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3D PRINTING TECHNOLOGY IN EARLY CHILDHOOD EDUCATION: BRIDGING IMAGINATION AND PRACTICE THROUGH PRE- SERVICE TEACHER ENGAGEMENT

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ABSTRACT

This research aims to develop the competencies of preschool pre-service teachers in using 3D printer technologies in their educational processes and to increase the awareness of children towards this technology. In the study with a mixed-methods design, 10 pre-service teachers studying in the Preschool Teaching program at Trabzon University and 10 children studying in a kindergarten participated. During the implementation process, pre-service teachers were given 10 weeks of online design training; the pre-service teachers modelled the materials imagined by preschool children using the Tinkercad software, and these models were presented to the students after being produced with 3D printers. As data collection tools, the "Attitude Scale Towards the Use of 3D Printers by Pre-service Teachers" and open-ended interview forms for pre-service teachers and children, were used. In the analysis of quantitative data, the Wilcoxon signed-rank test was used, while the content analysis method was employed for the analysis of qualitative data. As a result of the research, it was determined that there was a significant increase in the attitudes of pre-service teachers towards 3D printer technology ($p < .05$). Additionally, pre-service teachers stated that this technology is important for solving material shortages, supporting creativity, and enriching learning processes in preschool education. Children, on the other hand, expressed that meeting 3D printers was exciting and that they felt pleased, confident, and creative when the toys they imagined came to life. In line with these findings, it has been concluded that 3D printer technology can be considered an innovative and functional learning tool for both teachers and students in preschool education.

Keywords: 3D Printing, Early Childhood Education, Pre-Service Teacher, Material Design, Educational Technology.

1. INTRODUCTION

1.1. 3D Printing in Education

3D printing, also known as additive manufacturing, is a digital fabrication process in which three-dimensional objects are created by adding material layer by layer according to a computer-generated model. Designs are typically developed using computer-aided design (CAD) software and then transferred to the printer, which fabricates the object using materials such as plastic, resin, or metal. In educational contexts, 3D printing enables the rapid production of customized learning aids, models, and interactive tools that help transform abstract concepts into tangible forms [1-2]. This technology has been increasingly integrated

into classrooms-from higher education to early childhood settings-due to its potential to foster creativity, problem-solving, and hands-on engagement [3].

1.2. 3D Printing in Early Childhood Education

Early childhood education (ECE) is increasingly seen as a valuable setting for using 3D printing to foster creativity and support teacher development. Based in constructivist learning theory [4] and experiential learning frameworks [5], this educational reform stresses the part of learners as active participants in building knowledge by tangible, meaningful interaction. In early childhood environments

where sensory experience and hands-on learning are central [6] offer a developmentally appropriate platform for promoting curiosity, problem-solving, and visual-spatial reasoning.

Recent studies stress the capabilities of 3D printers to overcome material shortages in classrooms while promoting STEAM-based instructional design [1-2]. However, most existing research has concentrated on middle or secondary education, with relatively few studies exploring the use of 3D printing in early childhood contexts [7-10]. The limited body of work in this area often focuses on short-term, isolated activities rather than comprehensive, curriculum-integrated approaches, leaving a significant gap in understanding how this technology can be systematically implemented to support young children's learning and creativity.

Using 3D printing technology to support children's creativity and improve pre-service preschool teachers' digital competencies requires a varied strategy combining technological innovation, effective instructional training, and a framework for developing children's imaginative capacity. According to Enochsson and Ribaeus [11], access to digital tools within preschools empowers children to express their ideas and collaborate more effectively with peers. By incorporating 3D printing into the preschool curriculum, children can visualize their concepts in tangible forms, enhancing their learning experience through interactive play and experimentation. Additionally, careful pedagogical approaches, including 3D printing in project-based learning environments, help children's learning results to match their digital literacy. According to Masoumi and Bourbour [12], teachers who view technology as a creative pedagogical tool contribute to a learning environment that fosters children's problem-solving abilities and innovation.

ECE's incorporation of digital technologies is of more and more importance to equip children to satisfy current educational needs. Different studies show that pre-service teachers must acquire sufficient digital competencies, which include not only technical skills but also pedagogical methods to properly use these technologies in the classroom [13-14]. Stepić et al. [14], underline that developing children's

digital literacy depends on a larger knowledge of the pedagogical value of technology, which is included within digital competency. Also, studies show how different the ICT instruction given to upcoming pre-service preschool teachers is from the skills needed in the real world, therefore stressing the need for improved curricula including practical experience with technologies like 3D printing [14-16].

ECE remains an understudied environment for its application even if increasing data suggest the educational value of 3D printing [3,17]. Most of the current work has focused on middle and secondary education levels or handled digital fabrication from a technical rather than pedagogical approach [18-19]. Furthermore, neglected in isolation from children's direct involvement is teacher training, so ignoring the possibility for mutual influence in collaborative design environments [13,20]. Few studies have examined how children's engagement with 3D printing technology can contribute to pre-service teachers' instructional development and foster the children's own creativity through the cooperative production of educational resources [3,7-8]. In addition, lacking is empirical research on integrated instructional models combining digital technology training for pre-service teachers with child-centred design principles in early childhood settings [7,21-22].

1.3. Digital Competencies of Pre-service Teachers

3D printing is also a necessary beginning for pre-service teachers to understand technology-enhanced learning. By means of digital fabrication projects, pre-service teachers (PSTs) acquire not only technical competence but also pedagogical insight, learning to create, implement, and evaluate learning aids that match various developmental needs [23-24].

Professional development programs emphasizing digital literacy might greatly help PSTs to embrace these new technologies. Farisia and Syafi'i [25] show that organized training encouraging cooperative contacts among teachers improves their capacities to produce digital content and apply creative teaching approaches. When PSTs work with instruments like 3D printers, these kinds of cooperative approaches can be quite helpful since they give chances for group problem-solving and creative design [26].

Schools and other educational organizations must work together if 3D printing is to be properly included in preschool education. Forsling [21] advises courses on successful technology integration as well as studies on the necessity of continuous professional development for instructors. In this atmosphere of continuous learning, pre-service teachers can become familiar with 3D printing technology and develop lesson plans that encourage children's creativity through practical projects. Including digital competency in official teacher preparation courses would provide future teachers with the necessary tools to properly utilize 3D printing technology [15]. Collaborations between colleges, teachers, and young children can help build comprehensive support systems from which both instructors and children can benefit from these digital advancements [27].

1.4. Research Gap and Aim of the Study

This study addresses the lack of integrated research on the use of 3D printing in early childhood education, particularly in terms of connecting PSTs' digital competencies with children's creative engagement. While previous studies have focused predominantly on secondary or higher education, there is a clear gap in systematic investigations of how 3D printing can be implemented in preschool contexts to support both teacher training and children's learning.

Therefore, the purpose of this study is to explore how the integration of 3D printing in early childhood education contributes to the development of pre-service preschool teachers' digital and pedagogical competencies, while simultaneously fostering creativity, engagement, and motivation among preschool children.

To achieve this purpose, the study seeks to address the following research questions:

- To what extent does participation in 3D printing projects change pre-service preschool teachers' attitudes toward 3D printer technology?
- What are pre-service teachers' perceptions, expectations, and experiences regarding the use of 3D printing in preschool education?

- How do preschool children perceive and experience the integration of 3D printing in their learning environment?

2. METHOD

In the study, a convergent parallel mixed methods design was preferred, using concurrent pre/post [28]. Quantitative (pre- and post-test attitude scale) and qualitative data (semi-structured interviews with PSTs and preschool children) were collected within the same application window, analyzed independently, and then combined through side-by-side comparison (and, where appropriate, with a joint representation) during the interpretation phase. This design choice aligns with the goal of simultaneously examining lived experiences, facilitating a more comprehensive understanding of the phenomenon. The research findings were interpreted from a more holistic perspective thanks to this mixed methods design [29].

2.1. Participants

The study group of the research consists of 10 third-year PSTs studying in the ECE Program at Trabzon University Faculty of Education and 10 children attending a kindergarten in Trabzon province. Purposive sampling methods were used for participant selection. In this context, the study included pre-service teachers who had no prior experience with 3D printing technologies but were willing to receive training in this area, as well as children aged 5-6 who were attending the same kindergarten. None of the PSTs had previously taken any courses or lessons related to 3D printer usage. Preschool children were selected from among volunteer students who were interested in technology and whose parents' approval was obtained for participation in the project. Ethical permissions and informed consent forms were obtained from all participants in the study.

2.2. Data Collection Tools

Different tools were used in the research to collect both quantitative and qualitative data.

2.2.1. Quantitative data collection tool

As a quantitative data tool, the "Attitude Scale Towards the Use of 3D Printers by Pre-service Teachers" was applied [30]. This scale consists of 18 items and is answered using a 5-point Likert type. The Cronbach's alpha reliability coefficient of scale was 0.94. The scale was

administered twice within the scope of the project, as a pre-test (before the training) and a post-test (after the training).

2.2.2. Qualitative data collection tool

Qualitative data were collected through semi-structured interview forms for PSTs and children. The interview form prepared for PSTs consists of seven open-ended questions aimed at determining the PSTs' level of knowledge, expectations, and opinions regarding 3D printers at the beginning of the project. The interview forms for PSTs and children were developed based on the study's research questions and a review of relevant literature on 3D printing in educational contexts. Draft versions were reviewed by two experts in early childhood education and one expert in educational technology to ensure content validity. The children's version was adapted to include age-appropriate language, simplified question structures, and visual prompts to facilitate understanding. Both versions were pilot-tested with a small sample (n=10) to identify ambiguities and refine wording before the main data collection phase. Among these questions, for example, "What do you know about 3D printer technology?" and "What are your views on the necessity of using 3D models in preschool education?" were included. Similarly, a five-question interview form suitable for the age level of preschool students has been prepared. In this form, children were asked questions such as "Is there a toy you wanted to play with but couldn't find anywhere?", "Do you know what a 3D printer is?", "Would you like to design a toy of your dreams with a 3D printer?" Additionally, at the end of the application, a six-question final interview form was used to evaluate the children's experiences after the project (e.g., "Did you like the design of your dream toy with the 3D printer?", "Did the toy that emerged turn out as you expected?").

2.3. Implementation

The research implementation was carried out step by step in a planned manner. Throughout the process, PSTs and children participated in activities simultaneously but at different levels. The implementation basically consisted of the following stages:

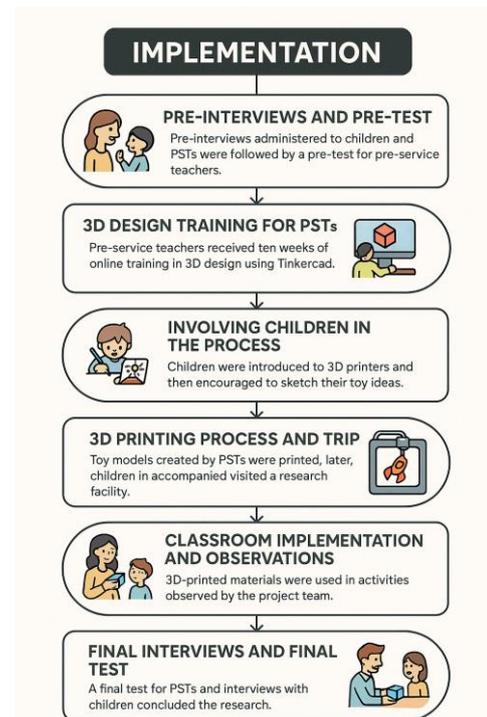


Figure 1. Implementation process

The process involving PSTa and students after the initial applications is detailed below:

Introduction and Idea Elicitation: Children were introduced to 3D printers using age-appropriate language and asked to draw their dream toy.

Hands-on Exploration: Children used 3D pens (under close supervision and in child-safe settings) to experience layered production and 3D thinking.

Digital Modeling by PSTs: During the 10-week training, PSTs translated children's drawings into printable Tinkercad models.

Fabrication and Exposure: Models were printed at the university lab; during a lab visit, children observed the printing process and examined the outputs.

Classroom Use and Observation: Printed materials were later used in classroom activities (e.g., math matching, storytelling), and researchers observed engagement and interactions.

2.3.1. Pre-Interviews and pre-test

In the initial stage, the project team visited the relevant preschool met with the children and asked pre-interview questions to them. The toys that the children dream of but cannot find, their level of knowledge about 3D printers, and their expectations were identified during this interview. In the same week, a meeting was held

with the PSTs, and a preliminary interview form was administered to them as well, recording their existing knowledge and attitudes towards 3D printers. Subsequently, a pre-test of the attitude scale towards 3D printers was administered to the PSTs.

2.3.2. 3D design training for PSTs

Online training sessions lasting 10 weeks have been conducted with PSTs. These trainings were conducted under the guidance of an expert from Karadeniz Technical University (from the field of Metallurgy and Materials Engineering). In the first session, the project was introduced, and the software to be used was decided upon. Participants were given a hands-on training on how to use the Tinkercad 3D modelling software and its basic commands. In the second session, "What materials can be designed? Which resources can be utilized? Which tools can be used?" questions were discussed, and material design processes for 3D printing were planned. In the third and subsequent sessions, various educational material designs were created, considering the achievements in the preschool education program. For example, models aimed at children's development, such as matching cards, geometric shapes, take-apart toys, and symmetry activities, have been designed. At the end of each session, the PSTs' designs were reviewed, the challenges they faced were discussed, and feedback was provided by an expert (Figure 2).

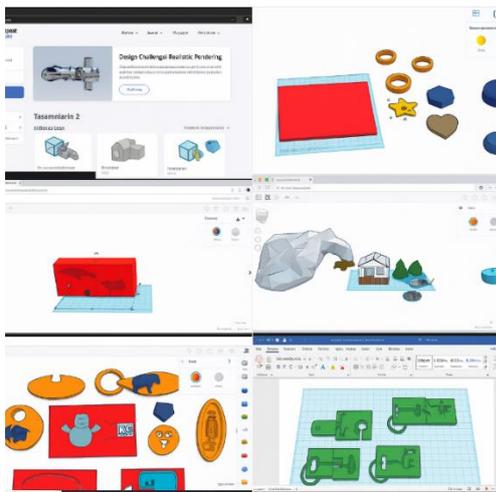


Figure 2. Images related to 3D model design process

As the process progressed, the pre-service teachers became more proficient in using the software, and they began to comfortably apply the commands they initially struggled with

through practice. Towards the final sessions, each PSTs developed an original teaching material prototype and completed the 3D model. Revisions were made as necessary, ensuring that the designs were safe, durable, and engaging for children.

2.3.3. Involving children in the process

While PSTs' training was ongoing, the project team revisited the preschool at an intermediate stage to introduce 3D printers to the children. During this visit, the children were explained what 3D printers are, how they work, and what they can do, using language appropriate for their age level. By answering the questions, the children were curious about, they were introduced to the technology at a basic level. In the next step, the children were asked to design a toy of their dreams by drawing it on paper. Each child drew a picture of a toy they most wanted but did not have; thus, original drafts emerged that would guide the pre-service teachers. After these drawings, the children were given the opportunity to work with 3D pens as a fun activity. Safety measures included close adult supervision when using 3D pens, ensuring pens operated at child-safe temperatures, and providing protective mats. All activities were conducted in compliance with the school's safety regulations, and parental consent was obtained prior to participation. Each child attempted to draw a simple version of the toy they had sketched, layer by layer, using a 3D pen, thereby experiencing three-dimensional thinking and creative expression skills. All implementation activities were standardized in alignment with the National Early Childhood Curriculum, with slight contextual adaptations permitted. Children's drawings and 3D pen models were collected, catalogued, and analyzed thematically to contribute to the study's qualitative dataset. This phase lasted five weeks and was conducted jointly by the researchers and PSTs, with classroom teachers providing additional support where necessary.



Figure 3. Some 3D designs by children

2.3.4. 3D printing process and trip

Towards the end of their training, PSTs completed toy models in the digital environment, considering children's drawings. Then, the printing process of these models was carried out using the 3D printers located in the METAM laboratory of Karadeniz Technical University. While the printing processes were carried out by the project team and experts, PSTs had the opportunity to observe and see how 3D printers' work. After the printing of the children's designs was completed, a trip was organized to the Scientific Research Centre (METAM) laboratory at Karadeniz Technical University for preschool students as part of the project (Figure 4).



Figure 4. Image of the research centre trip

During this trip, 10 preschool children, accompanied by pre-service teachers, saw the environment where 3D printers were located and experienced the working principle of the devices on-site. Experts gave a suitable presentation to the children, demonstrating the process of sending an object from the computer to the printer and its solidification in layers in a hands-on manner. The children watched how their designed toys were printed on a 3D printer and had the opportunity to touch and examine the resulting product for the first time in this

environment. This phase lasted approximately 2 hours and was conducted jointly by the researchers, 3D printing experts and PSTs, with classroom teachers providing additional support where necessary.

2.3.5. Classroom implementation

The teaching materials produced by the 3D printer were used in the classroom activities conducted by the PSTs as part of their Teaching Practice II course. Each PSTs (n=3) implemented the material they designed in a preschool class within an activity plan appropriate to the relevant learning outcome (Figure 5). For example, while some PSTs used the matching toy in a math activity, others used 3D figures to assist storytelling in a language development activity. During these activities, the project team was also present in the classroom to observe the process. The children's reactions, interests, and interaction levels with the 3D materials were noted. This phase lasted approximately 15 hours and was conducted jointly by researchers and classroom teachers providing additional support where necessary.



Figure 5. Image of the use of materials in the classroom

2.3.6. Post interviews and post test

At the end of the implementation process, PSTs were brought together again, and the post attitude scale test was administered. Thus, the pre- and post-training attitude scores have been prepared for comparison. A post interview was conducted with preschool children to gather their thoughts at the end of the project process. By asking the children questions from the post interview form, insights were gained on whether they liked the experience of designing toys with a 3D printer, how they evaluated the resulting product, and whether they found using this technology easy or difficult. This phase

lasted approximately two hours and was conducted jointly by researchers.

2.4. Data Analysis

In the analysis of quantitative data, the Wilcoxon Signed-Rank Test was applied to compare pre-test and post-test measurements. Due to the small sample size and the paired nature of the measurements, this non-parametric test was preferred. The obtained p-value was interpreted according to the 0.05 significance level. In the analysis of qualitative data, the content analysis method was used [31]. Qualitative data were analyzed using an inductive coding approach, allowing themes to emerge directly from the data without imposing pre-existing categories [32]. The responses obtained from the interview forms were first transferred to text documents, and then separately read by the researchers to extract codes. The data collected under similar codes were organized by creating higher-level categories/themes. To enhance reliability during the coding process, inter-rater consistency was checked, and differences were discussed to reach a consensus on a common code list.

The themes and codes that emerged from the responses given by PSTs to the interview questions are presented in tables, enriched with frequency values. In addition, quotations from PSTs are also included. The children's responses were not presented in tabular form because the nature of their answers was predominantly short, varied, and context-dependent, making quantitative tabulation less meaningful. Instead, representative quotations were selected to preserve the authenticity, richness, and contextual nuances of the children's perspectives. This approach also ensured that the data retained its qualitative depth and reflected the expressive language of the participants, which might have been lost in a condensed tabular format.

3. FINDINGS

The findings obtained at the end of the research are presented in the context of quantitative and qualitative results. First, quantitative changes in the attitudes of the PSTs (Wilcoxon test) were presented, followed by qualitative themes obtained from interviews with the PSTs and children. The findings were then combined with side-by-side narratives to show how the

observed attitude changes were consistent (or inconsistent) with the participants' reported experiences.

3.1. Findings from the Attitude Scale toward the Use of 3D Printers

The table below shows the findings obtained from the analysis of the scores obtained from the "Pre-service Teachers' Attitude Scale towards the Use of 3D Printers" before and after the 3D model design and printing training. The analysis used the Wilcoxon signed-rank test. The main reason for this is the small sample size of the study group ($n=10$) and the fact that the obtained data do not meet the assumptions of parametric tests (especially normality). The Wilcoxon test is a non-parametric test that operates on ranked data, taking into account the direction and magnitude of the difference between two dependent measurements. Due to the data set not showing a normal distribution and the small sample size, the Wilcoxon test was used as the most suitable non-parametric alternative for dependent samples.

Table 1. Wilcoxon Signed Rank Test results of attitude scale scores

Post-Test	n	Mean Rank	Sum of Ranks	z	p
Negative Ranks	0	.00	.00	-2.677	.007
Positive Ranks	9	5.00	45.00		
Ties	1				
Total	10*				

*: The total sample size ($n = 10$) refers exclusively to preservice teachers (PSTs) who participated in both the pre-test and post-test. No attrition occurred during the study; all participants completed the entire intervention and both measurement points.

It was determined that there was a significant difference between the pre-test and post-test scores of the PSTs' attitude scale in favour of the post-test ($p<.05$).

3.2. Pre-service Teachers' Opinions (Pre and Post Interview Form)

The findings obtained from the pre-interview form applied before the application revealed the PSTs' initial perceptions and knowledge levels about 3D printer technology. When their responses to the question "What do you know about 3D printer technology?" were analysed through content analysis, the current knowledge of the PSTs was grouped under three themes.

Table 2. Findings obtained from the responses to first question

Theme	Code	f
3D Printer Technology	Three-dimensional design	3
	Layered production	2
	Material usage	2
Application Areas	Education	4
	Manufacturing and industry	3
	Creativity and design	5
Technological Development	High technology	3
	Power to transform into reality	4

Some of the PSTs discussed the 3D printer primarily in terms of its technical dimension; they mentioned concepts such as three-dimensional design, layered production, and material use. While some of them stated that 3D printers are used in education, production and industry, others defined this technology in the context of “*high technology*” and “*creative design*” in general. For example, a pre-service teacher described the technical process by saying “*3D printers transform an object designed on a computer into a real product layer by layer*”. Another one emphasized the application area by saying “It is used in prototype production in the industry, maybe an experiment set can be made in education”. When the answers given to this question are analysed, it is seen that pre-service teachers have a general idea about the concept of 3D printer. As a matter of fact, all the PSTs answered “No” to the question “*Have you ever printed from a 3D printer before?*”, that is, none of them have experienced this technology.

Another question posed to the PSTs in the pre-interview was “*What are your views on the necessity of using 3D models in the preschool education process?*”. PSTs stated that 3D models can provide many benefits in preschool education (Table 2).

Table 3. Findings obtained from the responses to third question

Theme	Code	f
Use of 3D Models in Preschool Education	Realistic learning	3
Enrichment of Learning Environment	Learning by touching	4
	Creativity and imagination	3
Enrichment of Learning Environment	Ease of understanding the subject	3
	Addressing material shortages	3

	Encouraging creative thinking	5
Fun and Engaging Learning	Being fun for children	6
	Providing convenience	3

Among the most frequently emphasized points were that 3D models enable tactile and realistic learning, develop children's creativity and imagination, enrich the learning environment, and provide engaging and fun experiences. For example, many of the PSTs stated that when concrete models are used, children understand concepts more easily and abstract topics become tangible. Some of them stated that 3D printers can produce materials that are not available in the classroom and close the teaching material gap under the code “*Eliminating material deficiency*”. In the creativity dimension, the PSTs emphasized that thanks to 3D printing, children can transform their imaginations into products, which will encourage creative thinking. In addition, there were PSTs who thought that learning with 3D models would be fun for children by perceiving it as a game (Table 3).

Another focal point of the pre-interview form was the views of the PSTs on what materials are generally needed in preschool education. When the answers given to the question “*What are the materials that preschool children mostly need in the teaching process?*” were analysed, it was seen that the PSTs gave a wide variety of answers to this question, but in general, concrete and tactile materials, natural and recyclable materials, and educational toys were mentioned.

Table 4. PSTs' views on the materials most needed in the education process of preschool children

Theme	Code	f
Concrete and Tactile Materials	Feeling by touching	4
	Visual perception	4
Natural and Everyday Life Materials	Exploring the natural world	3
	Daily life practices	5
Supporting Imagination	Creative play	6
	Free thinking	3
Educational and Mentally Stimulating Materials	Math and science materials	5
	Puzzles and blocks	4

Many PSTs mentioned that materials such as puzzles, blocks, Legos, puppets, story cards are indispensable in preschool. Tools for different learning centres such as musical instruments, experiment sets, picture books were also listed (Table 4).

One of the important questions in the pre-interview form is, "What materials do you think you will need the most when you start your job as a teacher?".

Table 5. PSTs' views on the materials they will need when they start working as teachers

Theme	Code	f
Instructional Materials	Puppets	3
	Books	4
	Science materials	4
	Removable costumes	2
	3D books	2
Toys and Hand Skills	Blocks	6
	Puzzles	6
	Coloring and drawing materials	5
Technology and Sound	Projector	5
	Speaker	3
General Toys and Educational Tools	Toys	3

A few PSTs have also mentioned digital tools such as interactive whiteboards, computers, and projectors. In addition, the PSTs have stated that they would like to have various materials available that serve all areas of the curriculum (language, cognitive, social-emotional, motor). One of the questions in the final section of the preliminary interview form is about which area the PSTs would focus on if they were tasked with designing a model using a 3D printer. "If you were asked to design 3D models for use in a teaching practice course, which developmental area would they be aimed at?" When examining the PSTs' responses to the question "Why?", all PSTs indicated that they plan to use 3D models in various developmental areas of preschool education (Table 5).

Table 6. PSTs' preferences regarding the areas of development in which they would like to utilize 3D models

Theme	Code	f
Social-Emotional Development	Prevention of social isolation	3
	Development of emotional intelligence	4

Cognitive Development	3D models for teaching mathematics	3
	3D models for science development	5
	Supporting the cognitive domain	4
Psychomotor Development	Development of the sense of touch	6
	Supporting physical movements	3

The areas they emphasized the most were cognitive development (e.g., concretizing concepts like numbers, shapes, and letters), psychomotor development (e.g., three-dimensional puzzles that improve hand-eye coordination), and social-emotional development (e.g., toys that encourage sharing and cooperation). Some PSTs suggested creating 3D figures of story characters for language development, while others considered designing animal and plant models for science-nature activities (Table 6).

Some prominent answers that emerged from the responses to the statements measuring creative design preferences (such as flexible/rigid structure, single piece/multiple pieces, single colour/multiple colours) in the final section of the pre-interview form are as follows: A significant portion of the PSTs want the 3D model they will produce to be durable. Therefore, while some PSTs said, "I would want it to be as sturdy as Lego", others argued that "I would want it to be as flexible as a bouncing ball" claiming that flexible materials would be safe and fun. Similarly, while some PSTs preferred the model to be a single piece, justifying it with "not losing parts, being safe as a whole" others indicated that models made of several pieces would help develop assembly skills. Different opinions have also emerged regarding colour. Some PSTs said, "It should be a single colour, understandable and simple" while others expressed the idea that "if it is colourful, it will attract children's attention and be more entertaining."

The answers provided by PSTs to the questions within the scope of the post interview are presented in tables below. The question, "What insights did you obtain regarding 3D models during the project?" was directed to the PSTs. Their replies to this question are presented in Table 7

Table 7. Findings related to what PSTs learned during the project period

Theme	Code	f
Design and Use of 3D Models	Having design freedom	2
	Durability and robustness of models	3
	Wide range of use and easy production	2
	Ease of need-oriented design	1
Imagination and the Design Process	Connection between imagination and design	1
	Making abstract entities concrete	1
	Enjoyable design experience	2
3D Modeling and Mathematical Design	Combining and separating shapes	3
	Purposes of mathematical design	5
	Creation of 3D mathematical models	3

According to the data presented in Table 7, PSTs stated in their views on 3D models that almost any object can be designed thanks to the Tinkercad application. Additionally, it has been stated that the generated models can be robust and durable. PSTs emphasized that imagination is directly related to the design process and that abstract concepts can be concretized through this process. However, the view that the design process, while occasionally challenging, offers a highly enjoyable and educational experience has emerged. The responses of PSTs to the question, "Which topic or concept was your 3D model, designed during the project, intended to teach?" are presented in Table 8.

Table 8. Findings regarding the subject or concept to which the designed 3D model relates

Theme	Code	f
Educational Objectives of 3D Model Design	Teaching the concepts of symmetry and matching	4
	Improving matching skills	3
	Designing models related to sports branches	3

According to the data in the Table 8, 4 out of 10 PSTs stated that 3D model designs were effective in teaching the concepts of symmetry and matching. Other participants stated that the designs contributed to improving matching skills (f=3) and modeling for sports (f=3). These findings indicate that PSTs incorporate both cognitive skills and real-life applications into

the 3D modeling process. The responses to the question "What are your views on the necessity of using 3D models in the preschool education process?" asked of PSTs are given in Table 9.

Table 9. PSTs' views on the use of 3D models in preschool education

Theme	Code	f
The Necessity of 3D Models in Preschool Education	Addressing the lack of materials	4
	Supporting creativity	2
	Developing 21st-century skills, increasing self-confidence and motivation	2
	Development of imagination and creativity	2
Contributions to Students	Integration with technology	2
	Gaining a sense of reality	2
	Increased class participation and motivation	1
Versatility of 3D Models	Versatile design and usage	3
	Potential for enhancing imagination	2
	Enhancement of sense of reality	3

According to Table 9, PSTs stated that 3D models have a multifaceted structure and can serve many different purposes. It has been stated that these models can be shaped according to need, allow children to interact with technology, have the potential to develop imagination, and provide a sense of reality. All PSTs answered "Yes" to the question of whether the project contributed to the necessity of using 3D models in the preschool period. Regarding their views on the direction of the contribution provided, the prominent expressions were the development of creativity, the exploration of new fields, the offering of new career opportunities, the ability to produce their own educational materials, and increased self-confidence.

The answers to the question asked to PSTs, "What are your views on the ability of preschool preservice teachers/teachers to use 3D printer technology? Please explain with reasons." are presented in Table 10.

Table 10. The perspectives of PSTs concerning their proficiency in utilizing 3D printing technology after the project

Theme	Code	f
Teachers' Competence in Using 3D Printers and Student Development	Teachers' competence in using 3D printers	3
	Contribution to student development	2
	Supporting 21st-century skills	2
	Developing problem-solving skills and alternative perspectives	1
Teachers' Training and Skill Acquisition	The need for training and skill acquisition	3
	Potential skills to be gained through training	2
	The role of teachers in meeting the needs of the modern world	1
The Importance of Preschool Education and 3D Printers	Preschool period and student development	3
	The role of 3D printers in preschool education	5

Table 10 summarizes the opinions of PSTs regarding their ability to use 3D printing technology, based on themes and frequencies. PSTs stated that this technology contributes to students' development, supports 21st-century skills, and provides problem-solving and different perspectives. Additionally, it was emphasized that teachers need to be trained in this area to use technology effectively, and the importance of professional competence, the requirements of the age, and innovation in education was highlighted. It has been stated that 3D printers support student development by increasing material diversity in preschool education, and that they should be seen as an important tool in education in this respect.

Table 11. Views on the project's impact on pre-PSTs' 3D model design skills

Theme	Code	f
Contribution of 3D printer technology to personal development	Acquiring knowledge and skills	3
	Development of creative skills	2
	Gaining new perspectives	2
	Contributing to professional development and investing in the future	2

Effect of 3D printers on learning	Ideas for integrating into preschool education	3
	In-depth learning and enjoyment	3
	Contributing to professional development	2

According to Table 11, it is observed that 3D printer technology offers significant contributions to both personal development and the learning process, based on the statements of PSTs. Within the theme of "*Contribution of 3D printer technology to personal development*" the participants stated that this technology enables the acquisition of knowledge and skills (f=3), enhances creativity skills (f=2), and helps gain new perspectives (f=2). In addition, it was emphasized that 3D printing supports professional development and is considered an investment for the future (f=2). Under the theme of "*Effect of 3D printers on learning*" gains such as developing ideas for integration into preschool education (f=3) and creating deep and enjoyable learning environments (f=3) were highlighted.

Table 12. Perspectives of PSTs regarding the project's influence on preschool children's aspirations

Theme	Code	f
Supporting Children's Creativity and Imagination	Enabling children to design the toys they imagine	1
	Increase in self-worth and self-confidence	3
The Role of 3D Printers in Education	Problem-solving and modeling skills	1
	Increased motivation and positive outlook	4
The Role of 3D Printers in Education	Creating unique materials and supporting children's creativity	4
	Gaining a realistic and progressive perspective	4

Table 12 shows that PSTs consider 3D printers enhance children's creativity and imagination, in addition to benefiting the entire educational process. Under the theme of "*Supporting Children's Creativity and Imagination*" it was noted that this technology enhances children's capacity to design their envisioned toys (f=1), fosters self-esteem and self-confidence (f=3), augments problem-solving and modeling abilities (f=1), and bolsters motivation and a positive perspective (f=4). Participants

highlighted that, under the theme “*The Role of 3D Printers in Education*” these devices facilitate the development of distinctive educational materials and foster children's creativity (f=4), while also providing children with a pragmatic and future-oriented outlook (f=4).

The PSTs stated that their perspective on 3D printing technology changed very positively by the end of the process. Many PSTs initially perceived this technology as difficult and hard to access, but by the end of the project, they stated that they were able to use it comfortably and realized that it could be a practical tool in education. Additionally, the PSTs stated that they observed with their own eyes how 3D printers would be very useful in addressing the material shortages in preschool education, capturing children's attention, and increasing their motivation. As a result of these experiences, all the PSTs expressed that they would consider using 3D printers in their professional lives if given the opportunity.

3.3. Children's Opinions (Pre and Post Interview Form)

In the pre-interviews at the beginning of the process, some of the children (n=7) expressed that they wanted toys they had wished for but had not been able to have before. Mostly, cartoon characters, unusual animal figures, or original toy ideas born from their own imagination stood out (e.g., a car with wings, a talking treehouse, etc.). Almost all the children (n=10) indicated that they were not familiar with what a 3D printer is; only a few (n=2) mentioned that they had heard about 3D printers at home or on television. When asked, “*Would you like to use a 3D printer?*” all the children (n=10) answered, “*Yes.*” Additionally, when the children were asked which materials they liked to play with at school, they generally mentioned classic toys like Lego, blocks, toy animals, and cars; some said they enjoyed drawing and playing with playdough. When asked, “*Can you find the toys you want at school?*” a few children (n=5) responded, “*Some are there, some are not*” particularly noting that they do not see the special character toys they want at school. When asked, “*Do you have difficulty sharing with your friends?*” the majority answered (n=8), “*No.*”

At the end of the project, during the final interviews with the children, all of them (n=10) expressed that they were very pleased with the process of designing their dream toy with a 3D printer. “*Did you like it?*”. In their responses to the question “*Why?*”, they expressed opinions such as, “*Yes, because the toy I wanted was made*” (n=4), “*Because it was very fun, it became my own toy*” (n=3). A few children (n=3) said their toys were exactly as they imagined, while some noted small differences (e.g., “*I wanted it to be pink, but it turned out blue; still very nice*”). When asked, “*Do you think using 3D printers is difficult or easy?*” most children (n=7) responded that using a 3D printer was easy or moderately difficult, with some commenting, “*The machine does it on the computer.*” To the question, “*Would you like to work in a profession where you would use 3D printers in the future?*” more than half of the children (n=7) answered “*Yes.*” Especially the children (n=8) who saw the 3D printer during the tour and were impressed by it said that they wanted to become engineers, inventors, or teachers and use such machines when they grew up.

4. CONCLUSION, DISCUSSION AND RECOMMENDATIONS

4.1. Conclusion and Discussion

This study brought pre-service preschool teachers and children together around 3D printer technology, revealing important results for teacher and early childhood education. The results of the study align with the relevant literature in terms of the PSTs' knowledge levels and inexperience before the application. Although the PSTs involved in the study were acquainted with 3D printers, they lacked practical knowledge of on applying this technology in the classroom. Pre-service science teachers had limited, theoretical knowledge of 3D printers and occasionally confused them with other new technologies, including simulations or holograms, Karagöz and Şahin [33] also found. In this study, pre-service teachers experienced the possibilities of 3D printers in education and rapidly closed this knowledge gap by means of the implementation and training program. According to results from the attitude scale, pre-service teachers' opinions on 3D printers became noticeably more favourable following training. This finding aligns with the results of a study by Şahbaz, Gökçe and Karabulut [34], which involved

teachers. Those who experienced 3D printer training felt they could incorporate this technology into their courses and understood how 3D printer's work. Consequently, it can be said that the self-confidence and perceived competency of PSTs in 3D technology were greatly enhanced by the theoretical and practical training they received in a controlled program.

The diverse advantages highlighted in the literature are consistent with PSTs' opinions regarding the function of 3D models in preschool education. The PSTs stated that concrete models produced with 3D printers would provide more realistic and tactile learning environments for children. This perspective overlaps with the findings of Martínez et al. [7] study on 3D interactive applications in preschool. In this study, it was stated that the learning outcomes of children who experienced guided interaction with 3D objects improved and retention increased. Another point emphasized by PSTs is that 3D models develop children's creative thinking and imagination. This situation suggests the results obtained in McNally et al. [8] study on children's use of 3D technologies in their daily lives; it was stated that children revealed their creativity while making 3D designs and enjoyed designing original products. Likewise, they emphasized that the use of digital fabrication in education improves students' design thinking skills and brings innovative approaches to problem solving [35]. In this study, both pre-service teachers and children experienced the 3D design process as a creative learning experience.

Another important outcome of the study is the contribution potential of 3D printers in developing instructional materials. PSTs stated that many materials that are frequently needed in pre-school can be produced with 3D printing and saw 3D technology as a solution especially in overcoming the lack of materials. This finding is consistent with the results of a similar study conducted by Aslan [36]. In this study, it was emphasized that both preschool teachers and PSTs had difficulties in providing the materials they needed in education and that 3D printer technology could play a key role in overcoming these difficulties. The PSTs initially stated that they needed different materials and toys in schools, and at the end of the research, they personally experienced that

some of these needs could be met with 3D models they designed themselves. As a matter of fact, the materials designed and produced by the PSTs were successfully used in classroom activities and enriched children's learning experience. This touches upon an important point discussed in the literature on teachers' material development skills: Teachers' ability to go beyond ready-made materials and design their own materials, especially in STEAM-oriented education, is seen as part of the 21st century educational vision [37]. This study has shown with concrete examples that 3D printers can be very helpful in making this vision a reality.

What children gained from the 3D printer experience is a separate topic of discussion. While children usually do not have the opportunity to interact with technology at this level, with this study, they had a unique experience such as giving a design idea to a machine and seeing its output at the age of 5-6. According to the findings of the final interview, the children developed a positive attitude towards 3D printers and stated that they would like to work with this technology again. These findings are in line with some studies on the place of technology in preschool. Imheid, and Al-Maadadi [38] found that technology integration in early childhood programs positively affects children's attitudes towards technology and improves teachers' practices in using technology. In particular, children's exposure to technology through concrete experiences makes them active explorers instead of passive consumers and creates a solid foundation for their future. In this study, children had the opportunity to learn by doing by actively participating in the process of producing a toy with a 3D printer. In the literature, it is stated that activities such as Makey Makey, robotics, and simple programming support creativity and problem solving in preschool [39-40].

This research contributes to the literature by bringing together PSTs and children in a joint production process, fostering a two-way learning experience. In this process, PSTs learned how to design by being inspired by children's imagination, while children enjoyed producing using technology with the help of PSTs. This mutual interaction is an example of what is defined in the literature as learner-

teacher role [41]. In maker activities, teachers' involvement in the learning process with students transforms classroom roles and creates a more democratic learning environment. In this study, PSTs became learners and producers together with children, which increased their professional awareness. As a matter of fact, at the end of the project, the PSTs stated that they better understood the experience of using technology through the eyes of the students and realized the importance of the sense of achievement together in the teacher-student relationship.

In summary, this study highlights the potential of integrating 3D printing technology into early childhood education to enhance creativity and instructional preparedness among PSTs. While the findings indicate promising trends, they are based on a small, self-selected sample and thus should be interpreted cautiously. Future research should examine these effects with larger, more diverse participant groups and across different educational settings to strengthen the evidence base.

4.2. Recommendations

Considering the results of the study, some suggestions are presented for future studies:

1. Further integration of 3D printer technology into teacher training programs will improve PSTs' ability to use this technology effectively.
2. Workshops and practical trainings can be organized for PSTs to provide them with practical experiences in the use of 3D printer technology.
3. Preschool education institutions should be provided with 3D printers and related materials to encourage the use of this technology in classroom applications.
4. Research and development studies should be conducted to examine the effects of 3D printing technology in education more comprehensively.
5. The study is based on a small, purposeful sample (10 teacher candidates; 10 children) drawn from a single institution, which limits its generalisability. A non-parametric test, suitable for small samples, was used to conduct quantitative analyses. Qualitative findings reflect context-specific experiences. Future research should include larger, multiple samples, longer-term follow-up, and additional objective learning measures.

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