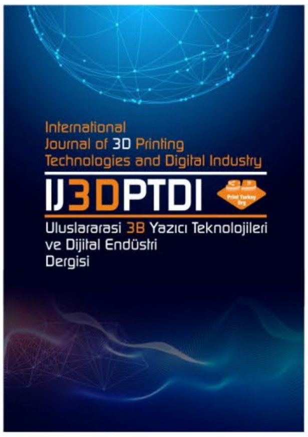

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USING 3-DIMENSIONAL MODELS AS TEACHING TOOLS IN SCIENCE EDUCATION FOR PRIMARY SCHOOL STUDENTS

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ABSTRACT

This research aims to identify the concepts that elementary school students struggle to understand in their science classes and to overcome these difficulties by utilizing a design thinking model. Specifically, the impact of instructional methods based on the use of 3D models on students' academic achievements has been examined. The study adopted a mixed method approach. The sample of the research consists of 3rd grade (N=31) and 4th grade (N=29) students attending an elementary school in Trabzon. This study used a mixed-method research design. Before using the final 3D models in the lessons, a "Concept Achievement Test" consisting of 10 questions each was administered as a pre-test to the students. One week after the pre-tests were administered, lessons were given using the final 3D models developed by the researchers. These models were used interactively with the students in the classroom environment for two class hours. Three days after this interactive lesson process using the models, post-tests were administered to evaluate the learning levels of the students. Comparison of the pre-test and post-test results revealed a statistically significant improvement in favor of the post-test for both 3rd grade ($t_{(sd)}$=-5.005; p<.05) and 4th grade ($t_{(sd)}$=-2.813; p<.05) students. In analyzing the data, a dependent samples t-test was used on the students' test results. In addition, in the qualitative dimension of the study, semi-structured interviews with students and teachers and classroom observations were also conducted. The results of the research demonstrate that the design thinking approach and three-dimensional models enhance understanding and comprehension levels in elementary school science classes. These findings can serve as an important resource for educators and policymakers in developing teaching methods that support active learning processes and encourage conceptual understanding.

Keywords: Science Education, 3D Model, Teaching Material, Primary School Students.

1. INTRODUCTION

The challenges in primary school science education are multifaceted, encompassing various aspects that affect both teachers and students. Primary teachers' attitudes, competence and self-efficacy towards science teaching are critical for effective science teaching [1]. Limited science pedagogical content knowledge among primary school teachers can lead to heavy reliance on activities that may not effectively support scientific conceptual awareness or learning [2]. Addition, challenges affecting learner performance in science include the medium of instruction, lack of adequate teaching and learning resources, overcrowded classrooms and learner indiscipline [3]. Despite reported increases in primary teachers' knowledge of science and confidence in teaching, difficulties remain, particularly in the area of physical science and uncertainty about higher-level scientific ideas [4].

Furthermore, primary school teachers' self-efficacy in teaching science is of great importance and can significantly impact students' interest and success in science-related subjects at higher education levels [5-7]. The influence of higher-order thinking and metacognitive skills on hands-on teaching in science among primary school teachers is also a critical aspect to consider [8]. Moreover, the hesitance of primary school teachers to teach science can be discouraging and may contribute to gaps in science education in the foundation phase [9]. Implementing innovative approaches, such as using multimedia boards for visualization and conducting pedagogical discussions, can enhance science teaching in primary schools [10]. Additionally, exploring the feasibility of implementing experimental inquiry approaches in primary schools is crucial for promoting effective science teaching and learning [11]. Addressing challenges encountered in the teaching and learning of natural sciences in rural schools is also essential for ensuring equitable access to quality science education [12]. Overcoming challenges in primary science teaching requires a comprehensive approach that takes into account teacher attitudes, competencies and self-efficacy, as well as available resources and innovative teaching approaches [13]. By addressing these challenges, it is possible to improve the quality of science education at the primary school level, thereby laying a strong foundation for students' future academic and professional success. Based on the provided references, the concept of "Student-Centered Design-Focused Learning" can be comprehensively understood through the integration of design thinking principles and student-centered learning approaches [14].

Lee and Hannafin [14], present a design framework that enhances engagement in student-centered learning by emphasizing ownership, active learning, and knowledge sharing. This framework aligns with the principles of student-centered design-focused learning, as it promotes students' active involvement in their learning process and encourages them to take ownership of their educational journey. Moreover, Morel [15] discusses the combination of constructivist, constructionist, and self-determination theories to address student-centered learning, highlighting the importance of contextualizing the learning experience. This approach resonates with the idea of student-centered design-focused learning, as it emphasizes the need to tailor the learning experience to the individual needs and interests of students, thereby fostering a more personalized and engaging educational environment. Additionally, [16] explore the pedagogic sense of design thinking in higher education, particularly in the context of problem-based learning and autonomous student decision-making. This aligns with the principles of student-centered design-focused learning, as it emphasizes the importance of empowering students to make autonomous decisions and take an active role in their learning process. Furthermore, the work of [17] emphasizes the significance of student-centered learning in acknowledging students' voices as central to the learning experience. This is consistent with the fundamental principles of student-centered, design-focused learning, which emphasize the active participation and input of students in shaping their educational experiences.

The implementation of 3D models in primary science instruction has been internationally recognized for enhancing students' grasp of scientific concepts. Educational studies across various countries have demonstrated that these innovative tools bolster engagement and facilitate a deeper understanding of complex principles. For instance, 3D printing has been identified as an excellent method for fabricating 3D models of molecules and extended solids, which has been shown to enhance students' comprehension of chemistry concepts [18]. Additionally, the use of 3D models has been found to facilitate the learning of material in chemistry education, as reported in student surveys [19]. Furthermore, the incorporation of 3D models in science education has been supported by research, particularly for teaching spatial concepts such as atomic orbitals and molecules [20].

In addition to their impact on student learning, 3D models have also been recognized for their potential in various fields. For instance, 3D technology has revolutionized the field of Health Sciences by facilitating low-cost manufacturing and custom surgical devices, 3D models for use in preoperative planning, and fabricated biomaterials [21]. Furthermore, the availability of 3D models on the internet is rapidly expanding, providing valuable resources for both students and educators [22]. The integration of 3D printing technology in education has been driven by the concepts of Science, Technology, Engineering, and Mathematics (STEM), emphasizing the broader implications of 3D models beyond science instruction [23]. Three-dimensional models presented to students play an important role in the learning of science concepts. These models enable students to visualize events they cannot observe, such as cell division, gene expression, heat transfer, etc. [24]. Moreover, the use of dynamic visualizations helps students to process information better, prevents misunderstandings (conceptual misconceptions), and reduces cognitive load [24]. Anđić, et. al. [25] aimed to determine the pre and post-implementation knowledge of primary school students on plant and animal cells and their views on the use of 3D models in biology education. The results of the study have shown that 3D models contribute to the learning of the students by improving their ability to count, identify, and visualize the cell and its parts, as well as correcting some of their misconceptions and enhancing communication in the classroom. In conclusion, the utilization of 3D models in primary science teaching offers a promising avenue for enhancing science education by providing students with interactive and visually stimulating learning experiences. This approach aligns with the broader trends in educational technology and instructional design, emphasizing the importance of technology-based learning and innovative instructional strategies in primary science education [26].

1.1. Purpose of the Study

This study aims to identify the topics that primary school students have difficulty in understanding in the science course and to overcome these difficulties by using the design thinking model. In particular, the effect of teaching methods based on using 3D models in science teaching on students' academic achievement was examined. In addition, students' opinions on the use of 3-dimensional solid models in science lessons were also taken. In line with this general purpose, answers to the following questions were sought:

- What are the opinions of primary school teachers about the topics that students have difficulty in understanding in science course units?
- What is the effect of using the teaching method based on using 3D models in science lessons on students' academic achievement?
- What are the opinions of the students about the use of 3D models in the lessons?

2. METHOD

2.1. Research Design, Research Variables and Ethics

This research adopted a mixed-method design, which is essentially an approach where data is gathered using multiple methods to bolster their reliability and validity, effectively mitigating the drawbacks of both qualitative and quantitative data [27.] Specifically, a sequential explanatory mixed model was employed, with a predominant emphasis on quantitative methodologies. The impact of the practice was gauged using quantitative data collection instruments, while the perspectives of the experimental group on the practice were elicited through the concurrent use of both qualitative and quantitative approaches. The study was conducted after permission had been obtained from the Social and Humanities Scientific Research and Publication Ethics Committee of Trabzon University (dated 17.11.2023 and numbered E-81614018-000-2300063426).

In the mixed methods research design, quantitative data from pre- and post-tests were rigorously integrated with qualitative insights from interviews and observations. This approach allows not only to measure progress in students' understanding of science concepts, but also to explore the subtle ways in which 3D models facilitate learning. In particular, it offers a holistic view of learning outcomes by examining how students' interactions with these models contribute to their conceptual understanding. A stratified random sampling technique was used to ensure a representative sample. This involved categorising the population according to key demographic characteristics and then randomly selecting participants from each category, thereby maximising the diversity and representativeness of the sample. Such a methodological approach strengthens the validity of the findings by providing a sound basis for both quantitative and qualitative analyses.

2.2. Research Group

The study group consisted of 31 3rd grade and 29 4th grade students randomly selected from a primary school in Akçaabat district of Trabzon province and 20 classroom teachers working in different schools in Trabzon province.

2.3. Data Collection Tools and Data Collection Process

Within the scope of the study, two different data collection tools were used for students and teachers. In the data collection tool prepared for teachers, a form including the units and subject areas in the 3rd and 4th grade science curriculum was created. Teachers were asked to fill out "Teacher Opinion Form" with the subjects that their students struggled to understand and that they were unable to embody in the teaching process. As the second data collection tool, "Concept Achievement Tests" consisting of ten questions on the related subjects of the science course were created separately for 3rd and 4th grade students. In addition, in the Concept Achievement Test, students were also asked (after implementation) their opinions on the use of 3D models in science lessons with three open-ended questions. The open-ended questions asked to students in the post-test were respectively: "What did teaching this course using the 3D model contribute to your learning? Can you explain?", "Did teaching this course using a 3D model facilitate your learning? Can you explain?" and "Which other subjects would you like to be taught using 3D models? Mark (x) in the table below and write why". The achievement tests were administered to the students as pre-test and post-test. In the preparation of the achievement tests, the "Attainment Comprehension Tests" published by the Republic of Türkiye Ministry of National Education were utilized. In the development of the data collection tools, "Teacher Opinion Form" and "Concept Achievement Tests", a rigorous process was carried out to ensure their validity and reliability. These instruments were designed in consultation with science education experts to accurately measure educators' perceptions and students' conceptual understanding and views. The data collection tools used in the study and the data collection process are shown in Figure 1.

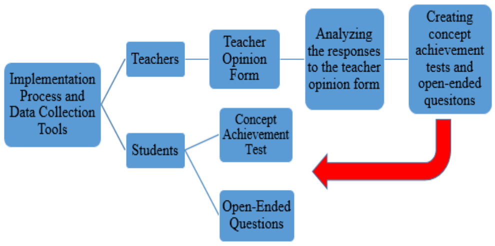

Figure 1. Data Collection Tools and Process

Within the scope of the study, first of all, based on the design thinking model, in the "Empathy" stage, the opinions of 20 classroom teachers were obtained by using the "Teacher Opinion Form" prepared by the researchers about the subjects that primary school students have difficulty in understanding in the science course units. Afterwards, statistical and descriptive analyses of the teachers' responses were conducted and it was determined that "The Structure of the Earth" for the 3rd grade level and "The Structure of the Earth's Crust" for the 4th grade level were the topics that students had difficulty in understanding. In the "Define the Problem" and "Generate Ideas" stages of the Design Thinking Model (DTM), the researchers decided what kind of 3D models (Figure 2) could be designed for teaching these topics.

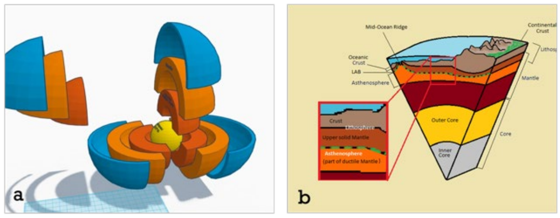

Figure 2. (a) An Exploded View of the Different Layers of Earth, **(b)** The Structural View of the Earth's Crust

After deciding how the 3D models would be, 2D drawings were made and designs were made by the researchers in the "Prototype Development" stage using 3D pens. The preliminary designs of the models were drawn on the computer and printed out on 3D printers (Figure 3, Figure 4).

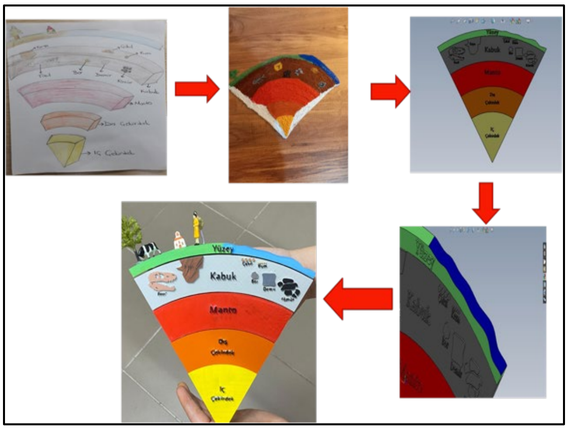

Figure 3. 3D Model Design Stages of the Structure of the Earth's Crust (4th Grade Students)

Figure 3 shows the 2D drawing of the Structure of the Earth Crust model, the drawing made using a 3D pen, and finally the image of the model designed in the drawing program and printed out using a 3D printer. In Figure 4, the 2D drawing of the Structure of the Earth model, the drawing made using a 3D pencil, and finally the image of the 3D printer output of the model designed in the drawing program are shared.

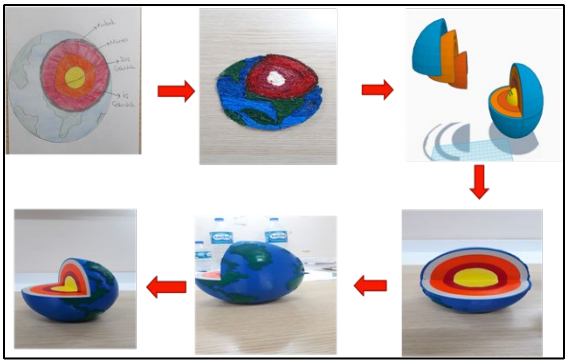

Figure 4. 3D Model Design Stages of the Structure of the Earth (3rd Grade Students)

Before the use of the final models in the lessons, the "Concept Achievement Test" consisting of 10 questions was applied to the students as a pre-test. One week after the pre-test implementation, the use of the final models in the teaching process was realized by the researchers. One week after the interactive use of 3D models in the lesson, post-tests were applied. In the post-test, students were also asked their opinions about the use of 3D models in science lessons with three open-ended questions. Some photos from the implementation are shared on Figure 5.

Figure 5. Photos from the implementation process

2.4. Data Analysis

This study employed a mixed-method research design to investigate the effectiveness of using 3D models in primary science education. The analysis involved both quantitative and qualitative data to identify the subjects that are difficult in primary school science learning and to offer a comprehensive understanding of the impact of 3D models on students' learning. The quantitative data obtained from the teacher opinion form were transformed into a frequency table. Qualitative data were analyzed descriptively. Other quantitative data were obtained from the pre and post-test scores obtained from the Concept Achievement Test administered to 3rd and 4th grade students. SPSS program was used to analyze the quantitative data. Comparative t-test was preferred due to the normal distribution of the data obtained. Content analysis was preferred to analyze the qualitative data obtained from the Concept Achievement Test.

In the qualitative analysis, a detailed method of content analysis was used to examine the transcripts of the interviews and the notes of the observations. Initially, two researchers independently examined a subset of the data, developing a preliminary codebook and providing a grounded approach to the data itself. Regular meetings were held to discuss and refine these codes, aiming for inter-coder reliability. The collected data was compared by the researchers at that point, and coding and categorization made by each of them were examined. Once consensus was reached, the final codebook was applied to the entire dataset. Using the formula developed by Miles and Huberman (1994), the percentage of agreement between the three researchers was determined to be 0.93. During the qualitative data analysis, 3rd grade students were coded as S_3 and 4th grade students were coded as S_4.

3. RESULTS

In the presentation of the findings, the implementation steps carried out in two stages were taken into consideration. First, the findings obtained from the analysis of teacher responses were presented, and then the findings of the achievement test and semi-structured interview form applied to the students were presented.

3.1. Results of the First Sub-question

Table 1 shows the frequency distributions of the 3rd grade science course units, topics and subject areas and the frequency distributions of the responses of the teachers regarding the learning difficulties of these units and subject areas for students.

Table 1. Frequency Table of the Difficulties Experienced for The Units and Subject Areas for the 3rd Grade Science Course

Units	Subject Areas	(f)
F.3.1. Let's Know Our Planet/ Earth and Universe	The Shape of the Earth	7
	Structure of the Earth	14
F.3.2. Our Five Senses /Living Things and Life	Sense Organs and Their Duties	3
F.3.3. Let's Recognize Force/ Physical Phenomena	Movement Characteristics of Entities	5
	Moving and Stopping Objects	5
F.3.4. Let's Know Matter /Matter and Its Nature	Properties Characterizing Matter	8
	States of Matter	9
F.3.5. Light and Sounds / Physical Phenomena in Our Environment	The Role of Light in Vision	3
	Light Sources	3
	Sounds Around Us	1
	The Role of Sound in Hearing	2
F.3.6. Journey to the World of Living Things / Living Things and Life	Recognize the Things Around Us	3
	Me and My Environment	3
F.3.7. Electric Vehicles /Physical Phenomena	Electrical Equipment	4
	Electricity Sources	7
	Safe Use of Electricity	4

According to Table 1, the "Structure of the Earth" subject is seen by teachers as the topic that students have the most difficulty in understanding among the 3rd grade science course topics. Teachers state that students have difficulty in making associations with concepts that they do not encounter in their daily lives, which affects the retention of the information learned. Teachers emphasized that abstract concepts should be supported with concrete materials and 3D displays. In particular, it is stated that explaining topics such as the structure of the Earth with concrete examples will help students understand. The importance of using visual materials and play dough in education is emphasized. It is stated that these materials can contribute to students' permanent learning of both information and visuality.

Table 2 shows the frequency distributions of the 4th grade science course units, and subject areas and the frequency distributions of the responses of the teachers regarding the learning difficulties of these units, and subject areas for students.

Table 2. Frequency Table of the Difficulties Experienced for the Units And Subject Areas for the 4th Science Course

Units	Subject Areas	(f)
F.4.1. Movements of the Earth's crust and our Earth /Earth and the Universe	Structure of the Earth's Crust	17
	Movements of our Earth	10
F.4.2. Our Food / Living Things and Life	Nutrients and Their Properties	13
F.4.3. Effects of Force /Physical Phenomena	Effects of Force on Objects	8
	Force Applied by Magnets	8
F.4.4. Properties of Matter /Matter and Nature	Properties Characterizing Matter	4
	Measurable Properties of Matter	10
	States of Matter	4
	Change of Matter Under the Effect of Heat	6
	Pure Substance and Mixture	9
F.4.5. Lighting and Sound Technologies / Physical Events	Lighting Technologies	3
	Proper Lighting	4
	Light Pollution	4
	Sound Technologies from Past to Present	7
	Sound Pollution	4
F.4.6. Human and Environment / Living Things and Life	Conscious Consumer	6
F.4.7. Simple Electric Circuits/ Physical Phenomena	Simple Electric Circuits	12

According to Table 2, it is seen that students mostly have difficulty in understanding concepts such as the structure of the earth's crust and the movements of the earth.

It was stated by the teachers those students had difficulties especially in the subject of "The Earth's Crust and the Movements of the Earth" due to conceptual and procedural knowledge. Students have difficulty in comprehension because they do not know the concepts and vocabulary sufficiently, cannot make associations with daily life and cannot understand abstract concepts without supporting them with concrete examples. Students confuse topics such as rotational and entanglement motions. While students have fewer problems with layers that can be observed, they cannot fully comprehend layers that cannot be observed. Teachers pointed out that students had difficulty in understanding concepts that they could not observe or hold in their hands and emphasized the importance of using animations and materials to overcome this situation. However, three teachers stated that students did not experience any difficulty in the topic of the "Structure of the Earth's Crust".

3.2. Results of the Second Sub-question

The results of the statistical comparison of the scores obtained from the achievement test applied to 3rd grade students before and after the implementation are given in Table 3.

Table 3. Comparison of the 3rd Grade Students' Achievement Pre-test and Post-test Scores

	N	$\bar{x}$	*sd*	*t*	*p*
Pre-test	31	72.26	16.27	-5.00513	0.00002
Post-test	31	87.10	10.71		

As a result of the comparative t-test, a significant difference was found in favor of the post-test ($t_{(sd)}$=-5.0051; p< .05)

The results of the statistical comparison of the scores obtained from the achievement test applied to 4th grade students before and after the implementation are given in Table 4.

Table 4. Comparison of the 4th Grade Students' Achievement Pre-test and Post-test Scores

	N	$\bar{x}$	*sd*	*t*	*p*
Pre-test	29	73.79	18.21	-2.8134	0.00886
Post-test	29	81.03	21.44		

As a result of the comparative t-test, a significant difference was found in favor of the post-test ($t_{(sd)}$=-2,813; p<.05).

3.3. Results of the Third Sub-question

After the using 3D models in science courses, the 3rd and 4th grade students were given the interview form containing three questions. In line with the answers given by the students, the answers given to these three questions were put together, and the results are presented in Table 5, Table 6 and Table 7.

The results derived from analyzing the responses to the first open-ended question on the achievement test, which was administered as a post-test following the intervention, are presented below. Here are the codes based on 3rd grade students' expressions of how models or certain teaching methods impacted their learning:

Table 5. Codes and Example 3rd Grade Students' Responses to First Open-Ended Question

Codes	Example Student Responses	Frequency (f)
Conceptual Understanding	"Explained with a model made it better understood." ($S_3$2), "Course dealing with the model helped keep the subject in mind." ($S_3$29)	12
Misconception Correction	"Corrected some misconceptions about the layers of the world." ($S_3$5)	1
Achievement and Success	"I succeeded." ($S_3$6), "My science class made me stronger." ($S_3$20)	2
Prior Knowledge Affirmation	"I already knew." ($S_3$7)	1
Enhanced Engagement	"3D model made me love learning." ($S_3$12), "Learned something new and I learned the lesson." ($S_3$14)	2
Information Acquisition	"3D model provided me a lot of information." ($S_3$25), "Helped me to research and understand more." ($S_3$26)	11
Effective Learning Experience	"Good time to have a good lesson." ($S_3$18), "Better because it was shown on the board and explained with a model." ($S_3$31)	3

Table 5 shows the codes derived from analyzing the responses of 3rd grade students to the first open-ended question on the achievement test administered as a post-test. The table presents various themes such as conceptual understanding, misconception correction, achievement and success, prior knowledge affirmation, enhanced engagement, information acquisition, and effective learning experience. These themes are illustrated with example student responses and their respective frequencies, highlighting the impact of using 3D models on students' learning experiences and understanding of scientific concepts.

The results derived from analyzing the responses to the second open-ended question on the achievement test, which was administered as a post-test following the intervention, are presented below. The codes and sample student responses obtained from the analysis of 31 3rd students' views on how teaching methods (especially models) facilitated their learning are as follows:

Table 6. Codes and Example 3rd Grade Students' Responses to Second Question

Codes	Example Student Responses	Frequency (f)
Enhanced Understanding	"It made it easier because he explained the layers of the world one by one." ($S_3$23), "It was easy because we researched it and because we saw it." ($S_3$26)	17
Learning Reinforcement	"Yes, it made it easier because I repeated the subject and learned new things." ($S_3$4), "It made it easier for me to learn what I didn't know." ($S_3$30)	3
Ease of Learning	"Yes, it made it easier because it is easier to do it with shapes, but it is more difficult to do it by showing it." ($S_3$15), "This lesson was a bit easy for me because we have never had a lesson like this before." ($S_3$29)	8
Success and Achievement	"I succeeded." ($S_3$6)	1
Prior Ease	"It was already easy." ($S_3$7)	1
New Information Acquisition	"Yes, because I have new information in my head." ($S_3$19), "We learned about the Earth's core." ($S_3$22)	2
Attention and Interest	"Models caught our attention at first glance." ($S_3$18)	1
Real-World Connection	"Understood how to recognize the real world made with the model." ($S_3$20)	1

Table 6 presents the analysis of 3rd grade students' responses to the second open-ended question on the post-test. The codes include enhanced understanding, learning reinforcement, ease of learning, success and achievement, prior ease, new information acquisition, attention and interest, and real-world connection. Each code is supported by example student responses, reflecting how the use of 3D models facilitated their learning and comprehension of the lesson topics. The frequency of each code indicates the prevalence of these themes among the student responses.

The frequency values obtained from the analysis of the responses of 3rd grade students to the last open-ended question in the achievement test applied after the implementation are presented in Table 7.

Table 7. Analysis of 3rd Grade Students' Responses to Last Question

Subject Areas	Frequency (f)
The Shape of the Earth	25
Structure of the Earth	27
Sense Organs and Their Tasks	26
Movement Properties of Entities	20
Moving and Stopping Objects	21
Properties Characterizing Matter	16
States of Matter	12
The Role of Light in Vision	16
Light Sources	9
Sounds Around Us	12
The Role of Sound in Hearing	10
Recognize the Things Around Us	16
Me and My Environment	14
Electrical Equipment	17
Electricity Sources	14
Safe Use of Electricity	14

Table 7 summarizes the frequency values obtained from the analysis of 3rd grade students' responses to the last open-ended question on the achievement test conducted after the implementation. The table lists various subject areas and the number of students who expressed interest in being taught these topics using 3D models. The subjects include the shape of the Earth, structure of the Earth, sense organs and their tasks, movement properties of entities, and more. The frequency of responses highlights the students' preferences and perceived benefits of using 3D models for different science topics.

To analyze the opinions of the 31 3rd grade students related to Table 7 and create codes based on their reasons for choosing science courses or topics. The codes created after the students' responses are presented below:

Table 8. Codes and Example 3rd Grade Students' Responses to Last Question

Codes	Example Student Responses	Frequency (f)
Ease and Relevance	"I learn more easily and while I am learning I know things that are relevant to the topic." ($S_3$1), "Because it's easier." ($S_3$28)	2
World Understanding	"I chose it to learn more about the world and other subjects." ($S_3$2), "I didn't know the layers of the earth, and when I did, it was very useful and helpful to me." ($S_3$26)	4
Specific Interests	"For example, I would like to know what harm the layers of the earth can do to people, and I would like to know what the layers of the earth are for." ($S_3$5), "I would like to understand different features, I would like to see different lights, I would like to see different electrical appliances." ($S_3$8)	4
Comprehensive Learning	"I would like to cover all subjects because I am a very curious person." ($S_3$13), "I would like to learn about the shape of the world, the structure of the world, the properties of beings, the states of matter, the sounds in the environment, electricity." ($S_3$30)	5
Teacher Influence	"This is what my own teachers and researcher told me." ($S_3$10)	1
Learning Enjoyment	"Because learning a new subject makes me very happy." ($S_3$14), "Because it would be better and more narrative." ($S_3$31)	3
Personal Preference	"Because I really want to learn what I have marked." ($S_3$15), "Because I like them all and they're all beautiful." ($S_3$19)	5
Novelty and Utility	"I wish our world wasn't round, I wish our sense organs were in charge." ($S_3$23), "The shape of the world, the structure of the world, sense organs and their functions." ($S_3$27)	5
Narrative and Illustration	"I would love to see the topics here in the figure and we would understand everything more easily and it would be a lot of fun." ($S_3$11), "I would like to see all of these issues illustrated." ($S_3$29)	3
Disinterest or Indifference	"None of them." ($S_3$7)	1

Table 8 summarizes the responses of 3rd-grade students regarding their preferred science topics taught using 3D models. The students highlighted that the use of 3D models facilitated easier understanding and engagement, particularly in abstract concepts like the structure of the Earth and the properties of matter. They expressed that visual and tangible representations helped them grasp these concepts better, making learning enjoyable and reinforcing their comprehension. The frequency of responses indicates a strong preference for topics that involve significant visual and spatial understanding, underscoring the effectiveness of 3D models in enhancing learning experiences in science education.

The results derived from analyzing the responses to the first open-ended question on the achievement test, which was administered as a post-test following the intervention, are presented below. Here are the codes based on 4th grade students' expressions of how models or certain teaching methods impacted their learning:

Table 9. Codes and Example 4th Grade Students' Responses to First Open-Ended Question

Codes	Example Student Responses	Frequency (f)
Reinforcement and Recall	"We remembered the topic again because we did it again." ($S_4$1), "So that when the researcher gives a test, we get a high score." ($S_4$12)	3
New Knowledge Acquisition	"I learned how the earth's crust is like and that there are minerals in the core." ($S_4$11), "I learned the subject much better and learned about the hydrosphere lithosphere." ($S_4$22)	9
Enhanced Comprehension	"It gave me a better understanding of the layers of the world because I learned better by modeling." ($S_4$5), "I didn't understand much about the earth's crust, thanks to you, I understood more." ($S_4$21)	9
Enjoyment and Engagement	"It was very fun for me and helped me to reinforce what we know." ($S_4$18), "It gave me fun and curiosity because I am interested in models and Tinkercad." ($S_4$27)	4
No Contribution	"I knew that's why he didn't contribute." ($S_4$14)	1
Learning Strategy Effectiveness	"I understood better, I was happy, I saw the 3D pen." ($S_4$16), "I understood better, I won't be surprised in the exams, we went over it twice and I remembered I better." ($S_4$23)	2

Table 9 presents the responses of 4th-grade students on how 3D models impacted their learning of scientific concepts. The students reported that 3D models significantly improved their comprehension by providing a concrete visual aid to abstract ideas. Many students noted that these models made learning fun and engaging, leading to better retention and understanding of topics such as the Earth's crust and its layers. The frequency of responses highlights the positive impact of hands-on learning tools, with a notable increase in students' enjoyment and interest in science classes.

The results derived from analyzing the responses to the second open-ended question on the achievement test, which was administered as a post-test following the intervention, are presented below. When the responses of 29 4th grade students regarding whether teaching the lesson with models facilitated their learning were analyzed, their opinions were coded thematically as follows:

Table 10. Codes and Example 4th Grade Students' Responses to Second Open-Ended Question

Codes	Example Student Responses	Frequency (f)
Enhanced Learning	"It made it easier because we understand better when there is a model." ($S_4$3), "It made it easier. We hadn't learned many things about that subject and now we have." ($S_4$28)	20
Fun and Engagement	"Yes, because a bit of fun makes us learn better." ($S_4$10), "Yes, it made it easier because the lesson taught with the model instead of paper was very fun and easy for me." ($S_4$18)	5
Repetition and Reinforcement	"Yes, and the more I went over it, the better I understood it." ($S_4$7), "Yes, because we went over it." ($S_4$23)	2
No Significant Effect	"No, because I knew." ($S_4$14), "No, because it doesn't matter whether we work with models or listen to the teacher's explanation, because if we listen, we understand." ($S_4$25)	2
Facilitated Understanding	"It made it easier to see the layers." ($S_4$4), "It made it easier because I learn more easily with the model." ($S_4$24)	11
Educational Accessibility	"It made it easier. We hadn't learned many things about that subject and now we have." ($S_4$28)	2

Table 10 details the 4th-grade students' opinions on whether 3D models facilitated their learning. Many of the students indicated that these models made the lessons easier to understand, emphasizing the effectiveness of visual aids in simplifying complex scientific concepts. The students appreciated the interactive nature of the models, which not only made the lessons more enjoyable but also reinforced their learning through repeated exposure and hands-on engagement. The responses reflect a consensus on the benefits of incorporating 3D models into science education to enhance learning outcomes.

The frequency values obtained from the analysis of the responses of 4th grade students to the last open-ended question in the achievement test applied after the implementation are presented in Table 11.

Table 11. Analysis of 4th Grade Students' Responses to Last Question

Subject Areas	Frequency (f)
Structure of the Earth's Crust	22
Movements of our Earth	18
Nutrients and Properties	13
Effects of Force on Objects	19
Force Applied by Magnets	20
Properties Characterizing Matter	13
Measurable Properties of Matter	15
States of Matter	17
Change of Matter with Heat Effect	15
Pure Substance and Mixture	17
Lighting Technologies	13
Appropriate Lighting	9
Light Pollution	12
Sound Technologies from Past to Present	20
Sound Pollution	10
Conscious Consumer	15
Simple Electric Circuits	15

Table 11 analyzes the 4th-grade students' preferences for science topics to be taught using 3D models. The students showed a strong interest in subjects involving significant visual and spatial elements, such as the structure of the Earth's crust, the effects of force on objects, and the properties of matter. The frequency of responses suggests that students find 3D models particularly useful in understanding and retaining information on these topics. The analysis underscores the potential of 3D models to improve engagement and comprehension in science education, especially for complex and abstract subjects.

To analyze the opinions of the 29 4th grade students related to Table 11 and create codes based on their reasons for choosing science courses or topics. The codes created after the students' responses are presented below:

Table 12. Analysis of 4th Grade Students' Responses to Last Question

Codes	Example Student Responses	Frequency (f)
Curiosity and Interest	"Because I am curious about these issues, and I want to learn." ($S_4$1), "Science is my favorite subject and it interests me." ($S_4$26)	9
Educational Engagement	"I chose these because they are better explained with models." ($S_4$10), "Because with models, it is easier, and I understand it very well and it is very beautiful." ($S_4$19)	5
Improvement and Understanding	"Because I don't know much about those subjects and to learn them in more detail." ($S_4$16), "It confuses me a lot, science is one of my worst subjects." ($S_4$21)	4
Academic Choice	"I chose more science courses because it was fun and beautiful." ($S_4$4), "Because we have two classes a day and because the class is busy." ($S_4$7)	2
Favoritism	"Because it's my favorite subject." ($S_4$12), "Science is my favorite subject and it interests me." ($S_4$26)	2
Educational Necessity	"To learn." ($S_4$6), "Because I want to learn about these things." ($S_4$14)	2
Content Specific	"Light pollution because I would like to learn. I would like to learn the force applied by the magnet because the structure of the earth's crust is fun, I would like to learn the measurable property of matter, I would like to learn how matter can be measured." ($S_4$11), "Because I want to know what pure matter and mixture are." ($S_4$24)	2
Aesthetic or Fun Preference	"I chose more science courses because it was fun and beautiful." ($S_4$4), "It would all be a lot of fun." ($S_4$25)	3

Table 12 categorizes the reasons why 4th-grade students chose specific science topics for 3D model-based learning. The students' responses highlight curiosity and interest in understanding the world around them, as well as the educational engagement and enjoyment derived from interactive learning tools. Many students pointed out that 3D models helped them understand difficult concepts more easily and made learning more fun and engaging. The analysis indicates a strong preference for hands-on, visually stimulating educational methods that enhance students' interest and performance in science subjects.

4. CONCLUSION AND DISCUSSION

Considering the results of the study conducted in two phases, the study indicates that teachers find certain abstract scientific concepts challenging to teach. Teachers observed that students struggle with topics not directly observable or relatable to their daily experiences. The study suggests that teaching methods incorporating visual and tactile elements could significantly enhance understanding. Integrating 3D modeling and printing in classroom instruction can help teach abstract scientific concepts to young learners across elementary, middle, and high school grades [28]. The results indicate a significant improvement in students' comprehension and retention of the structure of the Earth and its layers, when these models are incorporated into the teaching process. 3D printing in education improves students' practical ability, comprehensive quality, observation, concentration, creativity, and learning habits, including autonomous learning and cooperative learning [29]. Teachers noted that students frequently struggle with abstract concepts, finding it challenging to relate these to their daily experiences, ultimately affecting learning retention. Abstract concepts can indeed pose a challenge for students, as they often struggle to relate these concepts to their daily experiences [30] This difficulty can be attributed to various factors, including cognitive development, prior knowledge, and instructional strategies.

According to Piaget's theory of cognitive development, children in the concrete operational stage (ages 7-11) have difficulty understanding abstract concepts because they primarily focus on concrete experiences and struggle with hypothetical and abstract thinking. This developmental stage may explain why students find it challenging to relate abstract concepts to their daily experiences [31]. Furthermore, students' prior knowledge and experiences play a crucial role in their ability to grasp abstract concepts [32]. When students encounter abstract ideas that are disconnected from their prior experiences, they may struggle to comprehend and internalize these concepts [33-34]. This highlights the importance of building on students' existing knowledge and providing real-world examples to make abstract concepts more tangible and relatable. Instructional strategies also play a significant role in helping students bridge the gap between abstract concepts and their daily experiences. Hmelo-Silver, Duncan, Chinn [34] suggests that incorporating hands-on activities, visual aids, and real-life examples can enhance students' understanding of abstract concepts By providing concrete experiences and tangible connections, educators can help students relate abstract concepts to their daily lives. Educators can enhance the understanding of abstract concepts by relating them to familiar experiences. Moreover, encouraging discussions and critical thinking can help students explore the relevance of abstract concepts in their daily lives, fostering a more meaningful connection to the material [35-36].

In conclusion, the struggle that students face in relating abstract concepts to their daily experiences can be attributed to cognitive development, prior knowledge, and instructional strategies. Understanding these factors is crucial for educators in developing effective teaching methods that support students in comprehending and applying abstract concepts in their daily lives.

The use of 3D models in science lessons shows a positive impact on student achievement. The results suggest that these models make abstract concepts more tangible, aiding in better comprehension and retention. There's a noticeable improvement in students' test scores and conceptual understanding when 3D models are integrated into lessons. The use of 3D models as part of a more interactive and experiential approach in education effectively bridges this gap. By allowing students to handle and explore tangible representations of scientific concepts, these models facilitate a deeper understanding and increased student engagement [37]. The positive shift in students' academic achievements, as evidenced by pre-test and post-test results, underscores the potential of 3D models to enhance educational outcomes [38]. Students responded positively to the use of 3D models. They found these models engaging and helpful in visualizing complex scientific concepts. The hands-on experience provided by these models enhanced their interest in science and facilitated a deeper understanding of the subject matter. Students reported a newfound interest in science subjects, suggesting that the engaging nature of 3D models contributes to a more positive attitude towards learning. This finding is consistent with research indicating that interactive learning tools can significantly impact students' attitudes and interest in science [39]. Additionally, both teachers and students noted the potential of these models to correct misconceptions and reinforce content previously taught, thereby improving overall science literacy [40].

It is possible to say that 3D models can make important contributions in concertizing the subjects and concepts by enabling the transition from virtual objects to physical objects, verifying the theoretical knowledge learned by making applications, recognizing, and eliminating possible misconceptions in this process, and providing students with learning experiences by doing [41]. Many researchers argue that learning environments should be production and application-oriented to raise individuals who can keep up with the needs of the age and have these skills [42]. In this context, teachers and students can use 3D printing technologies in the design and production process of models suitable for the subject or problem situation, for example, in project-based learning activities Pinger [19] highlighted that students can choose what to print and how to print it, creating a platform for constructivist teaching, where educators encourage students to teach themselves how to use the technology. Additionally, Ishutov et al. [43] emphasized that the use of 3D printing in the K-12 environment could better prepare students for careers in emerging fields of technology, including STEM disciplines. Trust and Maloy [44] found that using 3D printing technologies in the teaching process is effective in the development of student skills such as 3D modelling skills, creativity, technology literacy, problem solving, self-learning and critical thinking, which are called 21st century skills.

The use of 3D printing technologies has been shown to have a positive impact on students' skill development, including cooperation, problem-solving, communication, responsibility, and leadership. For instance, studies have demonstrated that 3D printing technology can be effectively utilized to enhance project-based learning activities, providing students with opportunities to engage in hands-on, experiential learning and fostering interdisciplinary connections across various subjects [19], [41], [45-51]. Furthermore, the use of 3D printing in education has been reported to promote active student involvement in the teaching-learning process and better communication, which are essential skills for collaboration and cooperation [47]. On the other hand, the use of 3D printed models has been found to be directly applicable to students' intended careers, providing them with opportunities to develop leadership skills in their respective fields [51]. The findings show significant improvements in students' understanding of science topics using 3D models. However, the novelty effect is thought to have the potential to influence these results. The increased engagement and enthusiasm often associated with new educational tools may improve performance, a factor that should be considered when interpreting these results. Nevertheless, the integration of 3D models into science education addresses key challenges in teaching abstract concepts, improves academic performance and is well received by students, suggesting a useful approach to primary science education

The design thinking model, which constitutes the main framework of the study, has emerged as an effective method for concretizing abstract concepts in primary school science education and increasing students' academic achievement. By providing students with active learning experiences, this model enabled them to better understand and retain scientific concepts. The results of this study can be an important resource for educators and policy makers in developing teaching methods that support active learning processes and promote conceptual understanding.

5. RECOMMENDATIONS

The following suggestions can be made considering the study's findings regarding the implementation of 3D models in the teaching of science in elementary schools:

- Using 3D models to teach other complex scientific concepts in primary education is a good idea, since it improves student understanding and engagement.
- Give educators the tools and resources they need to successfully integrate 3D models into their lessons. Training on the creation and implementation of these models is part of this.
- More methodically incorporate 3D model-based learning into the science curriculum, making sure that it supports traditional teaching techniques and is in line with learning objectives.
- Encourage more studies examining the usefulness of 3D models for a range of age groups and other subjects. It is important to pursue innovation in technology and model design.
- Emphasize student-centered methods that allow students to actively interact with 3D models to develop their analytical and problem-solving abilities.
- Ensure that sufficient funds are set aside for the acquisition or development of 3D models as well as for the infrastructure required by technology to enable their use.
- Provide a feedback system so that students can voice their thoughts about the implementation of 3D models. This will help shape future modifications and enhancements.
- Future research could benefit from larger, more diverse samples that would enable a more comprehensive examination of these educational tools' impact across different demographic and educational settings.
- Future studies may aim to distinguish between the long-term educational benefits of 3D models and short-term increases in engagement and performance due to their novelty. This distinction is crucial for educators considering integrating innovative tools into their teaching practice.

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