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Research Article

The effect of problem-based STEM practices on pre-service science teachers' conceptual understanding

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Problem-based STEM education can be defined as the solving of real-life problems by using science, technology, engineering, and mathematics disciplines. This study aims to determine the effect of problem-based STEM practices on pre-service teachers' conceptual understanding. The pre-service science teachers participated in 12 weeks of STEM activities that focused on problem-solving. The study comprises four problem-based STEM activities that are based on real-life problems. This study employed a quasi-experimental, one-group pretest-posttest design. The study sample consisted of twenty-seven pre-service science teachers in a science teacher program at a state university in Türkiye. The researchers developed four conceptual understanding tests, each consisting of four or five open-ended questions, as a data collection tool in the study. The data obtained were classified using predetermined categories (e.g., complete understanding, no understanding), and the differences in conceptual understanding between the pre- and post-tests were determined using the paired samples t-test. The results indicate that problem-based STEM practices can enhance the conceptual understanding of pre-service science teachers in science education.

Keywords: Problem-based STEM; Conceptual understanding; Real-life problems

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1. Introduction

Due to rapid technological advancements, the demand for high-level skills and the ability to adapt quickly has increased. Consequently, countries have begun to take steps to develop the skills and competencies required for both work and life in the 21st century. Geisinger (2016) emphasized the importance of updating curricula to support the development of 21st-century skills. These skills provide students with the tools to gain a foothold in the ever-evolving job market and enable them to navigate a complex and interconnected global environment, supporting them to grow as versatile, innovative, and resilient members of society. Saavedra and Opfer (2012) also emphasized the importance of communicating, collaborating, and problem-solving in today's world.

STEM education is an educational approach in which science, technology, engineering, and mathematics disciplines are integrated and that supports the development of 21st-century skills.

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According to Singh (2021), "21st-century skills" generally cover fundamental skills, including digital literacy, critical thinking, and effective problem-solving in real-world contexts, and STEM education supports the development of these skills. Also, STEM education facilitates the development of core competencies required for the 21st century, such as collaboration, communication, and creativity. STEM education is high on many educational agendas because of its role in cultivating 21st-century skills and thereby boosting economic competitiveness (Uzun & Şen, 2023). STEM education has the advantage of relating the content taught to real-life problems (El Sayary et al., 2015). As Daugherty and Carter (2018) underlined, integrated STEM education cultivates problem-solving and cooperating skills and engages learners with engineering design. Bybee (2010) emphasised that engineering is linked to innovative thinking and problem-solving and that students must comprehend engineering and cultivate the necessary skills related to the design process.

One of the approaches that supports the development of some skills, such as problem-solving and collaboration, which is among the 21st-century skills, is problem-based learning [PBL]. Problem-based learning allows students to learn creative thinking, problem-solving, and collaborative work that traditional lessons cannot provide (Karamustafaoğlu & Yaman, 2015). In other words, PBL is a teaching approach that encourages students to take responsibility for their learning to solve real-world problems (Akçay, 2009; Merritt et al., 2017). According to Savery (2006), PBL is a student-centred approach that encourages students to research, combine theory and practice, and use knowledge and skills to solve problems. Scientists and engineers are problem solvers who design experiments, prepare prototypes for solutions to problems, analyse and interpret data and share it with relevant people (Dischino et al., 2011). The problem-based learning process also creates similar opportunities for students. According to Garrett (1986), problem-solving practices facilitate learning in science education and gain problem-solving skills. PBL is a learning method suitable for STEM education, as it increases students' ability to solve a problem they have not encountered before and, accordingly, their self-confidence (Ergün & Külekçi, 2019). Similarly, Daugherty and Carter (2018) underlined that STEM education offers an area for implementing problem-based learning and developing problem-solving skills. Problem-based STEM has the potential to develop learners' creativity, interest in STEM disciplines and collaborative skills (Rehmat & Hartley, 2020). As it is known, most of the problems in daily life can be solved by using the knowledge of many disciplines (The Korea Foundation for the Advancement of Science and Creativity [KOFAC], 2016). Therefore, including problem-based learning in the STEM approach would be advantageous, as it can contribute more to developing problem-solving skills. In some studies, focusing on STEM-based learning environments, learners sought design-oriented solutions to daily problems (Lou et al., 2011; Sarı et al., 2018; Uzun & Şen, 2023).

It is crucial for STEM education to be implemented by competent teachers, just as it is for many educational approaches to be implemented successfully. As Stohlmann et al. (2012) emphasized, content and pedagogical knowledge are essential to teacher competence. Therefore, developing pre-service teachers' conceptual understanding is necessary for increasing their professional competence. According to Gabel (2003), the primary objective of science education across all grades is to promote conceptual understanding and scientific inquiry. For conceptual understanding, the student must be able to think about that concept, apply it in other areas, redefine it with his/her own words, find a metaphor or an analogy, and build a physical or mental model of the concept (Konicek-Moran & Keeley, 2015). Due to the nature of problem-based learning, the problem-based STEM approach contributes to students' learning by asking questions about concepts. Conceptual understanding can also be achieved through processes such as prototyping, presentation, and marketing. Students may be required to design a prototype for a renewable energy source as part of a problem-based STEM approach, for example. Throughout the process, they will research and examine different renewable energy concepts, like solar and wind power. Their prototypes will then be developed using this information, taking into consideration factors such as efficiency and cost. In the end, they will present their prototypes and market them to further enhance their conceptual understanding. In STEM education, students can develop their conceptual understanding and solve problems more effectively through problem-based instruction.

Overall, it is expected that problem-based STEM education can enhance the conceptual understanding of pre-service science teachers. Studies on STEM education offer evidence-based information for educators and decision-makers regarding the effectiveness of STEM education (Uzun & Şen, 2023). Therefore, this study aimed to reveal the effect of problem-based STEM practices on pre-service science teachers' conceptual understanding. The research question is, '*How do problem-based STEM practices affect pre-service science teachers' conceptual understanding?*'.

2. Method

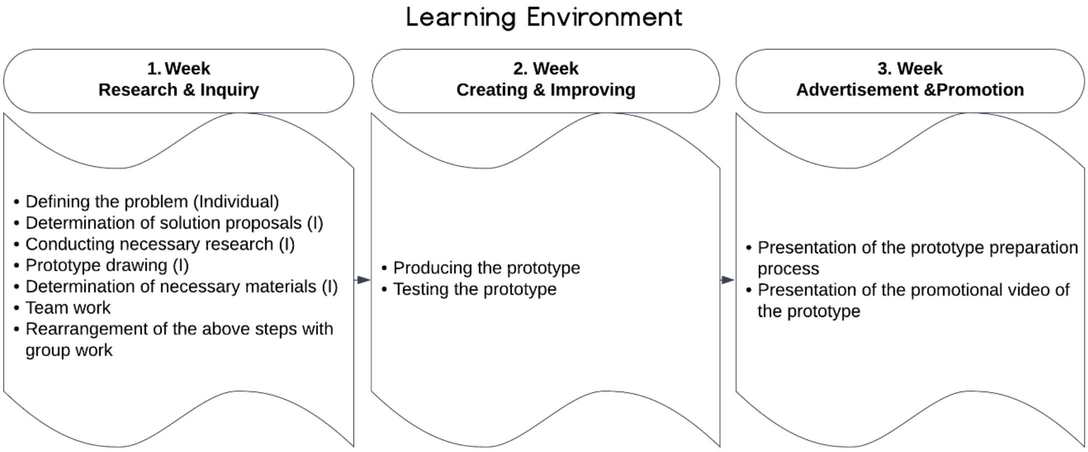
2.1. Research Model

This study aims to determine the effect of problem-based STEM practices on pre-service teachers' conceptual understanding. This is therefore a quasi-experimental research design that involves a pre-test and post-test without a control group. A study group of 27 junior pre-service teachers (8 males, 19 females) enrolled in teaching science at a state university participated in the study.

2.2. Implementation and Material

This study uses problem-based STEM activities based on real-life problems with multiple solutions and a variety of science disciplines. The process involved four problem-based STEM activities. For each activity, the worksheet contains a scenario and standard guide questions. A two-week course was offered to pre-service science teachers on the characteristics of STEM education. Pre-service science teachers engaged in STEM activities for 12 weeks after receiving instruction. A three-week process was used for each activity: 'Research & Inquiry,' 'Creating & Improving,' and 'Advertisement & Promotion'. Through the research-inquiry process, pre-service teachers developed their own answers to the topics, such as defining the problem, suggesting solutions, identifying and researching subjects, and designing prototypes and materials. Research was conducted individually, followed by group work. Pre-service teachers presented their suggestions in groups and decided on the best solution. Pre-service teachers produced the prototype in a laboratory environment in accordance with their best solution proposal during the creating-improving process. During the 'Advertisement-Promotion' week, pre-service teachers presented prototypes and commercials. The conceptual understanding of each activity was tested before and after it was implemented. Figure 1 illustrates the learning environment implementation process briefly.

Figure 1
Implementation process in the learning environment



2.3. Data Collection Tools

This study used conceptual understanding tests developed by the researchers as a data collection tool. The conceptual understanding tests were evaluated by two field experts to ensure validity, and the tests were arranged based on their feedback. In order to ensure the reliability of the tests, conceptual understanding tests were administered to 4th-grade pre-service science teachers before the actual implementation. Final versions of the conceptual understanding tests were created after examining if there were any questions that could not be understood. Four or five open-ended questions make up the conceptual understanding test.

The questions in the conceptual understanding test prepared for the "Frozen Roads" activity are given below as an example.

1. While cooking pasta, a frequently consumed food in many student houses, it is often advised that 'Do not add salt before the water boils'. What is the reason for this advice? Explain scientifically.
2. If you were to design a vehicle that can move freely and safely on snow, how would you design the parts of this vehicle that contact the ground? Explain scientifically.
3. During winter, the authorities salt the roads when snow falls or just before snow starts falling. Give a detailed scientific explanation of the purpose of this action.
4. On a freezing winter morning, you notice that your car's windscreen is covered with ice. Which method would you use to melt the ice most effectively and quickly? Explain scientifically how your method would work.
5. A vehicle can move freely on a flat, icy road but cannot climb an uphill road covered with ice. Explain this situation scientifically. In this case, what method should be followed for the vehicle to go on uphill road?

2.4. Data Analysis

An answer key, including possible scientific explanations and necessary information to solve the problem, was prepared for conceptual understanding tests. The answers of the pre-service science teachers were classified and scored according to predetermined categories. There are similar categorizations in the literature (Abraham et al., 1992; Baybars & Küçüközer, 2014; Hırça et al., 2011; Marek, 1986). Table 1 presents the scoring scale.

Table 1
Categories and scores used in the analysis of the conceptual understanding test

Categories	*Category Description*	*Score*
Complete Understanding (A)	A full explanation of a valid answer.	3
Partial Understanding (B)	Including an aspect of a valid answer but incomplete.	2
Alternative Partial Understanding (C)	It is not a valid answer, but it contains scientific knowledge that includes different aspects of relevant subjects.	1
No Understanding (D)	Leaving it blank, being scientifically incorrect.	0

The answers of the pre-service teachers were scored independently by two field experts using the answer key and the categorization in Table 1. The intra-class correlation coefficient was calculated as .98 according to inter-rater agreement. The t-tests were used to determine whether there were significant differences in the conceptual understanding scores of the pre-service science teachers. Quotations of the participants' answers are presented using pseudonyms, such as PSST1, PSST2.

3. Findings

The conceptual understanding test scores were analyzed using paired samples t-tests, and the results are presented in Table 2.

Table 2
Paired samples t-test results for conceptual understanding scores

	Test	*N*	*M*	*SD*	*SE*	*t*	*df*	*p*
1. Implementation	Pre-Test	27	5.37	2.54	0.48	−10.82	26	0.000
	Post-Test	27	9.25	2.21	0.42			
2. Implementation	Pre-Test	27	7.77	3.70	0.71	−4.78	26	0.000
	Post-Test	27	10.77	2.59	0.49			
3. Implementation	Pre-Test	27	4.59	2.69	0.51	−12.53	26	0.000
	Post-Test	27	10.62	2.67	0.51			
4. Implementation	Pre-Test	27	5.07	2.68	0.51	−9.80	26	0.000
	Post-Test	27	9.55	1.69	0.32			

As shown in Table 2, there are statistically significant differences between the mean scores in favour of the post-test mean scores for conceptual understanding. Considering the means, the lowest difference is in the conceptual understanding test of the second implementation and the highest in the conceptual understanding test of the third implementation.

Table 3 shows descriptive statistics of the conceptual understanding test before and after implementing the 'Should it be illuminated?' activity.

Table 3
Descriptive statistics of the conceptual understanding test before and after implementing the 'Should it be illuminated?' activity

Questions	*Test*	*A* f (%)*	*B* f (%)*	*C* f (%)*	*D* f (%)*
Q1	Pre-Test	4 (15%)	12 (44%)	4 (15%)	7 (26%)
	Post-Test	14 (52%)	9 (34%)	2 (7%)	2 (7%)
Q2	Pre-Test	11 (40%)	8 (30%)	0 (0%)	8 (30%)
	Post-Test	18 (67%)	3 (11%)	1 (3%)	5 (19%)
Q3	Pre-Test	2 (7%)	4 (15%)	8 (30%)	13 (48%)
	Post-Test	20 (74%)	4 (15%)	3 (11%)	0 (0%)
Q4	Pre-Test	2 (7%)	9 (34%)	10 (37%)	6 (22%)
	Post-Test	11 (40%)	9 (34%)	5 (19%)	2 (7%)

Note. *A: Complete Understanding, B: Partial Understanding, C: Alternative Partial Understanding, D: No Understanding.

The response rates for Question 1 (Q1) of the PSSTs for 'LED technology' are shown in Table 3, and 15% are categorized as 'complete understanding', while 26% are categorized as 'no understanding'. As a result of the implementation, 52% of PSST responses were classified as 'complete understanding' and 7% as 'no understanding'. For example, the answer given by a PSST to Q1 after the implementation is as follows; '*LED lamps are used because they provide more energy saving. They are 30-40% more efficient than normal lamps. Their lifespan is longer. LED lamps are light-emitting diodes.*' (PSST12-complete understanding). The answer given by another PSST to the Q1 before the implementation is as follows; '*LED products are preferred because they illuminate the environment more. Energy consumption in LED products is high, but efficiency is high. Therefore, these products are preferred.*' (PSST1-no understanding). For the question (Q2) about building an 'electric circuit', 40% of the PSSTs' responses were categorised as 'complete understanding' and 30% were categorised as 'no understanding' before the implementation. After the implementation, 67% of the PSSTs' responses were categorised as 'complete understanding' and 19% were categorised as 'no understanding'. For example, the answer given by a PSST to the Q2 before the implementation is as follows; '*X and Y do not light. Z and U light up. Because the M switch is closed, it cannot reach the battery even if current flows through the L key.*' (PSST14-complete understanding). The answer given by another PSST to the Q2 after the implementation is as follows; '*Z, U, X, Y give light. The current will circulate in the circuit. The M key will not have any effect. All lamps turn on.*' (PSST10-no understanding). For the question (Q3) on 'energy efficiency', 15% of the PSSTs' responses were categorised as 'partial understanding' and 48% were categorised as 'no understanding' before the implementation. After the implementation, 74% of the PSSTs' responses were categorised as 'complete understanding', and no responses were categorised as 'no understanding'. For instance, after the implementation, a PSST responded to Q3: '*To prevent such situations, I use renewable energy sources.* [Drawing: A road design featuring wind turbines, solar panels, and LED lighting].' (PSST2-complete understanding). A PSST drew a house that was not compatible with the context in the question before implementation (PSST21-no understanding). This conceptual understanding test's final question (Q4) discusses 'the properties of series-parallel circuits'. Table 3 illustrates how 7% of the PSST responses for Q4 were classified as 'complete understanding' and 37% as 'alternative partial understanding'. According to the PSSTs' responses after implementation, 40% of the respondents had a 'complete understanding', and 7% had a 'no understanding'. For example, the answer given by a PSST to Q4 after the implementation is as follows; '*I connected the bulbs in parallel. I did this because if one of the bulbs burst, the others would not light when connected in series. However, when connected in parallel, the others will continue to light even if one bursts.*' (PSST4-complete understanding). However, before the implementation, the same PSST explained, '*We enable two bulbs to light up with a single battery connected in series.*' (PSST4-no understanding).

Table 4 shows descriptive statistics of the conceptual understanding test before and after implementing the 'Frozen Roads' activity.

Table 4
Descriptive statistics of the conceptual understanding test before and after implementing the 'Frozen Roads' activity

Questions	*Test*	*A* f (%)*	*B* f (%)*	*C* f (%)*	*D* f (%)*
Q1	Pre-Test	15 (55%)	4 (15%)	0 (0%)	8 (30%)
	Post-Test	23 (85%)	4 (15%)	0 (0%)	0 (0%)
Q2	Pre-Test	9 (34%)	3 (11%)	9 (34%)	6 (22%)
	Post-Test	9 (34%)	6 (22%)	10 (37%)	2 (7%)
Q3	Pre-Test	8 (30%)	8 (30%)	7 (26%)	4 (15%)
	Post-Test	18 (67%)	7 (26%)	1 (3%)	1 (3%)
Q4	Pre-Test	4 (15%)	4 (15%)	14 (52%)	5 (19%)
	Post-Test	11 (40%)	7 (26%)	7 (26%)	2 (7%)
Q5	Pre-Test	2 (7%)	12 (44%)	4 (15%)	9 (34%)
	Post-Test	6 (22%)	8 (30%)	8 (30%)	5 (19%)

Note. *A: Complete Understanding, B: Partial Understanding, C: Alternative Partial Understanding, D: No Understanding.

The results of Table 4 indicate that 55% of the PSSTs had a "complete understanding" of factors that affect the boiling point of liquids, while 30% had no understanding before the implementation. It was found that 85% of the PSST responses were categorized as 'complete understanding', and none were classified as 'no understanding' after the implementation. The PSSTs' responses were categorized as 'partial understanding' in 15% of the cases. For example, the answer given by a PSST to Q1 before the implementation is as follows; '*Because salt affects the boiling point of water. Salt raises the boiling point of water and boils later.*' (PSST5-complete understanding). The answer given by another PSST to the Q1 before the implementation is as follows; '*If the salt is thrown away when the water boils, the salt dissolves more quickly.*' (PSST13-alternative partial understanding). Regarding the question (Q2) about 'the pressure-surface area relationship in solids', 34% of the PSSTs' responses were categorised as 'complete understanding', 34% as 'alternative partial understanding' and 22% as 'no understanding' before the implementation. After the implementation, 37% of the PSSTs' responses were categorised as 'alternative partial understanding' and 34% were categorised as 'complete understanding'. For example, the answer given by a PSST to the Q2 after the implementation is as follows; '*Increasing the surface area will allow us to move more comfortably on the snow. A spiked and wide pallet prevents slipping. There is more adhesion to the surface with nails.*' (PSST20-complete understanding). The answer given by the same PSST to the Q2 before the implementation is as follows; '*The rougher the surface in contact with the* *snow, the higher the chance of non-slip.*' (PSST20-alternative partial understanding). For the question (Q3) on 'factors affecting the freezing point', 30% of the PSSTs' responses were categorised as 'complete understanding' and 30% were categorised as 'partial understanding' before the implementation. After the implementation, 67% of the PSSTs' responses were categorised as 'complete understanding', and 3% were categorised as 'no understanding'. For instance, after the implementation, a PSST responded to Q3 as follows: '*Water freezes at 0 °C to form ice. When salt is added, the freezing point decreases as the freezing point decreases. In other words, it takes place below 0 °C.*' (PSST19-complete understanding). The answer given by another PSST to the Q3 before the implementation is as follows; '*The purpose of salting is to increase the friction on the asphalt and make the vehicle go more comfortably.*' (PSST6-alternative partial understanding). The question (Q4) is about the factors affecting the freezing point. As seen in Table 4, 52% of the PSSTs' responses for Q4 were categorised as 'alternative partial understanding', and 19% were categorised as 'no understanding' before the implementation. After the implementation, 40% of the PSSTs' responses were categorised as 'complete understanding' and 7% were categorised as 'no understanding'. For example, the answer given by a PSST to Q4 after the implementation is as follows; '*I would use antifreeze. Antifreeze does not freeze in cold weather. Or I would pour warm water. The warm water transitions to the temperature of the glass, and the frozen water dissolves. Saltwater can also be used. Saltwater freezing point is low.*' (PSST17-complete understanding). Again, after the implementation, another PSST explained, '*I heated the glass by touching it with my hands.*' (PSST18-no understanding). This conceptual understanding test's final question (Q5) concerns 'friction force, slope, and pressure in solids'. As seen in Table 4, 44% of the PSSTs' responses for Q5 were categorised as 'partial understanding' and 34% were categorised as 'no understanding' before the implementation. After the implementation, 30% of the PSSTs' responses were categorised as 'partial understanding' and 19% were categorised as 'no understanding'. For example, the answer given by a PSST to Q5 after the implementation is as follows; '*It cannot climb because uphill will have an adverse effect on the contact surface of the ground. A chain can be attached to the vehicle's tire. Alternatively, a direct-acting substance such as potassium acetate may be poured.*' (PSST22-complete understanding). After the implementation, another PSST explained, '*The vehicle should go up the slope in high gear. If it goes slowly, it will slip due to the slippery ice.*' (PSST3-no understanding).

Table 5 shows descriptive statistics of the conceptual understanding test before and after implementing the 'Let's Produce' activity.

Table 5
Descriptive statistics of the conceptual understanding test before and after implementing the 'Let's Produce' activity

Questions	*Test*	*A* f (%)*	*B* f (%)*	*C* f (%)*	*D* f (%)*
Q1	Pre-Test	5 (19%)	4 (15%)	8 (30%)	10 (37%)
	Post-Test	8 (30%)	7 (26%)	5 (19%)	7 (26%)
Q2	Pre-Test	3 (11%)	0 (0%)	11 (40%)	13 (48%)
	Post-Test	9 (34%)	10 (37%)	8 (30%)	0 (0%)
Q3	Pre-Test	1 (3%)	2 (7%)	12 (45%)	12 (45%)
	Post-Test	16 (59%)	8 (30%)	3 (11%)	0 (0%)
Q4	Pre-Test	1 (3%)	8 (30%)	9 (34%)	9 (34%)
	Post-Test	9 (34%)	7 (26%)	9 (34%)	2 (7%)
Q5	Pre-Test	0 (0%)	5 (19%)	16 (59%)	6 (22%)
	Post-Test	19 (70%)	7 (26%)	1 (3%)	0 (0%)

Note. *A: Complete Understanding, B: Partial Understanding, C: Alternative Partial Understanding, D: No Understanding.

Table 5 shows that 37% of the PSSTs' responses to the question (Q1) regarding 'equilibrium, force' were categorized as 'no understanding' before the implementation. As a result of the implementation, 30% of PSST responses were classified as 'complete understanding', 26% as 'no understanding', and 26% as 'partial understanding'. For example, the answer given by a PSST to

Q1 after the implementation is as follows; '[*Load x Load Arm = Force x Force arm]. The left side of the balance board stays down because the balance point is closer to the right side. Thus, there is a gain in the force but a loss in the distance.*' (PSST5-complete understanding). The answer given by another PSST to the Q1 before the implementation is as follows; '*[Incorrect drawing] The child on the left side always stays down because he/she is close to the centre of gravity.*' (PSST15-no understanding). Regarding the question (Q2) about the 'mass-weight relationship', 11% of the PSSTs' responses were categorised as 'complete understanding', and 48% were categorised as 'no understanding' before the implementation. After the implementation, 37% of the PSSTs' responses were categorised as 'partial understanding' and 34% were categorised as 'complete understanding'. For example, the answer given by a PSST to the Q2 after the implementation is as follows; '*The mass does not change. Weight changes because weight is related to gravity. Since the planet's gravity in the dream is less than the Earth's, the weight is proportionally less.*' (PSST11-complete understanding). The answer given by the same PSST to the Q2 before the implementation is as follows; '*Since the gravity of the planet seen in the dream is low, its mass appears low.*' (PSST11-no understanding). For the question (Q3) on 'simple machines, force gain', 45% of the PSSTs' responses were categorised as 'alternative partial understanding' and 45% were categorised as 'no understanding' before the implementation. After the implementation, 59% of the PSSTs' responses were categorised as 'complete understanding', and 30% were categorised as 'partial understanding'. For instance, before the implementation, a PSST responded to Q3 as follows: '*The system in the seat has a simple machine assembly. There are flexible and tense springs in the system.*' (PSST16-no understanding). The answer given to the same PSST to the Q3 after the implementation is as follows; '*There is a hydraulic system. Hydraulic systems provide force gain. When the pedal is pressed, it lifts easily due to compression.*' (PSST16-complete understanding). The question (Q4) is about 'the force-support point relationship'. As seen in Table 5, 30% of the PSSTs' responses for Q4 were categorised as 'partial understanding', 34% were categorised as 'alternative partial understanding' and 34% were categorised as 'no understanding' before the implementation. After the implementation, 34% of the PSSTs' responses were categorised as 'complete understanding', 26% were categorised as 'partial understanding' and 34% were categorised as 'alternative partial understanding'. For example, the answer given by a PSST to Q4 after the implementation is as follows; '*The most efficient point to crack a walnut with less force is number 3 because it is the furthest point from the fulcrum.*' (PSST27-complete understanding). Before the implementation, another PSST explained, '*They are simple machines in which the fulcrum is at number 2, the load is at number 1, and the force is at number 3.*' (PSST2-no understanding). This conceptual understanding test's final question (Q5) concerns 'pressure and force in liquids'. As seen in Table 5, 59% of the PSSTs' responses for Q5 were categorised as 'alternative partial understanding' and 22% were categorised as 'no understanding' before the implementation. After the implementation, 70% of the PSSTs' responses were categorised as 'complete understanding', and 26% were categorised as 'partial understanding'. For example, the answer given by a PSST to Q5 after the implementation is as follows; '*In hydraulic jacking, liquids are incompressible and transmit pressure as they are. Pascal explained this [a correct drawing]. There is a loss in distance but a gain in force.*' (PSST21-complete understanding). Before the implementation, another PSST explained, '*The jack handle is long. If the place where it lifts the car is the centre, more effective results are obtained with less force as it moves away. More force would have been required if he held it closer to the jack's centre.*' (PSST11-alternative partial understanding).

Table 6 shows descriptive statistics of the conceptual understanding test before and after implementing the 'Agriculture of the Future' activity. Table 6 shows that 52% of the PSST responses were classified as 'complete understanding' when asked about the 'photosynthesis-respiration relationship', while 30% of the responses were classified as 'no understanding' prior to implementation. After the implementation, 100% of the PSSTs' responses were categorised as

Table 6
Descriptive statistics of the conceptual understanding test before and after implementing the 'Agriculture of the Future' activity

Questions	*Test*	*A* f (%)*	*B* f (%)*	*C* f (%)*	*D* f (%)*
Q1	Pre-Test	14 (52%)	2 (7%)	3 (11%)	8 (30%)
	Post-Test	27 (100%)	0 (0%)	0 (0%)	0 (0%)
Q2	Pre-Test	3 (11%)	0 (0%)	13 (48%)	11 (40%)
	Post-Test	18 (67%)	4 (15%)	4 (15%)	1 (3%)
Q3	Pre-Test	5 (19%)	6 (22%)	5 (19%)	11 (40%)
	Post-Test	17 (63%)	5 (19%)	2 (7%)	3 (11%)
Q4	Pre-Test	4 (15%)	7 (26%)	8 (30%)	8 (30%)
	Post-Test	7 (26%)	9 (34%)	9 (34%)	2 (7%)

Note. *A: Complete Understanding, B: Partial Understanding, C: Alternative Partial Understanding, D: No Understanding.

'complete understanding'. For example, the answer given by a PSST to Q1 before the implementation is as follows; '*Plants photosynthesise during the day and respire at night. So, the first dialogue is correct [Wrong dialogue].*' (PSST26-no understanding). The answer given by the same PSST to the Q1 after the implementation is as follows; '*Plants respire day and night. They convert oxygen into carbon dioxide day and night. Plants perform photosynthesis only during the day because they can get the solar energy required for photosynthesis only during the day.*' (PSST26-complete understanding). To the question (Q2) about 'factors affecting germination', 48% of the PSSTs' responses were categorised as 'alternative partial understanding' and 40% were categorised as 'no understanding' before the implementation. After the implementation, 67% of the PSSTs' responses were categorised as 'complete understanding', 15% were categorised as 'partial understanding', and 15% were categorised as 'alternative partial understanding'. For example, the answer given by a PSST to the Q2 before the implementation is as follows; '*In container 1, germination occurs. It photosynthesises because it receives sunlight. In the second container, it respires because it is dark, but not as much as the first one. Since there is no air in the third container, germination does not occur because carbon dioxide will accumulate inside.*' (PSST19-no understanding). The answer given by the same PSST to the Q2 after the implementation is as follows; '*Germination requires water, temperature, and oxygen. For three containers with equal amounts of water, 1 and 2 germinate similarly. Because light does not affect germination. Since there will be no air in the third container, there will be no germination.*' (PSST19-complete understanding). For the question (Q3) on 'factors affecting the rate of photosynthesis', 22% of the PSSTs' responses were categorised as 'partial understanding' and 40% were categorised as 'no understanding' before the implementation. After the implementation, 63% of the PSSTs' responses were categorised as 'complete understanding', and 19% were categorised as 'partial understanding'. For instance, after the implementation, a PSST responded to Q3 as follows: '*Chlorophyll absorbs light. It reflects green light. Other colours are absorbed. Since purple and red colours have the highest frequency among the colours in the light spectrum, photosynthesis occurs the fastest in these lights.*' (PSST7-complete understanding). Before the implementation, for example, the answer given by another PSST to the Q3 before implementation is as follows; '*Algae is a green plant. Since it reflects red and purple light, bacteria density is high in those colours.*' (PSST2-no understanding). This conceptual understanding test's final question (Q4) concerns 'nutrients and energy in plants'. As seen in Table 6, 30% of the PSSTs' responses for Q4 were categorised as 'alternative partial understanding' and 30% were categorised as 'no understanding' before the implementation. After the implementation, 26% of the PSSTs' responses were categorised as 'complete understanding' and 34% were categorised as 'partial understanding'. For example, the answer given by a PSST to Q4 before the implementation is as follows; '*Plants get their food from water and minerals in the soil.*' (PSST23-no understanding). However, the same PSST explained after the implementation, '*Plants produce their food due to photosynthesis. They obtain energy by using this food.*' (PSST23-complete understanding).

4. Discussion and Conclusion

The purpose of this study was to provide insight into how problem-based STEM implementations affect pre-service teachers' conceptual understanding of science. It was found that problem-based STEM practices contributed to the conceptual understanding levels of pre-service science teachers. Research was conducted by pre-service teachers as part of the implementation process to define and solve the problems. The pre-service teachers should decide which subjects to investigate in order to address the problems in the activities. STEM problems require the use of more than one discipline to solve, and pre-service teachers studied multiple fields to gain an understanding of these topics. As a result of these efforts, pre-service teachers can gain a deeper understanding of the concepts and subjects they are studying. Guzey et al. (2019) underlined that integrating engineering with science education assists in learning science through experience. Dedetürk et al. (2021) also reported that a design-oriented STEM learning environment supports learners' conceptual understanding in science education. As it is known, it is essential in STEM education to connect problems with daily life (Breiner et al., 2012; Hansen & Gonzalez, 2014), and the connection may also contribute to conceptual understanding and meaningful learning. Kartal Taşoğlu and Bakaç (2014) noted using daily life problems promotes learners' conceptual learning in science education. Similarly, studies reported that STEM education improves conceptual understanding (Karahan et al., 2015; Karahan et al., 2021; Nasir et al., 2022; Thahir et al., 2020).

In the 'Should it be illuminated?' activity, the pre-service teachers had opportunities to gain knowledge of science topics such as 'electrical circuits, energy efficiency, and LED technology' as they searched for a solution to the problem. Additionally, they designed many road lighting systems to solve the problem and used different sensor technologies in these designs. In STEM education, many disciplines are used in problem-solving, and a conceptual understanding of each discipline is expected to develop throughout the process (Prastika et al., 2022). Studies reported that the STEM approach increases STEM literacy and conceptual understanding in electricity and energy subjects (Bakırcı et al., 2022; Prima et al., 2018). The highest score difference occurred in the third question of the conceptual understanding test that evaluates the conceptual understanding of science topics linked to this activity. Regarding responses to this question about energy efficiency and alternative energy sources, 74% of the pre-service teachers' answers were under the 'complete understanding' category after the implementation. Hiğde (2022) and Yıldırım and Selvi (2016) emphasised that a STEM-based learning environment raised pre-service teachers' perceptions and attitudes about renewable energy sources. Cavas (2011) states that affective factors such as motivation and attitude support conceptual understanding in science education. The STEM-based learning environment in this study may have increased the motivation of pre-service teachers to learn these subjects and thus contributed to their conceptual understanding.

The pre-service teachers had opportunities to gain knowledge of science topics such as 'factors affecting the freezing point, surface area-pressure relationship, frictional force, solutions' as they searched for a solution to the problem in the 'Frozen Roads' activity. As part of this activity, pre-service teachers created prototypes to prevent or reduce black ice formation. A majority of these prototype systems are working in real-world conditions. STEM education must include prototyping as a critical step to problem-solving (Carrol, 2015; Tabarés & Boni, 2023). On the conceptual understanding test linked to this activity, the biggest difference in scores occurred on the first question. Following the implementation, 85% of the pre-service teachers answered this question about solutions and boiling points with a 'complete understanding'. On the other hand, no differences were observed in the 'complete understanding' category in the second question of the conceptual understanding test that assessed conceptual understanding related to this activity. There is a difference in scores in favor of the conceptual understanding post-test for other questions. For the second question, there is an increase in answers in the 'partial understanding' category. Pre-service teachers were asked to design a vehicle that could move freely and safely on snow and explain it scientifically in the second question related to frictional force and pressure. Pre-service teachers may have found this question challenging because it required design thinking in a short amount of time and a scientific explanation of why they designed the vehicle in the first place. Razali et al. (2022) highlighted that learners encounter challenges in design thinking. However, Li et al. (2019) emphasized that STEM education allows learners to develop design thinking. In this context, it can be underlined that learners may develop their design thinking skills by becoming more involved in such activities.

The 'Let's produce' activity provided pre-service teachers with an opportunity to become familiar with science topics such as simple machines, mass-weight, force, and hydraulic systems. Pre-service teachers designed a 'robotic arm' to solve the problem using STEM disciplines. Students are most easily introduced to STEM disciplines through robotics, which is the most commonly used STEM implementation method (Benitti & Spolaor, 2017; Bers, 2010; Chalmers, 2017; Ching et al., 2019). Although robotic arms were designed using different technologies during the implementation process, most of the robotic arms designed by the groups work with hydraulic systems. For this reason, although there was an improvement in the conceptual understanding levels of pre-service teachers in simple machines, mass-weight, and force, their conceptual understanding of hydraulic systems developed more. Some studies reported that STEM practices on subjects of the force, simple machines, and hydraulic systems improve students' academic achievement, motivation, attitudes towards science, critical thinking and conceptual understanding (Aydın & Karslı Baydere, 2023; Ergün & Kıyıcı, 2019; Gazibeyoğlu, 2018; Gülseven et al., 2021; Pagan, 2018; Yılmaz Baltabıyık & Duru, 2021).

Pre-service teachers participated in the 'Agriculture of the Future' activity, which provided them with opportunities to learn about science topics as 'photosynthesis, respiration, germination, and food production in plants'. To gain a better understanding of plants and to control germination and growth, pre-service teachers constructed a prototype of a soilless agriculture (hydroponic farming) system. In order to design these systems, Arduino and various sensor technologies were used. When pre-service teachers were asked about photosynthesis and respiration after the STEM implementation, all of their responses fell into the category of 'complete understanding.' Similarly, Öztürk and Özdemir (2020) reported that STEM education enhanced students' understanding of photosynthesis in plants. A minor improvement in conceptual understanding was observed in 'food and energy production in plants'. It is expected that pre-service teachers will attain a higher level of conceptual understanding of 'food and energy production in plants' if the prototypes are 'Soilless agriculture' systems. In the complete understanding category, however, pre-service teachers' responses were lower than expected. Perhaps this is due to the limited conceptual understanding of the 'plant nutrient solutions' by pre-service teachers. As it is known, in soilless agricultural systems, external sources provide necessary elements and minerals to the plants. These solutions containing elements and compounds such as 'nitrogen, phosphorus, potassium, magnesium, and iron' are sold as labelled 'plant food' in the markets. Due to its incompatibility with the statement that the plant produces its own food, this label may have caused conceptual confusion. According to the studies, students often believe plants obtain food from the soil (or the outside) and derive energy directly from sunlight (Barman et al., 2006; Wood-Robinson, 1991).

The Problem-Based STEM practices introduced in this study included 'research and inquiry', 'creating and improving design', and 'advertisement and promotion'. Despite the fact that all of these processes were designed to promote conceptual understanding, some stages, particularly during the research-inquiry process, positively contributed to preservice teachers' conceptual understanding, such as defining the problem, determining possible solutions, and researching the subjects needed to solve the problem. According to Gabel (2003), inquiry is one of the steps in developing conceptual understanding in science education. While pre-service teachers develop their conceptual understanding of the inquiry process, they also learn the steps scientists use in problem-solving. STEM education offers numerous advantages, including hands-on learning, taking responsibility for learning, and creating authentic learning environments (Gya & Bjune, 2021). The engineering design process in STEM education allows individuals to learn through experience and improve their conceptual understanding (Apedoe et al., 2008; Dedetürk et al., 2021). Finally, during the advertisement-promotion process, the pre-service teachers presented information about how they developed their prototypes, where they focused, their research, and whether they solved the problem. They also created and showed an advertisement video to market their products. The pre-service teachers used various multimedia technologies in this process. Multimedia technologies are powerful tools for creating and presenting multilevel scientific thinking (Shchyrbul et al., 2022). Using multimedia in learning environments allows students to present the concepts they learned in their own style and words. Thus, meaningful learning is supported (Laksana et al., 2019). One indicator of conceptual understanding is individuals re-express acquired knowledge in their own words (Konicek-Moran & Keeley, 2015). The findings indicate that problem-based STEM practices can enhance the conceptual understanding of pre-service science teachers.

A limitation of this experimental study is the lack of a control group. Experimental studies with control groups are therefore recommended to evaluate the effects of STEM learning environments on conceptual understanding when compared to other educational approaches. Moreover, qualitative studies can be conducted to identify factors that influence pre-service teachers' conceptual understanding of STEM learning environments.

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