STEM Education

https://www.aimspress.com/journal/steme

STEM Education, 5(4): 688–713
DOI: 10.3934/steme.2025032
Received: 28 January 2025
Revised: 13 June 2025
Accepted: 19 June 2025
Published: 01 July 2025

Research article

Examining the materials and processes developed by preservice preschool teachers with 3D printers and CNC machines

Sait Bulut[1], Ali Özkaya[1,] *, Gözdegül Arık Karamık[1] and Gizem Şahin[2]

[1] Department of Mathematics and Science Education, Faculty of Education, Akdeniz University, Antalya, Turkey; saitbulut@akdeniz.edu.tr, aliozkaya@akdeniz.edu.tr, gkaramik@akdeniz.edu.tr

[2] Department of Mathematics and Science Education, Institute of Educational Sciences, Akdeniz University, Antalya, Turkey; gizemsahin242@gmail.com

* **Correspondence:** Email: aliozkaya@akdeniz.edu.tr; Tel: +90-242-227-4400.

Academic Editor: Jingjie Yeo

Abstract: This study aimed to examine the development process of materials created by preservice preschool teachers using a 3D printer and a computer numerical control (CNC) machine. The study group consisted of preservice preschool teachers enrolled in the second grade during the fall semester of the 2022–2023 academic year at a state university located in the Mediterranean region of Turkey. An embedded mixed-methods research design was employed in this study. The self-efficacy scale of teaching material utilization (SSTMU) was utilized to collect quantitative data, while the intervention status evaluation form (ISEF) and the daily intervention evaluation form (DIEF) were used to gather qualitative data. During the implementation phase, preservice teachers developed materials using a 3D printer and a CNC machine for science, technology, engineering, and mathematics (STEM) education over a period of six weeks. At the conclusion of the implementation, an increase in the self-efficacy scores of the preservice teachers regarding the utilization of teaching materials was observed. An analysis of the pre- and post-implementation feedback from the preservice teachers revealed that they were able to apply the knowledge they acquired in areas, such as message design, visual design, and usage, demonstrating this through the personal competencies they developed. Based on the quantitative and qualitative findings, the research suggests that materials developed with 3D printers and CNC machines can be effectively used in STEM education and that their implementation in this context can assist teachers in acquiring knowledge and skills relevant to the subjects being taught.

Keywords: STEM teaching, 3D printer, CNC machine, material development, educational material, teaching material utilization, self-efficacy

1. Introduction

Teachers organize the teaching and learning environment to support students' engagement in the classroom and skill acquisition, where teachers are expected to generate ideas on how to present teaching-learning materials [1]. Teachers can use existing teaching materials or design materials in line with the learning outcomes in the curriculum [2]. Planning lesson processes that attract students' attention and curiosity by using and designing teaching-learning materials is one of the competencies that teachers should have [3].

Preschool period is a critical period for the use of teaching-learning materials for children. Froebel, who laid the foundations of preschool education, emphasized that the materials to be used by children should support their experiences and that materials should be designed accordingly. In order to support children's life skills, it is important to choose materials whose shape, texture, and color can be observed realistically as educational materials. It is also important that teachers are able to prepare these preferred materials. In this respect, emphasizing the process of teachers' preparation of materials also creates the possibility of controlling the materials that contain the knowledge and skills that students will need [4]. In an educational environment, children can learn about different disciplines through the materials they use. Thanks to this acquisition, students can act in line with the achievements of the science, technology, engineering, and mathematics (STEM) discipline while confronting and trying to solve some of the problems they may encounter in their lives. For example, students can observe the movement of a car on a ramp by considering factors, such as the length of the ramp, the slope, and the type of its surface, and may need information about disciplines, such as mathematics and science. The fact that this process becomes more understandable for an individual in early childhood is directly related to the knowledge and experience of the teacher [5]. Studies focusing on preschool education also emphasize that teacher training to meet the needs of students should begin in the preservice period [6].

Teachers need to gain knowledge and skills for STEM activities and have an idea about the relevant materials for their implementation [7]. For example, there are studies [8–11] that address 3D printers and laser cutters for material design in STEM education environment. Although there are studies [12–17] on the use of 3D printers and computer numerical control (CNC) machine technologies (e.g., a laser cutter) to make appropriate designs in the teaching process and the use of these technologies in the material design process is preferred with the changes in technology, their number is limited. Considering the integration of 3D printing and CNC machining technologies in design processes, we focused on the experiences of preservice preschool teachers in designing STEM teaching materials that incorporate these technologies while also addressing their learning outcomes.

The current study may provide insight into the process of designing technology-supported materials to ensure the teaching of STEM disciplines and supporting teachers' self-efficacy development in developing appropriate materials. In this study, preservice preschool teachers were provided with the help of a 3D printer and a CNC machine to develop educational materials and the aim was to examine the material development process. In the light of the sub-dimensions of the self-efficacy scale of teaching material utilization (SSTMU), the sub-problems of the study were as follows:

1) What are the thoughts of preservice teachers about the materials developed with a 3D printer and a CNC machine to be used in STEM education before the intervention?

2) Does the intervention affect the self-efficacy of preservice teachers in using educational materials?
3) How did the intervention affect the views of preservice teachers on the design stage?
4) How did the intervention affect the views of preservice teachers on the usage stage?
5) How did the intervention affect the preservice teachers' lesson plan preparation process?

1.1. The importance of educational materials in early childhood

From early childhood onwards, there is a natural tendency for individuals to engage in learning activities, such as curiosity, research, questioning, and discovery. The experiences that children gain during this period support them in cognitive, affective, and psychomotor aspects in later periods. By meeting the educational needs of the child from this period onwards, the necessary information can be acquired, and skills, such as problem-solving, critical thinking, communication, and creative thinking, can be developed [18,19]. According to Piaget, individuals in early childhood structure knowledge through experiences. A rich stimulating environment can be created with materials, such as toys, to contribute to children's development. In order for children to learn the necessary concepts during this process, they need to be provided with materials that help them concretize the concepts [20]. It is also important that the concrete materials that teachers will present during this process are educational [21,22] and support the teaching process [23]. Activities that can be used by children in early childhood and are appropriate for their developmental levels should be developed with the knowledge and experience of educators [24,25]. Children in this period investigate the properties of the materials they encounter and can transform them into different forms [26–28]. At this point, STEM activities can help learners perform activities, such as observation, research, discovery, and playing [29–31].

1.2. Use of 3D printers and CNC machines in education to support STEM teaching

Scientific and technological developments support the development of an innovative perspective [32]. The place of innovative pedagogies in STEM education is increasing day by day [33]. The use of innovative materials contributes to the development of individuals [34]. While materials can be designed with various technologies in educational environments, these materials should support the learning process [35]. Technology and design implementations are also important in the STEM education process [36]. With these implementations, materials that appeal to more than one discipline can also be created. Technological tools and equipment can also be used in the design of teaching materials. 3D printers and CNC machine technologies can be given as examples of these tools and equipment. These technologies, which are widely used in the fields of aviation, defense, engineering, etc., are used in product production and are especially included in the education process in schools in European countries. While 3D printers that can be controlled via computers work on the principle of creating a solid object in layers on top of each other, CNC machine technologies perform the process of cutting and removing parts from solid raw materials. Different types of machines (e.g., lathe, drill, milling, and laser cutting) are available and vary in terms of usability and cost [16]. Such tools can be used in the education process to transform an idea into a physical object and in material design [37].

There is a need to train qualified teachers who can apply STEM-based activities in learning subjects, ensuring interdisciplinary integration [38]. In this process, teachers are an important factor in increasing the quality of preschool education and carrying out activities appropriate for the child's development. Monitoring children's cognitive, affective, and psychomotor skills according to the determined achievements and creating activities and materials appropriate for the children's levels depends on the teachers' experiences [19].

Supporting the use of technology does not mean that teachers and preservice teachers can easily access this technology. However, it is important for teachers and preservice teachers to know these technologies for a period when they are accessible. In this context, it is important for preservice teachers to have an awareness of using these materials during the undergraduate process, to use them and to reflect them in their practices. In Turkey, preschool teachers generally do not have access to 3D printers and CNC machines in their schools, but with the projects carried out in recent years, this technology support has started to be provided to schools, albeit to a small extent. In addition, there are two situations in which preschool buildings can be together with primary school buildings and/or separately. Although there are no specific standards developed for preschool students, the preschool curriculum published by the Ministry of National Education in 2024 emphasizes the implementation of small group activities as in STEM activities and STEM-A areas in integrated science education activities [39]. This emphasis can be interpreted as the importance given to STEM education will increase over time and the use of these materials in schools will become widespread.

1.3. Self-efficacy and self-efficacy in utilizing teaching materials

Self-efficacy refers to an individual's belief in their capacity to perform the behaviors required to complete a specific task [40]. It can also be defined as the belief that a person can demonstrate their potential and successfully complete a given task when faced with a challenge or performance requirement. Individuals with high self-efficacy beliefs tend to exhibit better performance as they believe that they can effectively handle problems, leading to increased levels of success and satisfaction [41]. To achieve job satisfaction, individuals need opportunities to feel competent and capable [42]. Self-efficacy significantly influences job satisfaction [43]. Teachers' stress levels and self-efficacy have significant impacts on their well-being both inside and outside the classroom. Higher stress and lower self-efficacy hinder teachers' ability to meet students' needs [44]. Research indicates that elevated teacher self-efficacy is linked to psychological well-being, job commitment, and job satisfaction [43,45]. Similarly, Caprara et al. [46] found that teachers with high self-efficacy reported greater values, happiness, and satisfaction in their profession.

When looking at the relationship between self-efficacy and job satisfaction, it is important to include teachers in the decision-making process, create opportunities for teachers to collaborate, provide adequate teaching materials, and support teachers in implementing effective strategies [47]. From this perspective, the main motivation of this study is that preservice teachers are involved in the process with the support of a measurement tool that determines the extent to which they can benefit from teaching materials [48], evaluate opportunities, reach strategy awareness with the help of these materials, and develop self-efficacy in using the materials.

Instructional materials are very important learning and teaching tools [49]. In this study, we focused on the significance of developing effective STEM education teaching materials tailored to various programs that address teachers' needs [50]. We emphasized the importance of ensuring alignment between objectives and content in the preparation of these materials, as well as their overall utility [51]. Additionally, we considered the benefits of providing teaching material support to students [52,53]. It is important to note that the materials utilized in this study were designed by the preservice teachers themselves. In addition, the fact that teachers have time constraints in STEM education [54–56] and the limited financial resources allocated [57,58] are negative situations. For this study, an attempt was made to minimize these negative situations during the intervention period by having 3D printers and CNC machines in the classrooms of preservice teachers while reducing the cost. The fact that the study was based on volunteering also allowed for no time limitation. It is thought that preservice teachers getting to know these tools and equipment during their undergraduate studies, using them, and deciding on their functionality can also support their teaching careers. Based on these contexts, the research investigated the educational material development processes of preservice preschool teachers with 3D printers and CNC machines and the changes in their self-efficacy in using educational materials as a result of this process.

2. Methodology

2.1. Research design

The study used embedded mixed research method. In an embedded mixed design, an experimental (through one group pretest-posttest design and one of the pre-experimental designs) intervention was implemented, and both quantitative and qualitative data were collected and analyzed. This information was utilized in an intervention study [59]. In such studies, a second data source is embedded in the pre- and post-intervention data collection [60]. The quantitative data for this study was collected using the SSTMU administered to participants both before and after the intervention. This scale measured the impact of the material development process on participants' self-efficacy regarding the use of teaching materials. The SSTMU provided quantifiable outputs regarding potential changes in participants' perceptions before and after the intervention. Data on participants' experiences with material development processes, specifically involving a 3D printer and CNC machine (laser cutting), was gathered through written reflections (i.e., a daily intervention evaluation form [DIEF]). This data was analyzed concerning the sub-dimensions of the SSTMU scale. Furthermore, the lesson plans created by the participants revealed the factors considered when developing lesson plans based on practical experiences. At the outset of the research process, it was crucial to define the intervention implemented for preservice preschool teachers. The type of intervention was determined by analyzing qualitative data collected from participants in the experimental setting through the intervention status evaluation form (ISEF). The intervention aimed to empower participants to utilize existing materials, despite their limited experience and knowledge of the products that could be created using a 3D printer and CNC machine. Additionally, participants were initially unaware of their self-efficacy in using these materials and lacked an understanding of how to effectively apply the developed materials in their courses. The implementation, which focused on these aspects, lasted for six weeks.

2.2. Participants

The participants of the study were determined according to the problem situation and consisted of preservice preschool teachers studying at a state university in the Mediterranean Region. A total of 18 preservice teachers (16 female and 2 male) in their second year of preschool teaching education constitute the participant group. The importance of the study is emphasized by the fact that children are exposed to STEM at an early age and the content of the courses taken by preservice preschool teachers at university is compatible with STEM. The main reason for not creating a control group in the study is that the content of the courses taken by the participants during the implementation period overlaps with the intervention. Special teaching methods, early childhood mathematics education, early childhood science education, and instructional technologies courses are the courses to be taken during the implementation period and it is thought that a possible significant difference will occur when a control group is assigned depending on the content of these courses. The implementation is enriched with detailed different materials (CNC machine and 3D printer) in addition to these contents. In other words, preservice preschool teachers take courses serving STEM in the second year of their education and therefore constitute the participant group of the study.

2.3. Data collection tools and process

Qualitative data was collected with the help of two forms prepared by the researchers. The first form is ISEF, consisting of six open-ended questions and developed to determine the content of the intervention. Eight questions were prepared for the ISEF, and opinions were received from two preschool teachers, two STEM field and two preschool education expert academicians. After the expert opinions, one of the questions in the evaluation form was removed and the other two questions were combined, and the form took its final form. These questions are as follows:

1. What criteria do you pay attention to when designing materials in your lessons? Why?
2. What effects can the use of technology in education have? Explain.
3. What are your ideas about 3D printers and CNC machines? Explain.
5. How do you establish interdisciplinary relationships in the material development process? Explain.
6. How do you interpret the interdisciplinary relationships you establish in the material development process?

The other form is the DIEF and was prepared to determine the effects of daily practices. DIEF consists of 5 open-ended questions and was structured in light of the feedback given to ISEF. The thoughts of the participants after each practice were collected with the help of this DIEF. These questions are about what they paid attention to when preparing the designed materials after practice, how they used them, what the effects of the 3D printer and CNC machine were on this process, and how they interpreted the effects of these materials in the lesson plan they prepared.

Quantitative data was collected with the SSTMU. The 23-item scale with a 5-point Likert type (1: never, 2: rarely, 3: sometimes, 4: mostly, and 5: always) developed by Korkmaz [48] consists of three sub-dimensions: content (message design), usage, and design (visual). Scale items are included in Appendix 1, and some items are as follows: “I can design teaching materials that properly reflect the context.”; “When designing a teaching material, I can utilize sufficiently concrete visuals.”; “When planning educational statuses, I can decide on which phase of the course I will use the material.”; and “I can select the teaching materials with up-to-date context and visuals.” There are 10 items in the content sub-dimension, 6 items in the usage sub-dimension, and 7 items in the design sub-dimension. The Kaiser-Meyer-Olkin value calculated for factor analysis was .93, and the Bartlett test results were found as $X^2 = 2901.946$, Sd = 253, $p < .001$ (RMSEA = 0.055, SRMR = 0.057, GFI = 0.91, AGFI = 0.89, CFI = 0.97, NNFI = 0.96, IFI = 0.97). The Cronbach alpha value of the scale was .822, and when the sub-dimensions were examined, it was calculated as .835 in the content sub-dimension, .685 in the usage sub-dimension, and .620 in the design dimension [48]. In this study, the Cronbach alpha value was calculated as .949, and the sub-dimensions were .91, .83, and .89, respectively. The implementation of the data collection tools, and the research process are given in Table 1.

Table 1. Instruments and processes.

Week	Duration	Process	Instruments
1	60′	Deciding on experimental intervention, intervention status evaluation form	ISEF
2	30′	Implementation of quantitative measurement tool	SSTMU
3	320′	Experimental intervention	DIEF
4	320′	Experimental intervention	DIEF
5	320′	Experimental intervention	DIEF
6	320′	Experimental intervention	DIEF
7	320′	Experimental intervention	DIEF
8	320′	Experimental intervention	DIEF
9	30′	Implementation of quantitative measurement tool	SSTMU

Table 2. Experimental intervention process.

Week	Process	Content
3	Experimental intervention	3D printer and CNC machine introduction
		Drawing program implementations
		Curriculum knowledge
		STEM knowledge
4	Experimental intervention	Designing materials (playing cards) on 3D printer and CNC machine (visual design)
		Determining outcomes in STEM (message design)
		Preparing a lesson plan within the scope of STEM (message design)
		Activities for materials developed within the scope of STEM (implementation)
5	Experimental intervention	Designing materials (fishing) on 3d printer and CNC machine (visual design)
		Determining outcomes in STEM (message design)
		Preparing a lesson plan within the scope of STEM (message design)
		Activities for materials developed within the scope of STEM (implementation)
6	Experimental intervention	Designing material (bird house) on 3d printer and CNC machine (visual design)
		Determining outcomes in STEM (message design)
		Preparing a lesson plan within the scope of STEM (message design)
		Activities for materials developed within the scope of STEM (implementation)
7	Experimental intervention	Designing material (car) on 3D printer and CNC machine (visual design)
		Determining outcomes in STEM (message design)
		Preparing a lesson plan within the scope of STEM (message design)
		Activities for materials developed within the scope of STEM (implementation)
8	Experimental intervention	Designing material (balance scales) on 3D printer and CNC machine (visual design)
		Determining outcomes in STEM (message design)
		Preparing a lesson plan within the scope of STEM (message design)
		Activities for materials developed within the scope of STEM (implementation)

The experimental interventions in Table 1 lasted six weeks, and the study period lasted a total of nine weeks. The experimental intervention contents are given in Table 2.

When Table 2 is examined, it is seen that in the first week of the experimental interventions, each lasting three hours, the technological tools planned to be used by the preservice teachers during the process were introduced theoretically and practically (Tool1: 3D printer, Program1: Tinkercad and Ultimaker Cura; Tool2: CNC laser cutting machine, Program2: Inkscape and Laserwork). In addition, an information phase was included for the integration of the achievements to be determined for addressing STEM disciplines through the curriculum in line with the materials designed in the education process. Information notes were also shared for the use of the tools. In the following weeks, it is seen that the experimental interventions included the sub-dimensions of the SSTMU. Since the sub-dimensions of the scale were taken into consideration in each week during the experimental intervention process, the interview questions were also created based on this context. During the experimental intervention process, the preservice teachers were followed by the researchers and guidance was provided to the preservice teachers in cases where help was needed, such as the usage phase of the machines (e.g., making the printing settings of the 3D printer, changing the 3D printer filament, and making the cutting settings on the CNC laser cutting machine). The thoughts of the participants based on their experiences in the visual and message design stages and the implementation stages after the experimental intervention and the reasons why these thoughts changed for each stage were explained.

Figure 1. Some sections from the material development process of preservice teachers.

Some concrete materials prepared using a 3D printer are shown in Figure 2, and the materials prepared using a CNC machine are in Figure 3.

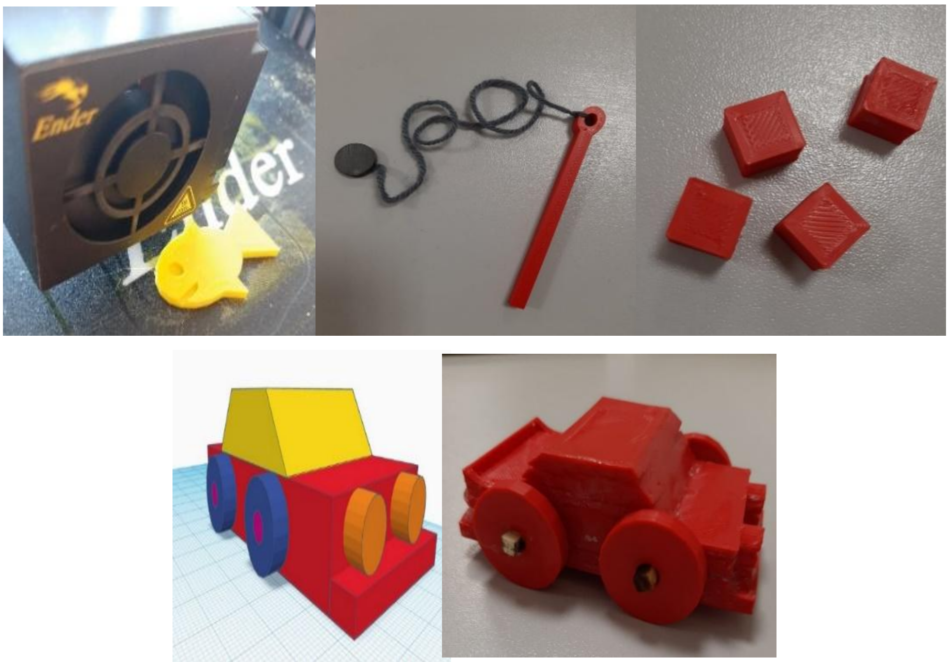

Figure 2. Materials prepared with 3D printer (a yellow fish, a fishing rod, game cubes, a car model).

Figure 3. Materials created with a CNC machine (playing cards with animal figures, colorful fish motifs, balance scales, car model and bird house).

Figures 2 and 3 show examples of participants' practices such as playing cards, fishing, birdhouses, cars, and balance scales. It was decided that these materials could be used to address the following: creating patterns with objects and shapes, recognizing plants and animals (classifying living things); distinguishing between living and non-living things, distinguishing between dirty and clean (environmental pollution), life in water, using magnets; distinguishing between living and non-living things, protecting animals, bird care; smooth and rough ground, touching, feeling the structure of the texture, movement; number sense, and balance. While determining the types of prepared materials, attention was paid to their suitability for preschoolers and their applicability. The feasibility of the determined teaching materials with a 3D printer and CNC laser cutting machine was examined with preservice teachers. The preservice teachers benefited from the preschool education program in terms of the message, visuality and usefulness of the material in determining the features that the materials could have. The preschool education program has been an important resource for preservice teachers in providing examples of materials for preschool students and clues about which outcomes these materials can be used with.

2.4. Data analysis

In order to determine the intervention status, descriptive and content analysis of the data collected with ISEF and DIEF was conducted. The data summarized and interpreted descriptively were subjected to content analysis [61] and themes and subthemes were created. The researchers and two field experts (a mathematics educator and a science educator) performed the analyses on the codes and themes and discussed the consistency of the codes and themes and reached a consensus. The themes created were structured based on the sub-dimensions of the scales. The researchers discussed the consistency of the codes and themes with the experts who performed the analyses on the codes and themes. Miles and Huberman [62] calculate this similarity, which they call internal consistency and conceptualize as consensus between coders, using the formula: $\Delta = C \div (C + \partial) \times 100$. In the formula, Δ: Reliability coefficient, C: Number of topics/terms on which consensus was reached, ∂: Number of topics/terms on which consensus was not reached. According to the coding audit that provides internal consistency, the consensus between the coders was found to be 95%. After the necessary arrangements, the final version of the codes and themes mentioned in the findings section was given. In other words, the codes were determined as the design of the material (message design and visual design) and its use, and the appropriate measurement tool was researched. The appropriate measurement tool was determined as SSTMU, and the pre-test and post-test scores of the measurement tool were determined. In the normality test conducted in the study to determine whether the data showed a normal distribution, when the Shapiro-Wilk values [63] used in cases with a sample size of less than 35 were examined, it was concluded that the quantitative data were not normally distributed ($p < .05$). For this reason, Wilcoxon signed-rank test was used in pre-test-post-test comparisons.

3. Results

3.1. Results regarding the sub-problem “What are the thoughts of preservice teachers about the materials developed with a 3D printer and a CNC machine to be used in STEM education before the intervention?”

Participants' pre-intervention thoughts on the materials developed on the 3D printer and CNC machine for use in STEM teaching are given in Table 3.

Table 3. Participants' thoughts on materials developed on 3D printers and CNC machine for use in STEM teaching.

Theme	Sub-theme	f
Personal competence	Lack of knowledge about material design on 3D printers and CNC machine	12
	Lack of knowledge on how to use materials designed on 3D printers and CNC machine in STEM teaching	8
	Lack of knowledge about the program/software to be used (Tinkercad, Ultimaker Cura, Inkscape, Laserwork)	7
	Belief in the difficulty of design stages	4
	Lack of experience with material design on 3D printer and CNC machine	9
	They do not have analytical thinking	5
Usability of materials	Contains a lot of variety	6
	A single material serves different disciplines	5
	Making materials more eye-catching	5
	A single material provides different perspectives	4
	Materials are very important in concretization	11
	Increasing interest in the lesson	5
	Being eye-catching	6

When Table 3 is examined, it is seen that the participants' thoughts before the intervention are gathered under the themes of personal competencies and usability of materials. Participants mostly stated that they do not have experience and knowledge about materials that can be developed on 3D printers and CNC machines. In addition, participants stated that they do not know how to use the materials they designed within the scope of STEM and how to relate them. It is also seen that they have beliefs about the difficulty of the design phase (i.e., the use of technology). In other words, it is seen that they stated that their self-efficacy is not sufficient in the processes of designing and implementing materials prepared with 3D printers and CNC machines. Additionally, some participants combined these negative statements with a lack of analytical thinking. Before the intervention, participants also stated that the materials are very important in concretization, are eye-catching, contain variety, increase interest in the lesson, a single material can serve different disciplines, making materials more eye-catching, and that a single material provides different perspectives.

3.2. Results regarding the sub-problem “Does the intervention affect the self-efficacy of preservice teachers in using educational materials?”

The Wilcoxon signed-rank test results for the pre-test and post-test scores of the self-efficacy scale for teaching material utilization of participants are given in Table 4.

Table 4. Wilcoxon signed-rank test results for pre-test and post-test scores.

Sub-dimension	Post-test-Pre-test	N	$\bar{X}$	Mean rank	Sum of ranks	Z	p
Message design	Negative ranks	5	37.50	8.20	41.00	-1.682	.093
	Positive ranks	12	40.44	9.33	112.00		
	Ties	1					

Usage	Negative ranks	3	22.78	6.00	18.00	-2.595	.009*
	Positive ranks	13	25.33	9.08	118.00		
	Ties	2					
Visual design	Negative ranks	3	28.22	10.17	30.50	-1.680	.093
	Positive ranks	12	29.94	7.46	89.50		
	Ties	3					
Total	Negative ranks	5	88.50	6.00	30.00	-2.208	.027*
	Positive ranks	12	95.72	10.25	123.00		
	Ties	1					

*p<.05

When Table 4 is examined, it is seen that according to the Wilcoxon signed-rank test results of the pre-test-post-test total scores of the self-efficacy scale for using teaching materials, a significant difference was detected in favor of positive ranks, that is, post-tests (Z = -2.208, p = .027). When each sub-dimension was examined, a significant difference was detected in favor of positive ranks, that is, post-tests, in the usage sub-dimension (Z = -2.595, p = .009), while an increase was detected in favor of the post-test in the message design and visual design sub-dimensions, but this increase was not significant (Z = -1.682, p = .093; Z = -1.680, p = .093).

3.3. Results regarding the sub-problem "How did the intervention affect the views of preservice teachers on the design stage?"

The themes and sub-themes show how the participants' views on the message design and visual design stages were affected after the intervention are given in Table 5.

Table 5. Indicators of how the intervention affected participants' views on the design stages.

Week	Process	Sub-dimension	Theme	Sub-theme	f
3-8	Experimental intervention	Message design	Compliance with teaching principles	Creating concrete materials with the 3D printer and CNC machine	11
				Ability to move from simple to complex structures with the prepared materials	4
				The prepared materials include the principle of near to far	3
				Ensuring materials are suitable for the age group	6
			Reflection of content	It's being materials that support STEM teaching	9
				It can be integrated into different fields because it supports STEM teaching	7
			Formal compliance	Being touchable	6
				The colors are attractive	7
				Visual dimensions can be fully adjusted with the 3D printer and CNC machine	4
			Parallelism with the method	Associating the materials prepared with 3D printers and CNC machine with different methods (such as drama, games, collaboration)	2
				Permanence of learning by establishing a	3

		method-material relationship	
Visual design	Designing visuals more understandable	Better understanding of the visuals as they use their subjective ideas during the drawing and painting phase	7
		Materials can be designed to be more understandable depending on the preferences of the children	6
	Ability to update material	Updating materials within the STEM framework and with technology support	9
		Ability to configure current materials with the 3D printer and CNC machine	11
	Making choices that are appropriate to the content	Determination of material according to outcomes	3
		Being able to decide which outcome the material will serve	4
		Using up-to-date material in lesson plans	3
Personal competence	Competence in the field	Gaining competence in creating concrete materials	8
		Gaining competence in preparing STEM materials	7
	Design competence	Gaining the ability to make drawings	7
		Gaining analytical thinking	4
		Creativity enhancement	3
		Gaining competence in the programs used	5

When Table 5 is examined, it is seen that the intervention was effective in the participants' views on the design dimensions; message design and visual design, and in addition to these, on their personal competencies. The themes of message design; compliance with teaching principles, reflection of content, formal compliance, and parallelism with the method were formed based on the participant expressions. Creating concrete materials with the 3D printer and CNC machine was mainly stated. This situation was stated by the participants as follows:

P7: "It is very important for this age group that the materials are concrete, especially, it would be good to think that they will take part in the designing, painting, that is, the process. We can also use these materials when moving from concrete to abstract."
P8: "These are actually simple plastics, but we produced better materials with CNC machine and 3D printers, which are much more suitable for the child's age and much more useful."

In addition, the participants stated that they designed visuals more understandably, were able to update the material and make choices appropriate to the content in the visual design after the intervention. Being able to configure current materials with CNC machine and 3D printers was mainly stated. This situation was stated by the participants as follows:

P1: "I didn't know anything about CNC and 3D printing, I was scared, but in the process, I saw that I could make the material I wanted in a more up-to-date form, and I could

apply it."
P3: "In fact, these are materials that have been used for years, but when we include technology, it seems more current and functional to me."

In addition to visual design and message design, it is observed that preservice teachers expressed that they felt competent after the intervention for these designs. This competence is varied as competence in the field and design and is mainly expressed as preparing concrete materials for STEM with the help of 3D printers and CNC machines. In addition, the participants stated that they gained analytical thinking skills as a result of the practices they did.

3.4. Results regarding the sub-problem "How did the intervention affect the views of preservice teachers on the usage stage?"

The themes and sub-themes showing how the participants' views on the stages of using the materials after the intervention was affected are given in Table 6.

Table 6. Indicators of how the intervention affected the participants' views on the stages of use of materials developed with 3D printers and CNC machines.

Week	Process	Sub-dimension	Theme	Sub-theme	f
3-8	Experimental intervention	Usage	Using for evaluation	As STEM is holistic, it includes process evaluation	6
				Ensuring that the evaluation is skill-focused	4
				Allows observation of early age groups	5
			Using in lesson plan	Functional use in prepared plans	6
				There is no difficulty in the lesson plan as it supports STEM outcomes	3
			Using for motivation	Increasing the desire to participate in activities	7
				Making their presence in the process sustainable	6
				Easy motivation because it attracts attention	7
			Using to attract attention	It's fun	11
				Can be structured to attract attention	8
		Personal competence	Competence in the field	Effective preparation of lesson plans	7
				Establishing relationship the outcome in STEM	5
			Competence for use	Competence in preparing and using STEM outcomes	6
				Competence in individually preparing and using materials developed with the 3D printer and CNC machine	9

When looking at Table 6, it is seen that the intervention affected the participants in terms of the use of materials prepared with 3D printers and CNC machines and in terms of personal competences.

The participants stated that the themes created for the use dimension included the lesson plan stages. These stages also constitute the themes and emerge as evaluation, motivation, attracting attention and use in the lesson plan after the coding made depending on the participants' statements.

It is observed that the participants stated that their personal competences increased after the intervention and that this was both in their field (preschool teaching) and in terms of usage. It is stated by the participants that they gained competence in individually preparing and using materials developed mainly with the 3D printer and CNC machine. The participants expressed their thoughts as follows:

P6: "At first, I thought I wouldn't be able to do it. It was very difficult, but the process was both fun and educational. Now I can prepare and use my individual materials."
PS7: "I had a hard time but then I realized that I could do it and that I have developed personally in this business and that will be useful for me."

3.5. Results regarding the sub-problem "How did the intervention affect the preservice teachers' lesson plan preparation process?"

The themes and sub-themes showing how the materials developed by the participants after the intervention affected the views of participants on the lesson plan preparation processes are presented in Table 7.

Table 7. Indicators of how the intervention affected the participants' views on the lesson plan preparation processes of the materials developed with 3D printers and CNC machines.

Week	Process	Sub-dimension	Theme	Sub-theme	f
3-8	Experimental intervention	Preparing a lesson plan	Making choices according to the principles of teaching	Ability to create concrete materials with the 3D printer and CNC machine	9
				Ability to move from simple to complex structures with prepared materials	6
				The prepared materials include the principle of near to far	4
				Ensuring materials are suitable for the age group	11
			Making choices according to the method	Ability to associate materials prepared with the 3D printer and CNC machine with different methods (such as drama, games, collaboration)	4
				Learning becomes permanent because it establishes a method-material relationship	4
			Making choices	Updating materials within the	10

	according to the currency of the material	STEM framework and with technology support	
		Ability to configure current material with the 3D printer and CNC machine	10
	Making choices that are suitable to the content	Determination of material according to outcomes	4
		Being able to decide which gain the material will serve	5
		Being able to decide which area (cognitive, psychomotor, affective) the material will serve	5
	Making choices suitable for the evaluation process	Materials serve for evaluation	6
		Evaluation should be process-oriented, not outcome-oriented	7

When Table 7 is analyzed, it is seen that the intervention affected the participants' lesson plan preparation process in the themes of making choices in accordance with the teaching principles, making choices in accordance with the method, making choices in accordance with the currency of the material, making choices in accordance with the content, and making choices in accordance with the evaluation process.

Under the theme of making choices in accordance with teaching principles, it is stated by the participants that they gained the competence to create concrete materials with the 3D printer and CNC machine, and that they were able to integrate the prepared materials into the lesson plan in terms of including the principle of simple to complex and near to far. It is also stated that since there are materials suitable for the age group under this theme, integration into the lesson plan is easy. Under the theme of making appropriate choices according to the method, the participants stated that the materials prepared with 3D printer and CNC machine supported the acquisition of the ability to associate with different methods (such as drama, game, cooperation) and that this ensured that the learning was permanent due to the method-material relationship.

In the theme of making a choice in accordance with the actuality of the material, the updateability of the materials thanks to STEM with the support of technology and the ability to create current materials thanks to CNC machine and 3D printers came to the fore. In the theme of choosing according to the content, the participants stated that they were able to determine the material according to the outcome, to decide which outcome and which area (cognitive, psychomotor, affective) it would serve with the development in the lesson plans. In the theme of making appropriate choices for the evaluation process, it is stated that the materials can serve the evaluation and that they can realize that the evaluation is process-oriented rather than result-oriented with the lesson plans.

> *P4: "Lesson plans were very difficult at the previous stage, but in the process, I realized that I could use them both in the introduction to the lesson and in the evaluation. I think there was an improvement compared to the first lesson plans I prepared because I was able to decide which material was suitable for which outcome.*

P5: "I had a hard time, but then I saw that I could establish the relationship between the stages in the lesson plan. How do I prepare which material for which outcome? Until the last week, I realized that different materials could serve different areas - psychomotor for example - and the lesson plans had a big impact."

4. Discussion and conclusions

In this study, which was conducted to examine the development processes of materials developed by preservice preschool teachers using 3D printers and CNC machines, an increase was observed in the participants' self-efficacy scores for teaching material utilization after the implementation. While this increase was significant in the usage sub-dimension, it was not significant in the message design and visual design sub-dimensions. When the pre- and post-implementation opinions of the preservice teachers were examined, it was observed that they could reflect the information they learned in the areas of message design (compliance with teaching principles, reflection of content, formal compliance and parallelism with the method), visual design (designing visuals more understandable, ability to update material, making choices that are appropriate to the content) and usage (using for evaluation, using in the lesson plan, using for motivation, using to attract attention) with their own expressions and could present it with their competencies (competence in the field, design competence, competence for use). The qualitative findings obtained from the research also support the increase obtained from the scale and in favor of the post-test. Before the implementation, the preservice teachers'; It was determined that the views of the participants such as containing variety, serving the knowledge of different disciplines with a single material, concretization, increasing interest and being eye-catching evolved towards the perspective of usability of materials that can be developed on 3D printers and CNC machines in STEM teaching after the implementation. The participants expressed their thoughts in detail in their views on the materials they developed during the implementation.

The preservice teachers stated that they will be able to ensure skill-based evaluation thanks to the material usage and that they will be able to benefit from this process in the evaluation stages since it allows the opportunity to observe students at an early age. It was stated that material usage can be used in lessons because it is also functional and supports STEM outcomes; it increases students' desire to participate in the activities, provides sustainability, attracts attention and motivating; it is fun and allows establishing, preparing, and using STEM materials. There are various studies [15,37,64–66] addressing the benefits of 3D printers integrated into the educational process and the materials produced with this technology (making the abstract concrete, providing interaction with concretization, attracting students' attention, providing design skills, providing the subjects planned to be taught, providing ease of learning, providing material support for the learning process). In the lesson plans examined as data sources, it was observed that the preservice teachers included these technologies in the teaching-learning environment by considering their benefits, and that they were able to address features such as the principles of teaching, method, currency of the material, and content knowledge that should be considered in the material design process. These findings also give an important idea about how to integrate the 3D printer and CNC machine into the teaching process. In addition, when the materials developed by the preservice teachers during the process were examined, it was observed that they dealt with various science and mathematics concepts (e.g., living things, balance, and numbers), prepared an environment for STEM teaching, and tried to attract attention visually, as well as that as a result, these materials were appropriate for the age group of children.

Another remarkable result of the study is that the score increases in the usage dimension related to the use of materials produced with 3D printers and CNC machines are significant; however, the increase in the design dimension expressing design is not significant. It can be implied that the preservice teachers believe that the use of ready-made materials can make the course easier. However, it is also reflected in the results that they see designing the materials themselves as a challenge. The preservice teachers' views show that they initially felt fear and anxiety about the implementation process. However, they observed an improvement in themselves as the process progressed. As a result of the implementation, it can be suggested that despite the personal competencies gained regarding the design process, the perceptions of inadequacy that are estimated to have formed in the minds of the preservice teachers and the beliefs regarding the difficulty of the design process continued, which caused the increase in the post-test scores to be insignificant. 3D printed educational materials have both advantages and disadvantages. These disadvantages include the need for knowledge and experience of the individuals who design the educational materials and the emergence of printing errors during the part production process [66]. A similar situation can also occur in implementations made with CNC machines (design errors, technical errors, etc.). It can be thought that the difficulties encountered by preservice teachers may negatively affect the efficiency of the material production process. However, when viewed from the student's perspective, it can be suggested that the errors that may be encountered in the production process cause students to learn faster and be more determined [67]. For preservice teachers, this result can be explained by the fact that creativity is negatively affected by age factor [68] and that students are more willing to take risks [69]. In line with the information obtained, although there was an increase in self-efficacy scores, the fact that it was not significant may be due to the disadvantageous situations encountered by the preservice teachers while using the 3D printer and CNC machine in the design process and the fact that they were new to this process may have caused them to approach these situations with prejudice. In addition, as another source of prejudice, it can be implied that preservice teachers think that they can design the teaching materials they want with simple materials. Because the Preschool Education Program usually suggests the use of materials such as paper, cardboard, fabric, etc. in the example activities. Considering the idea that technology integration contributes significantly to the improvement of employee performance and can encourage innovation and productivity in fresh graduated adults [70], it can be suggested that the use of technology plays an important role in supporting the knowledge and skills required for the teaching process and in producing appropriate materials that can be used in the teaching process. In addition, the more the preservice teacher is exposed to this process, the more they can increase their self-efficacy for teaching material utilization. In this context, they would not feel unfamiliar with the integration of these technologies into teaching activities. In line with the quantitative and qualitative findings, it can be concluded that materials developed with 3D printers and CNC machines can be used in STEM teaching and will facilitate teachers' acquisition of knowledge and skills appropriate to the subjects to be taught [71].

The study is limited to 18 preservice preschool teachers, the data collection tools used, and the planned experimental process (material development training with 3D printers and CNC machines, presentation of material samples suitable for preschool education level that are thought to support STEM achievements, the process of developing materials with 3D printers and CNC machines). A control group could not be created due to the small number of preservice teachers who volunteered. The generalizability of the results is debatable.

4.1. Recommendations

In order to develop materials suitable for the achievements with 3D printers and CNC machines to be used in the teaching of STEM disciplines, training activities can be carried out with both preservice teachers and teachers. The effects of materials to be developed with 3D printers and CNC machines on the teaching of relevant subjects and the 21st century skills planned to be acquired can be investigated. Training in designing materials with 3D printers and CNC machines can be organized for preservice teachers and teachers. In this way, the number of preservice teachers and teachers with knowledge and skills on these educational technologies can be increased. An enriched environment can be created with materials developed with 3D printers and CNC machines for children in early childhood. In addition to providing learning outcomes and motivation in the teaching process, research can be conducted on the use of materials developed with 3D printers and CNC machines as a tool for measurement and evaluation in STEM education. Research on materials developed with 3D printers and CNC machines can be designed not only with preschool preservice teachers but also with study groups with different characteristics (e.g., age, gender, and department). The training period can be extended to cope with the difficulties encountered during the design and production process. In this way, the time to acquire knowledge and experience can be extended.

Author contributions

All authors have played an equal role in all processes of the article. All authors have read and approved the final version of the study.

Use of generative-AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare that there is no conflict of interest with any institution or person within the scope of the study.

Ethics declaration

This study was conducted with the approval of the Akdeniz University Social and Human Sciences Scientific Research and Publication Ethics Committee (Protocol No. 2022/401) at its meeting dated 07.11.2022 and numbered 19.

References

1. Nithyanandam, G.K., A framework to improve the quality of teaching-learning process-A case study. *Procedia Computer Science*, 2020, 172: 92–97. https://doi.org/10.1016/j.procs.2020.05.013

2. Campbell, C.P., Instructional materials: Their preparation and evaluation. *Journal of European Industrial Training*, 1999, 23(2): 57–107. https://doi.org/10.1108/03090599910257515
3. Toledo-Figueroa, D., Révai, N. and Guerriero, S., Teacher professionalism and knowledge in qualifications frameworks and professional standards. In *Pedagogical knowledge and the changing nature of the teaching profession*, 2017, 73–95. OECD Publishing.
4. Kavak, Ş. and Coşkun, H., Erken çocukluk eğitiminde eğitici materyal geliştirmenin önemi (Turkish) [The importance of educational material development in early childhood education]. *International Journal of Early Childhood Education Studies*, 2017, 2(2): 11–23.
5. Çetin, M. and Demircan H.Ö., STEM education in early childhood. *Inonu University Journal of the Faculty of Education*, 2020, 21(1): 102–117. https://doi.org/10.17679/inuefd.437445
6. Ying, L. and Luen, L.C., Exploring effective pre-service teacher training methods: An analysis based on learner motivation and experience. *International Journal of Academic Research in Business and Social Sciences*, 2024, 14(8): 2582–2593. http://dx.doi.org/10.6007/IJARBSS/v14-i8/22243
7. Stohlmann, M., Moore, T.J. and Roehrig, G.H., Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research (J-PEER)*, 2012, 2(1): 28–34. https://doi.org/10.5703/1288284314653
8. Cai, R. and Chiang, F.K., A laser-cutting-centered STEM course for improving engineering problem-solving skills of high school students in China. *STEM Education*, 2021, 1(3): 199–224. https://doi.org/10.3934/steme.2021015
9. Lyon, E.G., Kochevar, R. and Gould, J., Making it in undergraduate STEM education: The role of a maker course in fostering STEM identities. *International Journal of Science Education*, 2023, 45(11): 946–967. https://doi.org/10.1080/09500693.2023.2179376
10. Mun, K., Aesthetics and STEAM education: The case of Korean STEAM curricula at the art high school. *International Journal of Science Education*, 2022, 44(5): 854–872. https://doi.org/10.1080/09500693.2021.2011467
11. Trujillo-Cayado, L.A., Santos, J., Cordobés, F. and Ramos-Payán, M., Influence of the use of 3D printing technology for teaching chemistry in STEM disciplines. *Computer Applications in Engineering Education*, 2024, 24: e22738. https://doi.org/10.1002/cae.22738
12. Aslan, A. and Çelik, Y., A literature review on 3D printing technologies in education. *International Journal of 3D Printing Technologies and Digital Industry*, 2022, 6(3): 592–613. https://doi.org/10.46519/ij3dptdi.1137028
13. Ford, S. and Minshall, T., *Where and how 3D printing is used in teaching and education*, 2019. https://doi.org/10.17863/CAM.35360
14. Jones, L.C.R., Tyrer, J.R. and Zanker, N.P., Applying laser cutting techniques through horology for teaching effective STEM in design and technology. *Design and Technology Education*, 2013, 18(3): 21–34.
15. Schelly, C., Anzalone, G., Wijnen, B. and Pearce, J.M., Open-source 3-D printing technologies for education: Bringing additive manufacturing to the classroom. *Journal of Visual Languages & Computing*, 2015, 28: 226–237. https://doi.org/10.1016/j.jvlc.2015.01.004
16. Uğur, E. and Özsoy, S.A., infrastructure studies for the use of CNC router in printing and publication technologies program workshop applications. *Journal of Current Researches on Social Sciences*, 2018, 8(4): 47–62.

17. Yıldırım, G., Teachers' opinions on instructional use of 3D printers: A case study. *International Online Journal of Educational Sciences,* 2018, 10(4): 304–320. https://doi.org/10.15345/iojes.2018.04.017
18. Chesloff, J.D., STEM education must start in early childhood. *Education Week,* 2013, 32(23): 27–32.
19. Ministry of National Education [MoNE], *Okul öncesi eğitim programı* (Turkish) [*Pre-school education programme]*, 2013. Available from: https://mufredat.meb.gov.tr/Dosyalar/20195712275243-okuloncesi_egitimprogrami.pdf
20. Tekin, G. and Özkaya, B.T., Çocuk ve oyun: Çocukların öğrenmesini anlama ve destekleme (Turkish) [Children and play: Understanding and supporting children's learning], (eds. N. Avcı, & M. Toran), in *Okul öncesi eğitime giriş* [*Introduction to preschool education]* (pp. 123–150), Eğiten Bookstore, 2012.
21. Kıldan, A.O., Preschool education settings. *Kastamonu Education Journal,* 2007, 15(2): 501–510.
22. Stueck, L.E., *The design of learning environments* [Doctoral dissertation]. University of Georgia, 1991.
23. Moomaw, S., *Teaching STEM in the early years: Activities for integrating science, technology, engineering, and mathematics*. Redleaf Press, 2013.
24. Campbell, C., Speldewinde, C., Howitt, C. and MacDonald, A., STEM practice in the early years. *Creative Education,* 2018, 9(1): 11–25. https://doi.org/10.4236/ce.2018.91002
25. Erol, A. and İvrendi, A., Erken çocuklukta STEM eğitimi (Turkish) [STEM education in early childhood]. *Journal of Early Childhood Studies,* 2021, 5(1): 255–284. https://doi.org/10.24130/eccd-jecs.1967202151265
26. Acer, D., A study on the viewpoints of preschool teacher candidates on design of instructional materials course. *Elementary Education Online*, 2011, 10(2): 421–429.
27. California Department of Education., *Visual and performing arts framework: For California public schools: Kindergarten through grade twelve,* 2004. Available from: https://files.eric.ed.gov/fulltext/ED483686.pdf
28. Szyba, C.M., Why do some teachers resist offering appropriate, open-ended art activities for young children? *Young Children*, 1999, 54(1): 16–20.
29. Çiftçi, A., Topçu, M.S. and Foulk, J.A., Pre-service early childhood teachers' views on STEM education and their STEM teaching practices. *Research in Science & Technological Education,* 2022, 40(2): 207–233. https://doi.org/10.1080/02635143.2020.1784125
30. Johnson, C.C., Implementation of STEM education policy: Challenges, progress, and lessons learned. *School Science and Mathematics,* 2012, 112(1): 45–55. https://doi.org/10.1111/j.1949-8594.2011.00110.x
31. Sanders, M., STEM, STEM education, STEMmania. *The Technology Teacher,* 2009, 68(4): 20–26.
32. de Putter-Smits, L.G., Taconis, R., Jochems, W. and Van Driel, J., An analysis of teaching competence in science teachers involved in the design of context-based curriculum materials. *International Journal of Science Education,* 2012, 34(5): 701–721. https://doi.org/10.1080/09500693.2012.656291
33. Akgündüz, D., Aydeniz, M., Çakmakçı, G., Çavaş, B., Çorlu, M.S., Öner, T., et al., *STEM education Turkey report*. Scala Publishing, 2015.

34. Coenders, F., *Teachers' professional growth during the development and class enactment of context-based chemistry student learning material* [Doctoral dissertation], Twente University, 2010. http://dx.doi.org/10.3990/1.9789036530095
35. Krajcik, J.S., Blumenfeld, P.C., Marx, R.W. and Soloway, E., A collaborative model for helping middle grade science teachers learn project-based instruction. *The Elementary School Journal*, 1994, 94(5): 483–497. https://doi.org/10.1086/461779
36. Lange, A.A., Brenneman, K. and Mano, H., *Teaching STEM in the preschool classroom: Exploring big ideas with 3-to 5-year-olds*, Teachers College Press, 2019.
37. Kökhan, S. and Özcan, U., Use of 3D printers in education. *Science Education Art and Technology Journal*, 2018, 2(1): 81–85.
38. Ramaley, J., *Facilitating change: experiences with the reform of STEM education*, 2007. Available from: www.researchgate.net/publication/239923463
39. Ministry of National Education [MoNE], *Okul öncesi eğitim programı* (Turkish) [*Pre-school education programme]*, 2024. Available from: https://tegm.meb.gov.tr/dosya/okuloncesi/guncellenenokuloncesiegitimprogrami.pdf
40. Bandura, A., Self-efficacy: Toward a unifying theory of behavioural change. *Psychological Review*, 1977, 84(2): 191–215. https://doi.org/10.1037/0033-295X.84.2.191
41. Ryan, R.M. and Deci, E.L., Intrinsic and extrinsic motivations: Classic definitions and new directions. *Contemporary Educational Psychology,* 2000, 25(1): 54–67. https://doi.org/10.1006/ceps.1999.1020
42. Timms, C. and Brough, P., "I like being a teacher" Career satisfaction, the work environment and work engagement. *Journal of Educational Administration*, 2013, 51(6): 768–789. https://doi.org/10.1108/JEA-06-2012-0072
43. Collie, R.J., Shapka, J.D. and Perry, N.E., School climate and social–emotional learning: Predicting teacher stress, job satisfaction, and teaching efficacy. *Journal of Educational Psychology*, 2012, 104(4): 1189–1204.
44. Hölscher, S.I., Gharaei, N., Schachner, M.K., Ott, P.K. and Umlauft, S., Do my students think I am racist? Effects on teacher self-efficacy, stress, job satisfaction and supporting students in culturally diverse classrooms. *Teaching and Teacher Education*, 2024, 138: 104425. https://doi.org/10.1016/j.tate.2023.104425
45. Klassen, R.M. and Chiu, M.M., Effects on teachers' self-efficacy and job satisfaction: Teacher gender, years of experience, and job stress. *Journal of Educational Psychology*, 2010, 102(3): 741–756.
46. Caprara, G.V., Barbaranelli, C., Borgogni, L. and Steca, P., Efficacy beliefs as determinants of teachers' job satisfaction. *Journal of Educational Psychology*, 2003, 95(4): 821–832.
47. Bahtilla, M. and Hui, X., The impact of school environment on teachers 'job satisfaction in secondary schools. *European Journal of Education Studies*, 2021, 8(7). http://dx.doi.org/10.46827/ejes.v8i7.3799
48. Korkmaz, O., Study of the validity and reliability of a self-efficacy scale of teaching material utilization. *Educational Research and Reviews*, 2011, 6(15): 843–853. https://doi.org/10.5897/ERR11.174
49. Kochhar, S.K., *The teaching of social studies*. Sterling Publishers Private Limited, 2012.
50. Lee, H.N., Son, D.I., Kwon, H.S., Park, K.S., Han, I.K., Jung, H.I., et al., Secondary teachers' perceptions and needs analysis on integrative STEM education. *Journal of the Korean Association for Science Education*, 2012, 32(1): 30–45.

51. Dağ, F. and Kırıkkaya, E.B., 8. sınıf doğal süreçler ünitesi için web tabanlı öğretim materyali hazırlığı: Farklı alan uzmanlarının materyal hakkındaki görüşleri (Turkish) [Preparation of web-based teaching materials for natural processes in 8th grade: Different views on the material of professionals]. *Education Sciences*, 2012, 7(1): 212–229. https://doi.org/10.12739/10.12739
52. McCullough, J. and McCullough, R., *The role of toys in teaching physics.* American Association of Physics Teachers, College Park, MD, 2000.
53. Thompson, G. and Mathieson, D., The mirror box. *Phys Teach*, 2001, 39(8): 508–509. https://doi.org/10.1119/1.1424606
54. Surif, J., Ibrahim, N.H. and Mokhtar, M., Implementation of problem-based learning in higher education institutions and its impact on students' learning, (eds. K. Mohd-Yusof, M. Arsat, M. T. Borhan, E. de Graaff, A. Kolmos, F. A. Phang), in *PBL across cultures.* Paper presented at Fourth International Research Symposium on PBL, 2013, Universiti Teknologi.
55. Osman, A. and Kriek, J., Science teachers' experiences when implementing problem-based learning in rural schools. *African Journal of Research in Mathematics, Science and Technology Education*, 2021, 25(2): 148–159. https://doi.org/10.1080/18117295.2021.1983307
56. Straw, S., MacLeod, S. and Hart, R., *Evaluation of the Wellcome Trust Camden STEM initiative*. NFER, Slough, 2012.
57. Wang, H.H., Moore, T.J., Roehrig, G.H. and Park, M.S., STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research* (J-PEER), 2011, 1(2): 1–13. https://doi.org/10.5703/1288284314636
58. Weber, E., Fox, S., Levings, S.B. and Bouwma-Gearhart, J., Teachers' conceptualizations of integrated STEM. *Academic Exchange Quarterly*, 2013, 17(3): 47–53.
59. Creswell, J.W. and Plano Clark, V.L., *Designing and conducting mixed methods research* (3rd ed.), Sage Publications, 2018.
60. Creswell, J.W. and Creswell, J.D., *Research design: Qualitative, quantitative, and mixed methods approach,* Sage Publications, 2017.
61. Yıldırım, A. and Şimşek, H., *Qualitative research methods in social sciences*. Seçkin Publishing, 2016.
62. Miles, M.B. and Huberman, A.M., *Qualitative data analysis: An expanded sourcebook*. Sage Publications, 1994.
63. Shapiro, S.S. and Wilk, M.B., An analysis of variance test for normality (complete samples). *Biometrika*, 1965, 52(3-4): 591–611. https://doi.org/10.2307/2333709
64. Brown, A., 3D printing in instructional settings: Identifying a curricular hierarchy of activities. *TechTrends*, 2015, 59(5): 16–24. https://doi.org/10.1007/s11528-015-0887-1
65. Güleryüz, H., Dilber, R. and Erdoğan, İ., Prospective teachers' views on 3D printer use in STEM. *Journal of Ağrı İbrahim Çeçen University Social Sciences Institute,* 2019, 5(2): 1–8. https://doi.org/10.31463/aicusbed.592061
66. Yavuz, İ., Yuran, A.F. and İkinci, F., Makine mühendisliği eğitiminde 3D yazıcılar ile yardımcı materyal tasarımı ve uygulaması (Turkish) [*Design and application of auxiliary materials with 3D printers in mechanical engineering education]*. In 4th International Congress On 3D Printing (Additive Manufacturing) Technologies and Digital Industry, 2019, Antalya, Türkiye. Available from: https://indexive.com/uploads/papers/pap_indexive15937958352147483647.pdf
67. Dickson, B., Weber, J., Kotsopoulos, D., Boyd, T., Jiwani, S. and Roach, B., The role of productive failure in 3D printing in a middle school setting. *International Journal of Technology and Design Education*, 2021, 31: 489–502. https://doi.org/10.1007/s10798-020-09568-z

68. Lau, S. and Cheung, P.C., Developmental trends of creativity: What twists of turn do boys and girls take at different grades? *Creativity Research Journal,* 2010, 22(3): 329–336. https://doi.org/10.1080/10400419.2010.503543
69. Galster, D.C., *The dissertation story: Effective behaviors and practices of principals that encourage and support teacher instructional risk-taking and innovation in high achieving middle schools* [Doctoral dissertation], Cardinal Stritch University, 2013.
70. Sitepu, J., Lumbanraja, P., Silalahi, A.S. and Siahaan, E., Teaching digital service skills and innovative behaviour to fresh graduates: An empirical analysis. *Novitas-ROYAL (Research on Youth and Language),* 2024, 18(2): 220–229. https://doi.org/10.5281/zenodo.13894294
71. Yılmaz, E., 21. yüzyıl becerileri kapsamında dönüşen okul paradigması (Turkish) [21st century skills in the context of transforming school paradigm], (eds. E. Yılmaz, M. Çalışkan & S. A. Sulak), in *Eğitim bilimlerinden yansımalar* [*Reflections from educational sciences]*, (pp.5–16). Çizgi Bookstore, 2016.

Author's biography

Dr. Sait Bulut is a professor of science education with Akdeniz University, Turkey. He focuses on STEM education research. He teaches university-level courses on interdisciplinary science education, material design for science education, instructional technologies, and environmental education.

Dr. Ali Özkaya is an Associate Professor at Akdeniz University Turkey in mathematics education with a strong research focus on STEM education. After completing his doctorate in realistic mathematics education, he continued to explore innovative and interdisciplinary approaches to teaching mathematics. His academic work spans topics such as mathematical modeling, digital games in education, and the integration of STEM activities into teacher training. He has led and contributed to multiple research projects examining the effects of STEM-based practices on students' mathematical reasoning, creativity, and attitudes.

Dr. Gözdegül Arık Karamık is an assistant professor of mathematics education with Akdeniz University, Turkey. She specializes in mathematics education with a strong focus on STEM-oriented instructional approaches. Her scholarly work prominently features interdisciplinary studies that combine mathematics, sustainability, technology, and creative pedagogies such as drama. Notably, she has contributed to STEM education through her research on the use of 3D printing in mathematics learning, sustainability-themed problem solving, and the integration of enriched learning environments for visually impaired students.

Dr. Gizem Şahin holds a Ph.D. in science education. Her research focuses on STEM education, engineering design process, 21st century skills, robotics and coding, educational technologies, environmental education practices, and teacher education. She has participated in training courses in related fields and obtained certifications. She has published numerous scientific papers and carried out various projects in these fields, and she is currently continuing her research.

Appendix: Self-efficacy scale items of teaching material utilization

Message design	1	I can design teaching materials that properly reflect the context.	1	2	3	4	5
	2	I can use figure-background color contrast in order to increase the understandability of the message in a teaching material.	1	2	3	4	5
	3	I can use the sizes of the visuals in order to create a sense of distance/closeness in a teaching material.	1	2	3	4	5
	4	When preparing teaching material, I can use texture in order to create a sense of realism of the visual.	1	2	3	4	5
	5	I can choose teaching materials conforming with the teaching principles such as arranging the content from concrete to abstract, from basic to complex.	1	2	3	4	5
	6	When designing teaching material, I can utilize sufficiently concrete visuals.	1	2	3	4	5
	7	I can select the teaching materials suitable for the teaching methods I use.	1	2	3	4	5
	8	When designing teaching material, I can make use of spaces in order to place emphasis on the message.	1	2	3	4	5
	9	I can design teaching materials suitable for the type of context (cognitive, affective, psychomotor, etc.).	1	2	3	4	5
	10	I can select the teaching materials that express the message to be given in the most explicit and short way possible.	1	2	3	4	5
Usage	11	I can use the information sources on the internet as teaching materials.	1	2	3	4	5
	12	I can sufficiently utilize teaching materials for evaluating students.	1	2	3	4	5
	13	When planning educational statuses, I can decide on which phase of the course I will use the material.	1	2	3	4	5
	14	I can sufficiently utilize teaching materials for motivating students.	1	2	3	4	5
	15	I can rearrange and use an already available teaching material.	1	2	3	4	5
	16	I can sufficiently utilize teaching materials in order to attract and maintain the attention of the students.	1	2	3	4	5
Visual design	17	I can select the teaching materials in which the visuals are designed in a more orderly and easily understandable way (where integrity is established).	1	2	3	4	5
	18	I can select the teaching materials in which the amount of information presented is suitable.	1	2	3	4	5
	19	When designing teaching material, I can properly utilize colors.	1	2	3	4	5

20	I can design up-to-date teaching materials in terms of context and visuals.	1	2	3	4	5
21	I can select the teaching materials with up-to-date context and visuals.	1	2	3	4	5
22	I can select the teaching materials suitable in terms of design elements such as texture, form-background, emphasize, line, size and space.	1	2	3	4	5
23	I can select the visuals in conformity with the type of context.	1	2	3	4	5