenty-six questions were calculated. The item difficulty index is the ratio of respondents who respond correctly to the whole group (Erkuş, 2003). Also, the item difficulty index has values between 0 and 1. These values indicate that if the item difficulty index is closer to 1, the item is easier, but if the item becomes difficult as it is closer to 0.

Moreover, the overall average of the test less than 0.50 indicates that the test is difficult. The item difficulty average for the developed test was lower than the accepted value (0.230); so, 6 test items that can be determined as difficult were eliminated from the analysis to increase the item difficulty index of the test to 0.50. Also, the effects of item representation of learning outcomes in the table of specification were taken into consideration when excluding the items. In order to determine the internal consistency of the test, the KR-20 value, for the tests scored as 0 and 1, was calculated (Özgüven, 1994, 90). The result of the analysis showed that the KR-20 value was acceptable with 0.66. At last, the 3D modeling achievement test consisting of twenty questions was developed.

The Questionnaire of the Contribution of 3D Computer Modeling Education questions the contribution of the 3D Modeling Education with Tinkercad to the achievement levels of critical thinking, problem-solving, communication, collaboration, entrepreneurship, information, and digital skills in the common themes from the perspective of students. The questionnaire consists of five sections. The item-pool was constructed in the light of the Framework for 21st Century Learning, which is prepared with the support of thirty companies, including 21 states in the USA, like Apple, HP, and Intel. The 4C skills constructed the skills and their definitions as Creative thinking and Problem Solving, Communication, Collaboration, and Creativity and Innovation under the title of Learning & Innovation Skills in the framework (P21, 2009). Besides, two different sections have been added to measure the contribution to learning success and entrepreneurship in various courses. The items firstly reviewed by two specialists of educational technologies and one specialist of evaluation and assessment for content and construct validity. Finally, three secondary school students read the items, and changes were made according to their feedback for the completion of the final version.

Table 4 The table of specifications

Learning outcomes	Remember	Understand	Apply	Analyze	Evaluate	Create
Examines sample 3d models and listing their properties				X	X	
Uses 3D Primitive Shapes		X	X			
Explores the Workplane		X	X			
Uses the shapes menus		X	X			
Views the object from all sides		X	X			
Controls the camera with the Mouse		X	X			
Views the object from all sides and zooms in on the object		X	X			
Works with Shapes in 3D Space		X	X			
Selects Multiple Shapes		X	X			
Translates Objects Along the Z, Y, X Axis		X	X			
Applies the X and Y Axes' Corner Handles		X	X			
Applies X and Y Axes' Side Drag Handles		X	X			
Makes Complex Shapes with Grouping		X	X			
Moves, Rotates, and Scales Objects		X	X			
Scales About the Center of an Object		X	X			
Deletes an Object		X	X			
Makes and Manipulates Grouped Objects		X	X			
Turns a Group into Negative Space		X	X			
Choose a Color and applies Multicolor		X	X			
Scales the Duplicate Object		X	X			
Aligns to an Object		X	X			
Uses the Align Tools and the Workplane Helper		X	X			
Prepares the 3d model for 3d printing		X	X			
Thinks about a problem				X	X	
Find solution with 3D modelling						X

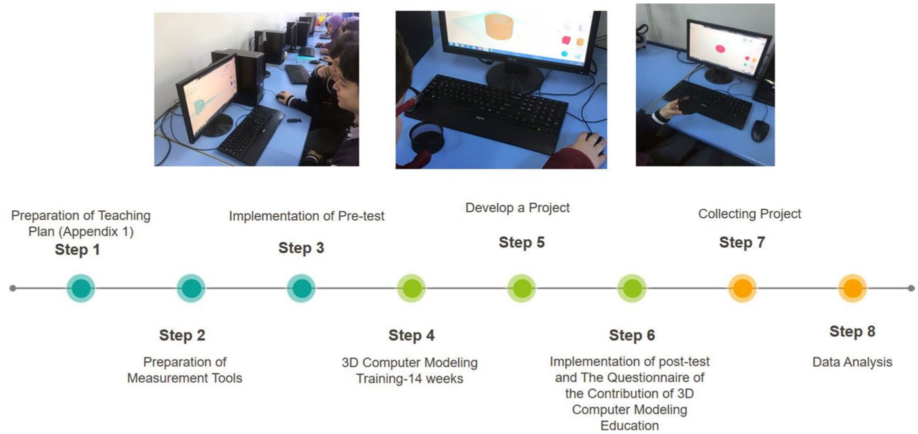
Table 4 (continued)

Learning outcomes	Remember	Understand	Apply	Analyze	Evaluate	Create
Analyses 3D models' properties to solve the problem				X	X	
Draws 3d models			X			X
Prepares for 3d printing			X			

Research process and data analysis

In the research process, a 14-week lesson plan has been developed for the Tinkercad education program. The 14-week lesson plan is given in Table 5.

When Table 5 is examined, it is seen that all the attainments on 3D Modeling Education are aimed to be acquired by students in a 14-week period. Besides, in the last two weeks, students produce solutions to a problem situation with 3D modelling. In this context, the image showing the research steps are given below.



In addition to two data collection tools, measuring some of the high-level skills included in the table of specification, the students had carried out a project at the end of the course. As a result of this study, they drew 3D models of some objects mentioned in Table 4 and made them ready to print from the 3D printer.

Firstly, to analyze the significance of the difference between the pre-test and post-test achievement scores, in other words, to identify the achievement of the education, the related samples t-test analysis was performed. The outliers and missing values were determined to decide whether the collected data is suitable for the study. Then, the Kolmogorov–Smirnov test was performed to test the significance of the data, and it was founded that the distribution did not show a significant difference from the normal distribution ($p > 0.05$).

A single sample chi-square test was conducted to compare the results of the Questionnaire of the Contribution of 3D Computer Modeling Education based on categories. In the sampling process, it was noted that the number of cells having an expected frequency of less than 5 in each group did not exceed 20%. Besides, frequency values related to the data are also included (Table 6).

Findings

The findings of the study gathered from the analysis of the data are as follows.

Table 5 14-week lesson plan

Week	Learning outcomes	Week	Learning outcomes	Week	Learning outcomes
1. Week	Discussing the concept of 3d modeling	2. Week	Introduction to 3D primitive shapes	3. Week	Navigation
	Sampling the areas used by 3d modeling		Cube		Exploring the workplane
	Examining sample 3d models and listing their properties		Cylinder		The viewcube
	Introduction of Tinckercad program and registration		Tube		What are hints?
			Sphere		Shapes menu
			Torus		Basic shapes
			Cone		Numbers and strings
					Characters
					Connertors
4. Week	Menus	5. Week	Viewing the object from all sides	6. Week	Working with shapes in 3D space
	Shape generator		Zooming in on the object		Finger recognition of X-Y-Z-coordinates
	Printable kits		Controlling the camera with the mouse		Translating objects along the Z axis
	Circuits				Translating objects along the Y axis
					Translating objects along the Z axis
7. Week	The hole property	8. Week	Moving, rotating, and scaling objects	9. Week	Moving, rotating, and scaling objects
	Selecting multiple shapes		Placing a box		Rotation protractor
	Making complex shapes with grouping		Nudgin		Rotating around the X and Y axes
			Rotation		Scaling an object

Table 5 (continued)

Week	Learning outcomes	Week	Learning outcomes	Week	Learning outcomes
10. Week	Moving, rotating, and scaling objects	11. Week	Making and manipulating grouped objects	12. Week	Making and manipulating grouped objects
	The X and Y axes' corner handles		Creating a compound shape		Choose a color
	X and Y axes' side drag handles		Duplicating shapes		Group inheritance
	Shift scale		Turning a group into negative space		Multicolor
	Scaling about the center of an object		Nested groups		Rotating groups
	Scale + rotation = skew!				Scaling the duplicate objects
	Deleting an Object				
13. Week	Use the align tools and the workplane helper	14. Week	Prepare the 3d model for 3d printing	Project homework 1	Make new project ideas
	Aligning to an object				Thing about a problem
	Grouping items for easy alignment				Find solution with 3D modelling
	Mirroring an object				Analysis 3D models properties to solve the problem
	Aligning a grouped object				
	Pasting on to a new workplane				
		Project homework 2	Make new project ideas		
			Draw 3d models		
			Prepare for 3d printing		

Table 6 The models constructed in the projects

3d model	f	%	3d model	f	%
Home	13	13.13	Key chain	2	2.02
Animal (like dragon, fish, rabbit)	9	9.09	Pen	2	2.02
Parentheses	8	8.08	Car	2	2.02
Bone	6	6.06	TapeBox	2	2.02
Fork	6	6.06	Game Characters	2	2.02
Pencil case	5	5.05	Ring	2	2.02
Robot	5	5.05	Eraser	2	2.02
Helmet	4	4.04	Junction box	2	2.02
Airplane	4	4.04	Hat	1	1.01
Human	4	4.04	Table	1	1.01
Stress wheel	4	4.04	Plates/CupsSet	1	1.01
Screwdriver	3	3.03	Computer	1	1.01
Cover	3	3.03	Tower	1	1.01
Skeleton	3	3.03	Tweezers	1	1.01

Table 7 The related samples t-test for pre-test and post-test scores

	X	N	s	sd	t	*p*
Pre-achievement test scores	3303	99	11,038	− 17,961	98	.000
Post-achievement test scores	62,980	99	166,739			

1. *Is there any significant difference between the achievement scores of pre-test and post-test of the secondary school students?*

In this study, the contribution of 3D computer modeling to the twenty-first century skills of secondary school students is investigated. However, the first hypothesis to be confirmed before analyzing this contribution is the hypothesis that "education increases success". Because if there were no increase in success, it would be meaningless to look at its contribution to twenty-first century skills. So, to detect a positive effect on the post-test would have been an indicator of the possibility of analyzing the relationship of twenty-first century skills. For this purpose, pre-test and post-test scores of secondary school students were compared with related samples t-test and reported in Table 7.

As shown in Table 7, a significant difference was found between pre-test and post-test achievement scores of secondary school students after 3D modeling education ($t_{(98)} = -17{,}961$, $p < 0.01$) and this difference was in line with the improvement in post-test when the average scores were examined. Based on this finding, the sub-questions of the research can be answered.

Table 8 The results of chi-square analysis about technology awareness

Theme: technology awareness		Agree	Neutral	Disagree	X^2	sd	p
I noticed new technologies when designing 3D with Tinkercad	n	78	13	5	100,188	2	.000
	%	78.8	13.1	5.1			

Table 9 Learning outcomes related to technology

Learning outcomes	n	%
Shortcut keys	37	17.45
Use of Word/Excel/PowerPoint	1	0.47
Use of paint	10	4.72
Use of the Internet	31	14.62
Use of flash/hard-disk	11	5.19
Use of e-mail	33	15.57
Use of keyboard	33	15.57
Use of mouse	32	15.09
Screen designing	24	11.32

2. *What is the direction of the effect of 3D modeling on students' knowledge and technology skills in the other courses?*

The analysis of this sub-question started by asking the question of "Have you noticed new technologies when designing 3D with Tinkercad?" to the students. The gathered data were subjected to a single sample chi-square analysis to determine the significant difference between the categories, and Table 8 reported the results.

As illustrated in Table 8, the results of the single sample chi-square analysis showed 78 of the secondary school students agreed that their technology awareness increased. At the same time, 13 of them were undecided, and five students disagreed. It is seen that the distribution of the secondary school students skewed in the category where 3D design increases technology awareness, and there is a significant difference between the groups ($x^2(sd = 2, n = 99) = 100{,}188$, $p < 0.001$). In line with this finding, the students were asked about the learning outcomes related to the technology they used mostly during the 3D Modeling process. The results are reported in Table 9.

It can be seen that 17.45% of the secondary school students indicated that the use of shortcut keys is the most developed learning outcome during the 3D design process. The results also show that 15.57% of the students stated e-mail and keyboard usage. 15.09% of them indicated the use of the mouse, 14.62% of them noted the internet usage, 11.32% of the students stated the use of screen design programs, 5.19% of them indicated the usage of Flash / hard-disk, and 4.72% of them noted the use of Paint. Also, 0.47% of the students stated the use of office programs. In light of these findings, it can be said that the contribution of 3D design to students' technology skills is positive.

There was also a need to study on the learning outcomes of the other courses that the students used during the 3D Modeling education by determining their contribution to technology. In this context, firstly, the students were asked with the question of "In which courses they used the information gathered in the process of 3D modeling education," and the answers were reported in Table 10.

Table 10 illustrated that the students mostly used the learning outcomes of the courses of mathematics and geometry (30.31%), and then the courses of Information Technologies (24%) and Technology Design (23.48%) during the 3D Modeling process. The other courses according to the percentages respectively are Painting (9.09%), English (4.55%), Science (3.79%), Social Studies (54.55%), Introduction to science (0.76%) and Turkish (0.76%). The first three courses that the students use mostly in the 3D modeling process are Mathematics-Geometry, Information Technologies, and Technology Design. In the light of these findings, students were questioned about the mainly used information they had previously learned in the course of Mathematics-Geometry, and Table 11 reported the data obtained.

It can be seen from Table 11 that the most commonly used learning outcome by the students in the 3D modeling education process is Cube and Cylinder (12.05%). Area calculations follow these learning outcomes, with 9.64% and unit conversions with 8.73%. The other learning outcomes are about the sphere, cone, four operations, pyramid, coordinate plane, hemisphere, ring, cubage, polygon, and prism, respectively.

Based on all of these results, it can be said that modeling with 3D computer helps students reinforce the learning outcomes that they have acquired in the courses such as mathematics-geometry, technology design, and information technologies; and also contributes to technology awareness.

3. *The contribution of 3D modeling education to the students' designing skills*

The third sub-question of the research is about the contribution of 3D modeling education to design skills from the perspective of the students. For this purpose, twelve different questions were asked to the students, and their answers were subjected to a single sample chi-square analysis (Table 12).

It can be seen that there are significant differences between the students' answers except for two. As mentioned before, students did not have received any training in 3D modeling before the study and did not have readiness for this subject. It was found that most of the students found 3D design enjoyable, and there are significant differences between the answers of the students ($x^2(sd=2, n=99)=84{,}182$, $p<0.001$). It was also observed that a large number of the students (n = 42.4%) were undecided about the ease of using 3D design and this difference was also significant ($x^2(sd=2, n=99)=8.061$, $p<0.005$). Students are undecided about the ease of using 3D design. However, most of them disagree that they had difficulties in "understanding X-Y-Z coordinates," "visualize

Table 10 The other courses related to 3D modeling education

The name of course	f	%
Mathematics-geometry	40	30.31
Technology design	31	23.48
Information technologies	34	25.76
Science	5	3.79
Introduction to science	1	0.76
Painting	12	9.09
Social sciences	2	1.52
English	6	4.55
Turkish	1	0.76

Table 11 Learning outcomes of the course of mathematics–geometry

Learning outcomes	N	f
Cube	40	12.05
Cylinder	40	12.05
Calculating area	32	9.64
Unit conversion (e.g., converting meter to the centimeter)	29	8.73
Sphere	28	8.43
Cone	25	7.53
Four operations (summation, multiplication, subtraction, etc.)	24	7.23
Pyramid	21	6.33
Calculations of coordinate plane (X, Y, Z coordinates)	20	6.02
Hemisphere	19	5.72
Ring	18	5.42
Cubage	18	5.42
Polygon	16	4.82
Prism	2	0.6

models in their minds," "saving designs," “drawing their models," “understanding the logic of modeling”, “creating holes” during 3D modeling design. Also, the difference between the students’ answers was significant. The two questions that do not have significant differences are the items of having difficulty in drawing their models and having the objects in coplanar.

Generally, it can be said that 3D modeling education contributes to the designing skills of the students positively.

4. *The contribution of 3D modelling education to the collaboration and communication skills of the students*

The fourth sub-question of the research examined the contribution of 3D modeling education to communication and collaboration skills from the perspectives of the students. For this purpose, six questions were asked to the students, and a single sample chi-square test was performed to analyze the significance of the observed differences between the answers. The results are summarized in Table 13.

The first question asked to the students is whether they have communicated and collaborated with their friends during the 3D design process or not. Most of the students (n = 76.8%) were answered as “agree” and there is a significant difference between the answers of the students (x^2(sd = 2, n = 99) = 84,182, $p < 0.001$). Similarly, it can be seen that the students are in cooperation and communication with their teachers in the 3D design process (x^2(sd = 2, n = 99) = 100,188, $p < 0.001$). The only different result is obtained from the family item. The students stated that they did not contact their families during the 3D modeling education process, and there was a significant difference between the answers of the students (x^2(sd = 2, n = 99) = 43,091, $p < 0.001$). Students’ behaviors of communicating not only with individuals but also with online people were also questioned. However, most of the students stated that they did not communicate and cooperate with people in online environments during the 3D design process and there is not any significant difference between the answers of the students (x^2(sd = 2,

Table 12 The chi-square test about the designing skills of the students

Theme: 3D design skills		Agree	Neutral	Disagree	X^2	Df	p
I had difficulties in understanding the X-Y-Z coordinates during 3D designing with Tinkercad	n	21	39	39	6545	2	.038
	%	21.2	39.4	39.4			
I had difficulties in using pre-designed models during 3D designing with Tinkercad	n	16	21	62	38,606	2	.000
	%	16.2	21.2	62.6			
I had difficulties about drawing my models during 3D designing with Tinkercad	n	38	24	37	5688	2	.058
	%	38.4	24.2	37.4			
I had difficulties in saving designs during 3D designing with Tinkercad	n	17	19	63	40,970	2	.000
	%	17.2	19.2	63.6			
I had difficulties in understanding the logic of 3D modeling during 3D designing with Tinkercad	n	23	28	46	9052	2	.011
	%	23.2	28.3	46.5			
I had difficulties with visualizing models in my mind	n	12	31	55	40,795	2	.000
	%	12.1	31.3	55.6			
I had difficulties in creating holes during 3D designing with Tinkercad	n	34	17	48	14,606	2	.001
	%	34.3	17.2	48.5			
I had difficulties with having the objects in coplanar during 3D designing with Tinkercad	n	32	25	42	4424	2	.109
	%	32.3	25.3	42.4			
It was delightful to design 3D models with Tinkercad	n	76	13	10	84,182	2	.000
	%	76.8	13.1	10.1			
It was effortless to design 3D models with Tinkercad	n	37	42	20	8061	2	.018
	%	37.4	42.4	20.2			

Table 13 The results of the chi-square test about collaboration and communication skills

Theme: collaboration and communication		Agree	Neutral	Disagree	X^2	Df	*P*
When I had difficulties with 3D designing with Tinkercad, I communicated and collaborated with my friends	n	76	10	13	84,182	2	.000
	%	76.8	10.1	13.1			
I helped my friends who had difficulties in 3D designing with Tinkercad	n	76	11	12	84,061	2	.000
	%	76.8	11.1	12.1			
When I had difficulties with 3D designing with Tinkercad, I communicated and collaborated with my family	n	24	12	63	43,091	2	.000
	%	24.2	12.1	63.6			
When I had difficulties with 3D designing with Tinkercad, I communicated and collaborated with my teacher	n	78	16	5	93,879	2	.000
	%	78.8	16.2	5.1			
When I had difficulties with 3D designing with Tinkercad, I communicated and collaborated with people on the internet	n	24	11	63	44,837	2	.000
	%	24.2	11.1	63.6			
	%	33.3	34.3	32.3			

n = 99) = 44,837, $p < 0.001$). Finally, it is seen that in addition to not getting help from friends, students do not help their friends inthe 3D design process. The results showed that most of the students "agree" the statement of "I helped to my friends who had difficulties in 3D designing with Tinkercad." and the difference between the answers was significant (x^2(sd = 2, n = 99) = 100,188, $p < 0.001$).

Generally, the results indicated that most of the students communicate and collaborate with their friends and teacher during the 3D modeling education process. These results can be interpreted as the 3D Modelling education contributes to the collaboration and communication skills of the students.

5. *The contribution of 3D modelling education to creative thinking and problem-solving skills*

The sixth sub-question of the research determined the contribution of the 3D modeling process to creative thinking and problem-solving skills. For this purpose, seven questions were asked to the students. The answers given by the students were subjected to a single sample chi-square test, and the results are summarized in Table 14.

It can be seen that there are significant differences in some answer categories, while there was not any significant difference in others. It is observed that 87.9% of the students "agree" with the item of "3D design with Tinkercad made it easy for me to produce new ideas". The difference between the answer categories is significant (x^2(sd = 2, n = 99) = 135,694, $p < 0.001$). In other words, students think that 3D design makes it easier for them to produce new ideas. The results are also significant for the item of "Making 3D design with Tinkercad increased my creativity". While 77.8% of the students agree with this item, 17.2% stated that they were undecided, and 5.1% did not agree with the item. The difference between the answer categories is significant (x^2(sd = 2, n = 99) = 90,182, $p < 0.001$). The difference between the answer categories of the item "I can produce solutions to real-life problems by making 3D designs." is also significant. It is seen that most of the students agree with this item. Also the difference between the answer categories is significant x^2 (sd = 2, n = 99) = 6788, $p < 0.005$). The other two items are "I have trials about the solutions for the problems that I faced with when designing in 3D with Tinkercad." and "I draw the same object in different ways while designing in 3D with Tinkercad". It is seen that the answer category that students choose mostly is "Agree" (52.5%, 60.5%). Moreover, the difference between the answer categories is significant in both questions (x^2(sd = 2, n = 99) = 17,152, $p < 0.00$, x^2(sd = 2, n = 99) = 33,515, $p < 0.001$). These two questions are about alternative ways of problem-solving and finding different solutions. The answers of the students showed that the 3D modeling education process contributes to alternative ways to solve the problem.

6. *The contribution of 3D modelling education to the entrepreneurship skills*

The last sub-question of the research questioned the contribution of 3D modeling education to entrepreneurship skills. Seven questions were asked for this purpose, and the single sample chi-square test was performed to compare the answer categories (Table 15).

Table 15 illustrates that 70.7% of the students stated that they wanted to continue to make the 3D design in the following periods, 20% were undecided, and 9.1% did not want to continue. This difference observed between the answer categories is significant

Table 14 The results of the chi-square test about creative thinking and problem-solving skills

Theme: creative thinking and problem solving		Agree	Neutral	Disagree	X^2	df	*p*
3D design with Tinkercad made it easy for me to produce new ideas	n	87	7	4	135,694	2	.000
	%	87.9	7.1	4.0			
Making 3D designs with Tinkercad increased my creativity	n	77	17	5	90,182	2	.000
	%	77.8	17.2	5.1			
I can produce solutions to real-life problems by making 3D designs	n	41	37	21	6788	2	.003
	%	41.4	37.4	21.2			
I was able to quickly solve all the problems I encountered when designing in 3D with Tinkercad	n	32	40	26	3020	2	.221
	%	32.3	40.4	26.3			
I have trials about the solutions for the problems that I faced when designing in 3D with Tinkercad	n	52	27	20	17,152	2	.000
	%	52.5	27.3	20.2			
I draw the same object in different ways while designing in 3D with Tinkercad	n	60	17	22	33,515	2	.000
	%	60.6	17.2	22.2			
I designed new models that have never been created before with Tinkercad	n	35	30	33	388	2	.824
	%	35.4	30.3	33.3			

(x^2(sd = 2, n = 99) = 64,061, $p < 0.001$). Similarly, 47.5% of the students stated that they wanted to design games by 3D modeling, and compared with other answer categories, the difference between answer categories was significant (x^2(sd = 2, n = 99) = 13,152, $p < 0.005$). In contrast to positive feedback on entrepreneurship, it was seen that most of the students “disagree” (49.5%) with the item of “I would like to work in a profession related to 3D design in the future.” and the difference between the answer categories is significant (x^2(sd = 2, n = 99) = 9455, $p < 0.05$). Moreover, it was observed that there was no significant difference between the answer categories in the other questions asked to determine the contribution to entrepreneurship. As a result, the contribution of 3D modeling education to entrepreneurship is questionable.

Discussion

The level of development of countries indicates the transition from the consumer society to the production society. This process necessitates alternative learning ways to develop high-level thinking skills of students in educational environments where human resources are developed and to contribute to production. From this point of view, the contribution of 3D computer modeling education to the standard skills of the twenty-first century was determined by the self-evaluation of secondary school students. In this context, a learning method is not intended, but it is aimed to present the contribution of computer-based acquisition to the twenty-first century skills as a subject area.

According to the students, 3D computer modeling education has been effective positively on the learning outcomes of the course of mathematics-geometry, technology design, and information technology. Explicitly, they stated that they had to use the knowledge gathered from mathematics and geometry such as the cube, cylinder, area calculation, unit conversion during the drawings process. A similar situation is also valid for computer issues. The students stated that they used some technology-related skills such as keyboarding, shortcut, paint usage, and internet usage in the 3D computer modeling process. So, it can be said that 3D modeling education is a good practice in terms of practicing the subjects of some courses and using them to produce solid materials that will be reflected in real life. These results are not surprising. Because, as stated in the literature, students acquire basic knowledge about the graphical representation of three-dimensional objects in plane and space (Mitrovic et al., 2012) and practice the acquired knowledge. This basic knowledge is directly in line with the learning outcomes of the courses of mathematics, geometry, design, and information technology course. Also, drawing helps the student to have better spatial skills (Olvera-García et al., 2019). This raises the question of whether 3D modeling education can be an alternative learning method that can be applied by combining the learning outcomes in some courses with real-life problems. This question is answered as defining 3D printing as a new emerging educational technology trend in supporting educational environments in the 2018-Higher Education 7 Edition of the NMC Horizon Report that is (Becker et al., 2018).

In the research process, the contribution of 3D computer modeling to the design skills of the students was also analyzed. According to secondary school students, 3D computer modeling education made a positive contribution to the design skills. Although the students were undecided about the difficulty of modeling, they stated that they did not have any trouble in visualization, understanding X-Y-Z coordinates, and saving the designs in the desired formats at the end of the education process. Besides, it is seen that they have

Table 15 The results of the chi-square test about Entrepreneurship skills

Theme: entrepreneurship		Agree	Neutral	Disagree	X^2	df	*p*
I would like to continue the 3D design in the future	n	70	20	9	64,061	2	.000
	%	70.7	20.2	9.1			
I would like to work in a profession related to 3D design in the future	n	20	30	49	13,152	2	.001
	%	20.2	30.3	49.5			
I would like to establish a club about 3D design in the future	n	24	34	41	4424	2	.109
	%	24.2	34.3	41.4			
In the future, I want to record and share videos with 3D design	n	25	31	43	5091	2	.078
	%	25.3	31.3	43.4			
I would like to take different courses /training to make a 3D design in the future	n	31	28	40	2364	2	.307
	%	31.3	28.3	40.4			
I want to design games by 3D design in the future	n	47	23	29	9455	2	.009
	%	47.5	23.2	29.3			
I would like to design cartoons by making 3D designs	n	31	26	42	4061	2	.131
	%	31.3	26.3	42.4			

started to draw their models at the end of the education and that they understand the logic of modeling. The result of the project shows that the students brought twenty-eight different models. This data supports students' data on 3D modeling. They also stated that they enjoyed in the designing process. Therefore, 3D modeling education contributes to the production of new things, which is considered among the twenty-first century skills.

Another skills subjected to this research is collaboration and communication skills. Secondary school students stated that they frequently communicate with other friends and teachers and perform collaborative studies during 3D computer modeling. So the modeling process has a positive effect on collaboration and communication skills. When the findings in the literature are examined, it is seen that 3D education provides students with fun and experimental learning experiences, and also help the students in the class about developing twenty-first century skills like communication and collaboration (Figg et al., 2018). Novak and Wisdon (2019) stated that students were encouraged to collaborate with others by actively participating in 3D printing courses. The most crucial factor that led to communication and collaboration was the difficulties in the 3D modeling process. It is seen that they communicate and collaborate with stakeholders in the processes in which they have a problem. This raises a discussion with 3D modeling training: Does the difficulty faced in subject areas by the students affect the development of communication and collaboration skills that are among the twenty-first century skills? The researchers plan further study on this question.

In the study, it was also determined whether the 3D modeling education of the students contributed to creative thinking and problem-solving skills or not. According to secondary school students, 3D modeling education requires producing something new and makes it easier to create something new. Besides, it provides the opportunity to solve problems by performing trials and gives the ability to produce similar types of products in different ways. Cano's (2015) study emphasizes that 3D modeling will provide practice in various styles of problem-solving. It is a process of designing an object, identifying the problems on the design, the production, and testing of alternative methods to solve these problems.

Similarly, in the study of Brookhart (2013), 'it is emphasized that 3D modeling and 3D printing may be a new way of developing students' creativity by taking into consideration the criteria of the creative child's characteristics' (Quoted by Cano, 2015). Novak and Wisdon (2019), in their research, also claims that 3D printing lessons provide opportunities for creative design and making processes. In general, it can be said that students' tendencies to trails during the 3D modeling process and presenting suitable practices to produce new ideas contribute to the operation of solving the problems.

The last theme is entrepreneurship. Following this theme, it was determined that students generally had a negative tendency. As a result of 3D design education, although many students declare that they want to continue to design, they do not volunteer to carry out different entrepreneurship activities by transferring these skills to the next level.

Conclusion

As a result, it can be said that 3D computer modeling education contributes to reinforcing the students' acquisitions in some courses and especially in the courses of mathematics, geometry, technology design, and information technologies. Moreover, it is seen that secondary school students cooperate and communicate more with teachers and other students during 3D modeling education. In addition to these, they state that there are severe improvements in their designing skills. Students who indicated that they had the opportunity to produce new products, to present new ideas and to solve problems through trials seem to have only negative opinions about entrepreneurship.

Research data was gathered based on the students' opinions and tended to give general information. In the subsequent studies, researchers can conduct studies comparing each twenty-first century skills with the subject area of 3D modeling. Also, there is a need to study in-depth about the relation between 3D modeling education and the subjects of other courses. 3D modeling training, which allows us to collaborate interdisciplinarily, can be developed to practice how different course outcomes are used in the real world. Another suggestion is the use of a different 3D modeling program except the Tinkercad to predict the impact on secondary school students.

References

Akıllı, M., & Seven, S. (2014). The effects of 3D computer models to academic achievement and spatial ability: Atomic models. *Turkish Journal of Education, 3*(1), 11–23. https://doi.org/10.19128/turje.18107

Arıcı, V. A. (2013). *A study on 3d-virtual reality in science education programs: "solar system and beyond: space puzzle" unit sample (Unpublished Master Thesis)*. Menderes University, Department of Elementary Education, Turkey.

Azimi, P., Zhao, D., Pouzet, C., Crain, N. E., & Stephens, B. (2016). Emissions of ultrafine particles and volatile organic compounds from commercially available desktop three dimensional printers with multiple filaments. *Environmental Science and Technology, 50*(3), 1260–1268. https://doi.org/10.1021/acs.est.5b04983

Becker, S. A., Brown, M., Dahlstrom, E., Davis, A., DePaul, K., Diaz, V., & Pomerantz, J. (2018). *NMC Horizon Report: 2018 Higher Education Edition Louisville*, CO: EDUCAUSE. Retrieved from https://www.learntechlib.org/p/184633/.

Bell, S. (2010). Project-based learning for the 21st century: Skills for the future. The Clearing House. *A Journal of Educational Strategies, Issues, and Ideas, 83*(2), 39–43. https://doi.org/10.1080/00098650903505415

Binkley, M., Erstad, O., Hermna, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining twenty-first century skills. In P. Griffin, E. Care, & B. McGaw (Eds.), *Assessment and teaching of 21st century skills* (pp. 17–66). Springer.

Brown, A. (2015). 3D Printing in instructional settings: Identifying a curricular hierarchy of activities. *TechTrends, 59*(5), 16–24. https://doi.org/10.1007/s11528-015-0887-1

Campbell, M., Saltmarsh, S., McPherson, A., & Drew, C. (2013). Issues of teacher professional learning within 'non-traditional' classroom environments. *Improving Schools*, *16*, 209–222. https://doi.org/10.1177/1365480213501057.

Cano, L. M. (2015). *3D printing: A powerful new curriculum tool for your school library*. Libraries Unlimited.

Chang, Y., Chen, M. C., Chuang, M. J., & Chou, C. (2019). Improving creative self-efficacy and performance through computer-aided design application. *Thinking Skills and Creativity, 31,* 103–111. https://doi.org/10.1016/j.tsc.2018.11.007

Chekrouni, N., Kleipool, R. P., & Bakker, B. S. (2020). The impact of using three-dimensional digital models of human embryos in the biomedical curriculum. *Annals of Anatomy—Anatomischer Anzeiger*. https://doi.org/10.1016/j.aanat.2019.151430

Despeisse, M., Baumers, M., Brown, P., Charnley, F., Ford, S. J., Garmulewicz, A., Knowles, S., Minshall, T., Mortara, L., Reed-Tsochas, F., & Rowley, J. (2016). Unlocking value for a circular economy through 3D printing: A research agenda. *Technological Forecasting & Social Change, Forthcoming*. https://doi.org/10.1016/j.techfore.2016.09.021

Emre, Ş, Yolcu, M. B., & Celayir, S. (2018). Use of three-dimensional printed models in the training of medical students in pediatric surgery: First impressions. *Çocuk Cerrahisi Dergisi, 32*(2), 55–60. https://doi.org/10.5222/JTAPS.2018.055

Erkuş, A. (2003). *Psikometri üzerine yazılar*. Türk Psikologlar Derneği Yayınları.

Figg, C., Jennifer, R., Shannon, W., & Pelchat, K. (2018). *Using Informal Learning of Makerspaces to Enhance Technological Pedagogical and Content Knowledge (TPACK).* Paper presented at the Society for Information Technology & Teacher Education International Conference 2018, Washington, DC, USA.
Frank, A. (2005). What do students value in built environment education? *CEBE Transactions, 2*(3), 21–29. https://doi.org/10.11120/tran.2005.02030021
Gretter, S., & Yadav, A. (2016). Computational thinking and media & information literacy: An integrated approach to teaching twenty-first century skills. *TechTrends, 60,* 3–9. https://doi.org/10.1007/s11528-016-0098-4
Haşlaman, T., Kuşkaya, F. M., & Usluel, Y. K. (2007). The integration of information and communication technologies in learning and teaching process: A lesson plan example. *Education and Science, 32*(146), 54–63.
Hatchuel, A., Masson, P. L., Reich, Y., & Subrahmanian, E. (2018). Design theory: A foundation of a new paradigm for design science and engineering. *Research in Engineering Design, 29*(1), 5–21. https://doi.org/10.1007/s00163-017-0275-2
International Baccalaureate (IB). (2013). *IB learner profile.* Retrieved from https://www.ibo.org/contentassets/fd82f70643ef4086b7d3f292cc214962/learner-profile-en.pdf.
ISTE. (2016). *2016 ISTE Standards for Students.* Retrieved from https://conference.iste.org/uploads/ISTE2017/HANDOUTS/KEY_108218083/2016ISTEStandardsforStudents.pdf.
Laar, E., Deursen, A. J. A. M., Dijk, J. A. G. M., & Haan, J. D. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Computers in Human Behavior, 72,* 577–588. https://doi.org/10.1016/j.chb.2017.03.010
Laar, E., Deursen, A. J. A. M., Dijk, J. A. G. M., & Haan, J. D. (2019). Determinants of 21st-century digital skills: A large-scale survey among working professionals. *Computers in Human Behavior, 100,* 93–104. https://doi.org/10.1016/j.chb.2019.06.017
Lee, S., & Yan, J. (2016). The impact of 3D CAD interfaces on user ideation: A comparative analysis using SketchUp and Silhouette Modeler. *Design Studies, 44,* 52–73. https://doi.org/10.1016/j.destud.2016.02.001
Liaw, S. Y., Soh, S. L. S., Tan, K. K., Wu, L. T., Yap, J., Chow, Y. L., Lau, T. C., Lim, W. S., Tan, S. C., Choo, H., Wong, L. L., Lim, S. M., Ignacio, J., & Wong, L. F. (2019). Design and evaluation of a 3D virtual environment for collaborative learning in interprofessional team care delivery. *Nurse Education Today, 82,* 64–71. https://doi.org/10.1016/j.nedt.2019.06.012
Lonsdale, M., & Anderson, M. (2012). *Preparing 21st century learners: The case for school community collaborations.* Australian Council for Educational Research. Retrieved from https://research.acer.edu.au/policy_analysis_misc/16/.
Luan, X., Xie, Y., Ying, L., & Wu, L. (2008). Research and development of 3D modeling. *IJCSNS International Journal of Computer Science and Network Security., 8*(1), 49–53.
Karademir, T (2018). *Ecologic approach to adaption of technology: A sustainable digital learning material development ecosystem (Unpublished PhD thesis).* Ankara University, Educational Science Faculty.
Kell, H. J., Lubinski, D., Benbow, C. P., & Steiger, J. H. (2013). Creativity and technical innovation: Spatial ability's unique role. *Psychological Science, 24*(9), 1831–1836. https://doi.org/10.1177/0956797613478615
Kereluik, K., Mishra, P., Fahnoe, C., & Terry, L. (2013). What knowledge is of most worth: Teacher knowledge for 21st century learning. *Journal of Digital Learning in Teacher Education, 29*(4), 127–140.
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. https://doi.org/10.1016/j.tele.2014.05.001
Kuzu Demir, E. B., Çaka, C., Tugtekin, U., Demir, K., İslamoğlu, H., & Kuzu, A. (2016). The use of threen dimensional printing technologies in education: Practices in Turkey. *Ege Eğitim Dergisi, 17*(2), 481–503. https://doi.org/10.12984/egeefd.280754
Mitrovic, A., Milosevic, D., & Radovic, M. (2012). New approach to 3D modeling in computer graphics course. *Metalurgia International., 17*(11), 80–86.
National Academy of Engineering [NAE]. (2010). *Standards for K-12 engineering education?* The National Academies Press. https://doi.org/10.17226/12990.
NEA (National Education Association). (2010). *21st century knowledge and skills in educator preparation*. Retrieved from http://www.p21.org/storage/documents/aacte_p21_whitepaper2010.pdf.
Novak, E., & Wisdom, S. (2019). *Using 3D printing in science for elementary teachers. Ed Mintzes, Joel J., Walter, Emily, Active Learning in College Science*. The case for evidence-based practice. Springer.
Olvera-García, E., Marín-Granados, M. D., & Ortíz-Zamora, F. J. (2019). Improving spatial abilities and comprehension in technical drawing students through the use of innovative activities and augmented

reality. In F. Cavas-Martínez, B. Eynard, F. Fernández Cañavate, D. Fernández-Pacheco, P. Morer, & V. Nigrelli (Eds.), Advances on mechanics, design engineering and manufacturing II. Lecture notes in mechanical engineering. Springer.

Özabacı, N., & Olgun, A. (2011). A study on computer based science and technology education on students' attitudes, master learning skills and achievement. *Electronic Journal of Social Sciences, 10*(37), 66.

Özgüven, İE. (1994). *Psikolojik testler*. Yeni Doğuş Matbaası.

P21 (The Partnership for 21st Century Skills). (2009). *P21 framework definitions*. Retrieved from http://www.p21.org/storage/documents/P21_Framework_Definitions.pdf.

Palys, T. (2008). Purposive sampling. In L. M. Given (Ed.) *The Sage encyclopedia of qualitative research methods (Vol. 2).* Sage.

Pantic, N., & Wubbels, T. (2010). Teacher competencies as a basis for teacher education? Views of Serbian teachers and teacher education. *Teaching and Teacher Education, 26*(3), 694–703. https://doi.org/10.1016/j.tate.2009.10.005

Prensky, M. (2001). Digital natives, digital immigrants, Part 2: Do they really think differently? *On the Horizon, 9*(6), 1–6. https://doi.org/10.1108/10748120110424843

Price, P. C., Jhangiani, R., Chiang, I. A., Leighton, D. C., & Cuttler, C. (2017). *Research methods in psychology* (3rd edn). Creative Commons Attribution.

Ravitz, J., Hixson, N., English, M., & Mergendoller, J. (2012). Using project based learning to teach 21st century skills: Findings from a statewide initiative. In *Annual meetings of the American Educational Research Association, Vancouver, BC*.

Remondino, F., & El-Hakim, S. (2006). Image-based 3D modelling: A review. *The Photogrammetric Record, 21*(115), 269–291. https://doi.org/10.1111/j.1477-9730.2006.00383.x

Schelly, C., Anzalone, G., Wijnen, B., & Pearce, J. M. (2015). Open-source 3-D printing technologies for education: Bringing additive manufacturing to the classroom. *Journal of Visual Languages & Computing, 28,* 226–237. https://doi.org/10.1016/j.jvlc.2015.01.004

Singapore Ministry of Education. (2018). *21st Century competencies*. Retrieved from https://www.moe.gov.sg/education/education-system/21st-century-competencies.

Solan, J., Hamilton, L. S., & Stecher, B. M. (2013). *Measuring 21st century competencies guidance for educators a global cities education network report*. Retrieved from https://asiasociety.org/files/gcen-measuring21cskills.pdf.

Sönmez, S., Kesen, U., & Dalgıç, C. (2018). *3 Dimensional printers*. The paper presented at 6th International Printing Technologies Symposium. İstanbul University.

Thornburg, D., Thornburg, N., & Armstrong, S. (2014). *The invent to learn guide to 3D printing in the classroom: Recipes for success*. Constructing Modern Knowledge Press.

Vidaurre, A. G., Hadeed, K., Retsimandresy, M., Karsenty, C., Dulac, Y., & Acar, P. (2019). Usefulness of 3D printed models of congenital heart diseases as educational tools for medical students. *Archives of Cardiovascular Diseases Supplements, 11*(3), 129–130. https://doi.org/10.1016/j.acvdsp.2019.04.055

Wagner, T. (2008). *The Global Achievement Gap: Why even our best schools don't teach the new survival skills our children need-and what we can do about it*. Basic Books.

Wu, K., & Shah, P. (2004). Exploring visuospatial thinking in chemistry learning. *Science Education, 88*(3), 465–492. https://doi.org/10.1002/sce.10126

Yaman, K., Savaş, S., Güler, O., Bodukcu, H., Özçelik, Ö. F., & Açan, H. (2015). *Using stereoscopic 3D visualization tehcnology in vocational education and evaluation with satisfaction scale*. Presented at XVII. Academic information conference on 4–6 February, Eskişehir, Turkey. Retrieved from: t.ly/GjK3m.

Yıldız, B., & Tüzün, T. (2011). Effects of using three-dimensional virtual environments and concrete manipulatives on spatial ability. *Hacettepe Üniversitesi Eğitim Fakültesi Dergisi, 41,* 498–508.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.