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Scaffolding Pre-service Science Teachers' Problem-Solving Strategies in a Methane Gas Detector Task Within an Earthquake-Robotics PD Course

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Abstract

Educational robotics (ER) has the potential to be a novel approach to teaching geohazards such as earthquakes at the college level. ER, which provides learners with problem-solving settings, requires proficiency in content knowledge and practical application to address ill-defined problems, challenging learners to master problem-solving strategies. Despite several efforts in the existing literature, it is necessary to scaffold the problem-solving strategies comprehensively. This qualitative study investigated the problem-solving strategies of nine pre-service science teachers aligned with a coding scheme containing problem-solving strategies not previously documented together. The participants were assigned to construct a methane gas detector with Tinkercad to mitigate post-earthquake explosion risks for rescue teams in an online robotics-integrated earthquake professional development (PD) course. Qualitative data, including artifacts, observations, and interviews, were analyzed using deductive coding. The results indicated that participants predominantly employed trial and error, expert opinion, and case-based reasoning. They rarely utilized heuristics and intuition and did not use capacity evaluation, prediction, or sketching strategies. Furthermore, the study synthesized different problem-solving strategies into a comprehensive framework, which was used as a coding scheme. This framework helps to clarify problem-solving mechanisms in an ER context, offering a structured approach.

Keywords Devising gas detection devices · Educational robotics · Pre-service science teachers · Problem-solving strategies · Teaching earthquake

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Introduction

Earthquakes may cause thousands of fatalities and widespread damage due to poorly constructed buildings and erroneous civil engineering practices. For instance, on 6 February 2023, a Turkey–Syria earthquake with a magnitude of 7.8 (with the maximum Mercalli intensity XII) struck the southeastern region of Turkey and the northern part of Syria, resulting in tens of thousands of fatalities, injuries, and the structural collapse of buildings (Naddaf, 2023). Likewise, in Indonesia, where earthquakes frequently strike, an earthquake occurred with a magnitude of 7.3, precisely in the Mentawai islands, on 25 April 2023, leading to a tsunami that damaged homes (Daryono, 2023).

The overall goal of science education is to assist students in comprehending natural phenomena such as earthquakes (NRC, 2012; OECD, 2023). Earthquakes are integral components of science curricula worldwide, and K-12 earthquake education conveys crucial scientific knowledge, including Earth's structure, seismic causes, epicenter point

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determination, magnitude measurement, preparedness, and building safety (MoE, 2017, 2018, 2020, 2022). Research in earthquake education ranges from elementary to college level. Lower-grade studies emphasize students' comprehension of earthquake causes and problem-solving skills, often using specialized teaching materials and games (Ardianto et al., 2019; Cifelli et al., 2019; English et al., 2017; Lownsbery & Flick, 2020; Novia et al., 2021; Tsai, 2001). Meanwhile, college-level research reveals the significance of innovative teaching methods, including earthquake machines and virtual laboratories, to deepen understanding and practical application of earthquake knowledge (Cavlazoglu & Stuessy, 2017; Kuester & Hutchinson, 2007; Novak et al., 2019).

Educational robotics (ER) enhances science education by improving comprehension of complex concepts such as gears, force, torque, and animal behavior (Barak & Assal, 2018; Barak & Zadok, 2009; Chambers et al., 2008; Cuperman & Verner, 2019). It also fosters creativity, spatial ability, computational thinking, and problem-solving skills (Cuperman & Verner, 2019; Fakaruddin et al., 2023; Jaipal-Jamani & Angeli, 2017; Julià & Antolí, 2016; Munoz-Repiso & Caballero-González, 2019). Additionally, ER benefits school attendance and teamwork (Kucuk & Sisman, 2017; Mac Iver & Mac Iver, 2019).

However, more research is needed on using ER, an emerging technology, for teaching earthquakes at the college level. Technology, such as ER, serves as an advantage to science education, especially on the topic of earthquakes (Auyelbek et al., 2022; Benitti, 2012; Sapounidis et al., 2023). Incorporating robotics with sensors and motors may enable learners to apply knowledge to real-world scenarios, improving their understanding of seismic phenomena and enhancing their learning experiences. Moreover, establishing well-defined problem-solving strategies tailored for educators within ER environments, including teachers and pre-service teachers, can promote professional development (PD) where teachers' needs can be fulfilled. Well-defined problem-solving strategies can guide PD designers in creating an environment where teachers can not only learn science content and robotics knowledge but also integrate insights on how to handle problems based on ER with effective problem-solving strategies.

Teachers play an essential role in guiding students through well-designed ER-based challenges, often demanding subject matter expertise, and applying this knowledge into practice to address these problems. Therefore, the objective of this study is to reveal pre-service science teachers' employed problem-solving strategies while engaging in a task involving the development of a gas detector used after an earthquake for rescue teams within an ER-based earthquake problem-solving setting.

In this study, we concentrate on the strategies employed by pre-service science teachers using ER in teaching about earthquakes. We ask the following research question:

What problem-solving strategies are employed by pre-service science teachers when engaged in an ER-based problem related to earthquakes, precisely, developing a gas detection device using Tinkercad?

Literature Review

To address the research questions comprehensively, we have examined existing literature in three distinct areas: teaching about earthquakes, ER, and problem-solving strategies.

Teaching about Earthquakes

Teaching and learning about geohazards, such as earthquakes, has become a prominent issue in science education. This content is incorporated into the curricula of various countries, including Finland (MoE, 2017), Singapore (MoE, 2020), the USA (NRC, 2012), and Turkey (MoE, 2018), reflecting its importance and widespread recognition. These topics also align with several educational frameworks, including the Sustainable Development Goals, the science content domains in Earth Science within the trends in the International Mathematics and Science Study (TIMSS) assessment framework, and the Programme for International Student Assessment (PISA) framework for assessing scientific literacy (OECD, 2023; TIMSS, 2023 Science Assessment Framework, 2021; Aydin & Ozcan, 2022). The knowledge of earthquakes in K-12 education encompasses essential scientific information, covering various aspects such as the structure of the Earth's crust, the causes of seismic activity, defining epicenter points, methods for measuring magnitude and intensity, earthquake preparedness, and constructing earthquake-resistant buildings (Christopherson & Birkeland, 2018). Understanding these subjects equips learners with crucial scientific knowledge to better comprehend and respond to earthquakes.

Some studies concentrated on interventions to improve students' understanding of earthquakes and disaster preparedness. For instance, English et al. (2017) focused on designing and constructing earthquake-resistant buildings to promote problem-solving approaches to an engineering-based problem of earthquakes. Cifelli et al. (2019) developed earthquake kits to test students' knowledge of earthquakes at a university to enhance their understanding. Rany and Mundilarto (2021) utilized android-based earthquake disaster learning media to improve students' problem-solving skills and disaster preparedness knowledge. Additionally, Novia et al. (2021) conducted laboratory experiments, challenging students to test earthquake-resistant buildings and promoting disaster literacy. Savasci (2011) also designed an activity for middle-grade students that aims to assist them in exploring

potential factors that influence the extent of earthquake damage, including distance, strength, duration, ground composition, height, and structure of the buildings, and educate them about effective strategies to mitigate such damages.

For college-level students, Ardianto et al. (2019) adopted a series of engaging STEM activities that provided compelling evidence and practical experience. These activities included building an earthquake machine, defining the epicenter point, and constructing earthquake-resistant buildings using hands-on apparatus. The researchers concluded that these activities are suitable for teaching about the causes of earthquakes and tectonic movements and using technology to reduce the effects of natural hazards like earthquakes. Novak et al. (2019) designed an escape room activity for college students, engaging them in earthquake preparedness activities. This innovative setting and its activities provide opportunities to prepare for and prevent earthquakes. In secondary school teacher PD programs, Cavlazoglu and Stuessy (2017) found that conducting discussions about earthquake reports, engaging in interactive games related to seismic events, interpreting seismic data, measuring magnitude, and conducting shake table demonstrations improved teachers' understanding of earthquake engineering and helped establish more precise connections between domain-specific scientific concepts. Moreover, Kuester and Hutchinson (2007) emphasized the importance of virtual reality-enriched web-based settings for observing, exploring, and comprehending complicated aspects of earthquake-related topics.

Considering the findings from earlier research (Ardianto et al., 2019; Cavlazoglu & Stuessy, 2017; Kuester & Hutchinson, 2007; Novak et al., 2019), it is evident that employing innovative and interactive teaching methods is crucial for effectively addressing earthquake education at the college level. The methods include developing earthquake machines, defining epicenter points, constructing earthquake-resistant buildings, designing escape rooms and games, interpreting seismic hazard maps, conducting magnitude measures, utilizing shake tables, and using virtual laboratories with Lego. These approaches contribute to a deeper understanding of earthquakes and earthquake preparedness, enabling students to apply this knowledge practically by solving problems related to the subject matter.

Educational Robotics

Robotics, the science of building robots, is a discipline in which engineering and computer science intersect to solve challenges in the human-made world (Michalec et al., 2021; Thring, 1966). ER is a teaching method that engages students in activities such as devising, constructing, and programming robots using popular robotics kits like Arduino, Lego, or Fischertechnik. Integrating ER into science education provides a unique problem-solving setting where students can autonomously apply scientific facts, concepts, or rules to real-life, authentic, and ill-defined problems or tasks (Chambers & Carbonaro, 2003). For instance, a typical ER task might involve constructing a Lego EV3 robot to model the behaviors of animals, such as snakes, and exploring how these behaviors contribute to survival (Cuperman & Verner, 2019).

ER aligns with constructivism, a learning theory emphasizing learners constructing new knowledge through their prior knowledge and experiences. By engaging in hands-on activities with robots, students actively participate in their learning process, leading to a deeper understanding of scientific facts, concepts, and rules (Barak & Zadok, 2009). Moreover, ER is grounded in constructionism, a concept proposed by Seymour Papert, which focuses on understanding the cognitive structure of learning by actively building knowledge structures through purposeful artifact production (Papert, 1993; Papert & Harel, 1991; Ucgul & Cagiltay, 2014).

During the past two decades, research has been conducted to examine the effects of robotics on learning outcomes. Some studies have focused on the role and impacts of ER in enhancing students' knowledge acquisition. For instance, Chambers et al. (2008) explored the mechanical advantages of gears, while Barak and Zadok (2009) delved into concepts like force, friction force, torque, mass, and gravity. Barak and Assal (2018) investigated distance, velocity, and time relations, and Cuperman and Verner (2019) explored models of biological systems. Applying ER in science education enhances learners' comprehension of subject matter and fosters mastery of essential knowledge (Benitti, 2012; Chambers & Carborano, 2003). This approach encourages learners to engage in more meaningful and authentic learning experiences with previously learned concepts, such as unit conversions, directions, and circle circumference (Somyürek, 2015). In addition, ER enhances creativity, spatial ability, computational thinking, self-efficacy, and analogical reasoning (Cuperman & Verner, 2019; Fakaruddin et al., 2023; Jaipal-Jamani & Angeli, 2017; Julia & Antoli, 2016; Munoz-Repiso & Caballero-González, 2019). For example, LEGO robotics improves problem-solving skills, and teachers play a vital role in linking problem-solving with ER (Zhang & Zhu, 2022). ER also boosts school attendance and teamwork skills when integrated into courses (Kucuk & Sisman, 2017; Mac Iver & Mac Iver, 2019).

Problem-solving Strategies in ER Settings

Problem-solving requires learners to apply their acquired knowledge, actively employ it, and master problem-solving strategies (Dewey, 1938; Gagne, 1965; OECD, 2023). These strategies encompass various approaches employed for resolving problems. Approaching a problem with the

correct strategy, especially for ill-defined problems, assists learners in achieving better performance and accomplishing tasks efficiently (Jonassen, 2011; Watts, 1991). Thus, defining a problem-solving strategy for tackling issues to enhance learners' problem-solving competencies is essential. Fraenkel and Wallen (2009) contend that the ways of knowing or problem-solving strategies people use comprise six components, including sensory experience, agreement with others, expert opinion, logic, and the scientific method.

Some studies (An et al., 2022; Barak & Zadok, 2009; Castledine & Chalmers, 2011) have explored students' and teachers' problem-solving strategies in an inductive way when engaged in ER tasks. Barak and Zadok (2009), for instance, assigned students to design a car capable of ascending an inclined plane, crafting a fishing rod, and creating a machine for propelling a ball, targeting junior high school students. They concluded that students tend to employ trial-and-error methods in the early phases of problem-solving. Subsequently, as they gain experience, they adopt other methods, including instinctive approaches and heuristics. These heuristics encompass techniques such as Scamper and Triz, eliminating a component, assigning a new function, and systematically examining. Another example is provided by Castledine and Chalmers (2011), who exposed sixth-grade students to challenges involving racing and navigating mazes using Lego robotics tools. They asserted that students could use problem-solving strategies like predicting and even trial-and-error techniques in real-world situations. Additionally, An et al. (2022) documented that teachers employed and refined strategies such as case-based reasoning, sketches, trial and error, and capacity evaluation through open-ended robotics projects. We also incorporated a well-known problem-solving method described by Fraenkel and Wallen (2009) as a way of knowing, called "expert opinion." This approach involves consulting an expert to solve the problem.

We have compiled the aforementioned strategies derived from the existing literature into a table with descriptions, and we have provided them in Table 1.

While there have been studies on problem-solving strategies in ER settings (An et al., 2022; Barak & Zadok, 2009; Castledine & Chalmers, 2011), relatively few of these scaffold problem-solving strategies tailored to ER tasks. Some studies have defined these strategies based on data analysis in an inductive way. For example, An et al. (2022) identified strategies such as case-based reasoning, sketching, and trial and error, using thematic analysis to identify patterns in how teachers utilize problem-solving strategies. Another study by Barak and Zadok (2009) did not employ a predefined coding scheme to identify problem-solving strategies. Instead, they developed codes and categories to outline strategies involving trial and error and heuristics.

Moreover, several other studies have also explored problem-solving skills, including those by Hussain et al. (2006), Norton et al. (2007), Dorotea et al. (2021), and Zhang and Zhu (2022). These skills involve mastering strategies for solving ER problems and acquiring content knowledge in areas such as earthquake science and robotics. The existing literature has predominantly focused on problem-solving skills, concluding that environments enriched by ER enhance these skills. However, the root cause of this improvement—whether it stems from mastering problem-solving strategies or from acquiring content knowledge—remains uncertain.

There needs to be more research exploring the impacts of ER on teaching earthquake concepts at the college level. ER is an emerging technology and can be an effective teaching tool in earthquake education at the college level. It offers broader possibilities for activities by incorporating sensors and motors (Benitti, 2012; Sapounidis et al., 2023). For

Table 1 Problem-solving strategies in ER-based problem-solving settings

Strategy	Description	Mentioned by
Capacity evaluation	Making adjustments due to the limitations of the ER tool/kit in addressing the problem	An et al. (2022)
Case-based reasoning	Using a construction or programming approach similar to that of problem-solving in a previously completed task	An et al. (2022)
Expert opinion	Asking for an expert to receive insight	Fraenkel and Wallen (2009)
Heuristics	Utilizing scientific knowledge to address a problem	Barak and Zadok (2009)
Instinction	Making decisions without the need for conscious reasoning	Barak and Zadok (2009)
Predicting	Forecasting the outcome of an upcoming event by identifying patterns in available evidence	Castledine and Chalmers (2011)
Sketches	Creating a diagram before diving into the construction and programming of an artifact	An et al. (2022)
Trial and error	Making guesses without relying on pre-existing knowledge, immediately applying them, and observing the results	Castledine and Chalmers (2011), Barak and Zadok (2009), An et al. (2022)

instance, during teaching rescue operations after an earthquake, ER can be used to construct gas detectors or implement early earthquake warning systems, aiding learners in comprehending how subject matter knowledge can be practically applied to solve authentic earthquake-related problems. By integrating ER into earthquake education, educators may enhance learning experiences and foster students' accurate understanding of seismic phenomena.

Methodology

Participants

The current study's participants comprised a cohort of nine pre-service science teachers in multiple universities across Turkey, all females aged between 19 and 22. Among them, six were sophomores, while the remaining three were juniors. This study was conducted during the summer break in 2023 as they engaged in an online PD course in which they were assigned to complete several ER-based problem-solving tasks. The PD course was offered as an extracurricular activity. All participants volunteered to take part in the study. None of them had previous experience in ER courses, and neither had they undergone any programming training as part of their pre-service science education curriculum.

PD Context as Procedure

A 48-h PD course was designed to empower pre-service science teachers with essential knowledge and skills in earthquakes and robotics, enabling them to integrate this expertise into problem settings based on ER effectively. We utilized Conner and Clawson's (2009) suggestions to design effective PD settings. This process involved identifying goals aligned with the specific needs, selecting appropriate content, and determining teaching methods such as expository teaching, workshops, collaboration, instructor quality, workshop duration, theoretical components, interaction, and ensuring feedback. We incorporated technology to enhance content access, provided rich and up-to-date materials, and established metrics for participant assessment in the PD. The PD content covered the structure of the earth, earthquake mechanisms, measuring and interpreting earthquake magnitude, scales, and precautions during, before, and after earthquakes. We thought about the earthquake and robotics content theoretically, followed by activities where the participants were assigned tasks related to ER. The instructors, who were professors, covered topics such as earth structure, earthquake mechanisms, rescue team operations, and robotics. They provided feedback on tasks and task presentations and then evaluated participants' problem-solving strategies.

The course lasted 6 days, featuring 8 h of daily instruction and problem-solving activities. The PD course was conducted online through Zoom, and professors studying geology, earthquake engineering, civil engineering, and computer science introduced the core knowledge integral to course components. As seen in Table 2, the course had three sections each lasting 2 days:

The initial section of the course (16 h), covering the first and second days, was dedicated to teaching earthquakes. This section covered a comprehensive range of topics, including the Earth's structure, mechanisms of earthquakes, earthquake-resistant building designs, and considerations surrounding search and rescue team operations following an earthquake, including searching for survivors by listening for voices, employing trained rescue dogs and specialized equipment, implementing gas detectors before commencing

Table 2 PD course contents and their durations

Day	Instructions or task	Duration (h)
1	-The Earth's structure and crust	4
	-Composition of ground and its effects on earthquakes	4
	-The causes of seismic activity	
2	- Methods for measuring epicenter point, distance, magnitude, and intensity of earthquakes -Constructing earthquake-resistant buildings	4
	- Earthquake preparedness, what to do before, during, and after an earthquake, and what save and rescue teams do	4
3	Robotics knowledge, including electronic structure and coding	8
4	Robotics knowledge, including electronic structure and coding	8
5	Practice tasks for ER problem-solving Task 1: Watering robot Task 2: Goldfish monitoring	4
	Main tasks for ER problem-solving Task 3: Earthquake early warning system	4
6	Task 4: Gas detection device	8

drilling in debris, making informed decisions regarding when to conclude operations, and efficiently managing debris removal. The topics were covered through the lecture method, wherein professors employed it to present the main ideas related to the critical factors for the central concept of the earthquake.

The second section (16 h), encompassing the third and fourth days of the course, involved robotics knowledge, exploring the definitions of robots and robotics, ER kits such as Arduino, and the intricate process of constructing robots involving electronic components like sensors and motors. Participants engaged extensively with electrical circuit design and block-based coding exercises on Tinkercad for their studies, transitioning virtual designs into tangible constructions. Tinkercad is an open-source and web-based application software. It also encompasses an Arduino simulator, allowing users to craft and program Arduino-controlled robots.

Participants engaged in two exercises as practice tasks and completed two primary tasks during the fifth and sixth days, referred to as the third section (16 h) with Tinkercad. This section allowed participants to create and assess electronic components, such as circuits, within an online environment, enabling them to share their work and seek guidance on the artifacts they produced. The initial practice task (Task 1) entailed designing a robot equipped with a moisture sensor to water a plant as required. The second practice (Task 2) focused on fish monitoring, enabling users to observe changes occurring in the water environment where goldfish reside. This monitoring aids living organisms in adapting to shifts in environmental conditions. These tasks were given to the participants so they were familiar with solving the primary tasks, Task 3 and Task 4, respectively.

Task 3 involved designing and programming an earthquake early warning system using Tinkercad. Figure 1a illuminates the task of detecting vibrations by P waves during an earthquake to provide protection and alert individuals about the destructive impact of S waves. Figure 1b also illustrates one of the participants' devised machines on Tinkercad on Zoom.

Task 4 encompasses creating and programming a methane gas detection device for rescue teams after an earthquake using Tinkercad. Figure 2a illustrates a task dealing with Task 4, and Fig. 2b shows one of the methane gas detection devices using Tinkercad, aimed at assisting rescue teams in mitigating the risk of gas-related explosions following an earthquake.

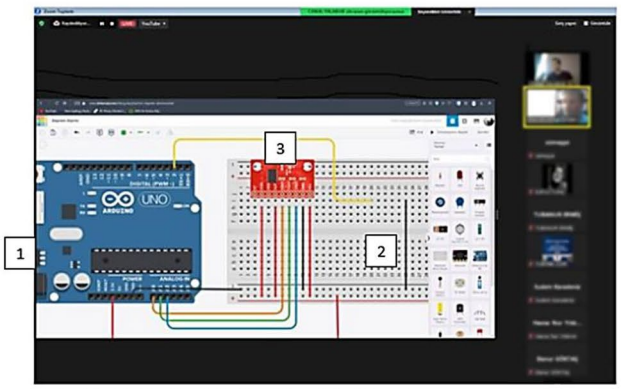
Each participant delivered their presentation, followed by a discussion aimed at providing feedback on the systems presented. These tasks were assigned individually to participants, involving the design and coding of a robot, as outlined in the task description.



As the picture above shows, you can see an earthquake early warning system. This system detects the motion of the ground produced by P-waves. It sends alerts to a center to notify individuals living near the epicenter point before encountering S-waves' destructive effects.

Our task today is to create a machine that detects vibrations produced by P-waves. You are requested to use components such as sensors, motors, and a piezo buzzer in Tinkercad. Afterward, share and introduce the artifact you have produced on Zoom. You have three hours to complete this task.

(a)



1: Arduino UNO Card, 2: Breadboard, 3: Vibration sensor

(b)

Fig. 1 **a** Task 3 provided for participants. **b** The presentation of an artifact related to Task 3 on the Zoom

Data Sources

We gathered data from the third section of the PD course, explicitly focusing on Task 4, which pertains to earthquake-oriented problem-solving with an emphasis on ER.

Artifacts generated by the participants after completing their assignments were gathered. Artifacts included virtual gas detection devices designed by participants for Task 4



During search and rescue operations, teams use drills and diggers to locate people trapped beneath collapsed buildings. However, one of the major challenges in such situations is the risk of explosions due to gas leaks from damaged pipes. Even a small amount of released gas can lead to a dangerous explosion when using drills or diggers. One effective solution to mitigate this risk is using gas detectors, which can identify the presence of gas and prevent explosions before rescue operations commence.

Our task today is to construct a device capable of detecting gas emissions following an earthquake. Please share the artifact with us and present it on the Zoom platform.

(a)



(b)

Fig. 2 **a** Task 4 provided for participants. **b** Presentation of a gas detection device by one of the participants

on Tinkercad's official website. Each participant had an account on the website to manage their artifacts.

Observations were conducted during the presentation of Task 4 on Zoom. These observations included the participants' presentations on their artifacts and a comprehensive examination of the construction and programming they were assigned, along with feedback from computer scientists and science educators. All presentations were recorded both on Zoom and Google Drive. Throughout the presentations, instructors posed probing questions to gain insight into the gas detectors, such as: (1) What type of gas is typically used in a gas detector?, (2) Can you explain the functioning of a gas detector?, and (3) Please provide an in-depth explanation of your construction and programming choices. We asked these questions to gain deeper insight into the construction and programming of the artifacts and understand the reasons behind their solutions to Task 4.

Interviews were conducted following the presentations to delve into the participants' reflections on their problem-solving approaches during the task. Interviews focused on how they solved the problem and the rationale behind their choices, including the factors influencing their strategy selection. We utilized interviews since we had already engaged participants in a task, making it convenient for us to inquire about their artifact design, preferences, and the process they used to construct the artifact on the Zoom platform. Structured interviews were employed to elicit information about participants' strategies when addressing the development of a gas detector problem. Initially, 16 questions were prepared to examine the expertise, but the final version of the interview protocol comprised 12 questions.

Data Analysis

The validation of a data source designed to measure problem-solving strategies begins with a thorough check to ensure alignment with the necessary approach for measuring these strategies. Problem-solving strategies can be measured through various methods, including think-aloud protocols, observations, self-reflection, performance-based tasks, or interviews (Jonassen, 2011).

The validation of these interview questions followed the recommendations of Yin (2003) and Fraenkel and Wallen (2009). This process included aligning the research question with the interview questions. The validation was carried out by two science educators and a computer scientist, all experienced in the tasks as instructors.

Additionally, a pilot study was conducted with a participant, although data collection was unsuccessful due to accessibility constraints. Following the pilot study, revisions were made to the interview questions to enhance their quality. This interview, conducted in accordance with a predefined interview protocol based on Creswell (2013) (see Appendix 1), lasted a minimum of 30 min each and was carried out individually online after the completion of the course.

The qualitative data gathered through artifacts as programming sheets on Tinkercad, artifact presentations as observations, and interviews were analyzed together, following the Data Analysis Spiral proposed by Creswell (2013). The analysis procedure encompasses steps such as data transcription, organization, reading and memoing, data categorization into codes and themes, and visualization

of the results. Additionally, inter-rater reliability is evaluated to ensure consensus among multiple coders. Inter-rater reliability assesses the extent of agreement or consistency among coders in evaluating identical data (Miles & Huberman, 1994). The acceptable level of inter-rater reliability typically falls within the 75 to 90% range (Hartman, 1977).

Two researchers studied together in the data analysis. Initially, artifacts, video from the presentations as observation data, and audio files from the interviews dedicated to unveiling problem-solving strategies were imported into NVivo software for analyzing data. Deductive coding was employed during the data analysis. We developed a coding scheme (see Table 1) to investigate the problem-solving strategies of pre-service teachers deductively. The coding scheme is derived from previous research on learners' problem-solving in an ER-based problem-solving setting. Both coders randomly selected five sources to ensure reliability and subsequently coded participants for Task 4, dealing with creating a gas detector. The initial inter-rater reliability was calculated at 84.30%. Any discrepancies were resolved through discussions, leading to a consensus. The entire dataset was then independently recorded, resulting in an inter-rater reliability of 90%. The names of the participants serve pseudonymously.

Results

This section details the problem-solving strategies employed, their distribution (see Table 3), and excerpts from participants' artifacts. It also includes the introduction of the artifacts during the presentation as well as observational data and interviews conducted.

Participants did not utilize three of the eight strategies: capacity evaluation, predictions, and sketches. No drawings were made, whether considering the minimum or maximum levels, to represent limitations. Furthermore, the prediction strategy was considered unsuitable for devising the gas detection device; hence, they chose not to employ it (see Table 3). Trial and error, which is the most commonly used strategy, is a decision-making or problem-solving method in which participants decide on a solution to a problem encountered while solving Task 4 intuitively. They then tested this solution to see if it worked. If not, they reviewed their decision, made the necessary corrections, and tried again. If the solution was successful, they continued working on Task 4; otherwise, they made another intuitive decision and entered into a cycle of trial and error. For instance, during her interview, Ela explained how she determined a gas detector's minimum and maximum measurement levels through trial and error. She observed that using a 1 k-ohm resistor resulted in readings ranging from a minimum of 85 to a maximum of 350. However, when she switched to a 10 k-ohm resistor, the readings changed, showing a minimum of 487 and a maximum of 869.

Another example comes from Sumay, who used this strategy to solve a problem while testing her device. She explained how to use trial and error during her follow-up interview, as exemplified by the following quotes:

> Sumay: My device can detect gas levels between 87 and 307. If the level drops below 87, an LED turns on. If it exceeds 307, a buzzer sounds, indicating that the gas level is dangerously high... After developing the gas detector, I simulated it in Tinkercad. However, the LED lights did not turn on, although the buzzer worked. I wondered what could be wrong. I first thought to check the LED cables, but they seemed fine. Then, I checked all the cables and connections. Eventually, I realized I had connected the resistor's edge to the wrong pin. After correcting this and plugging it into the right place, everything worked as expected. (The interview)

Expert opinion, a strategy nearly as preferred as trial and error, involves consulting specialists to tackle challenges encountered in the problem-solving process. The

Table 3 The distribution of frequencies coded in Task 4

Participants	Trial and error	Heuristics	Predictions	Case-based reasoning	Capacity evaluation	Sketches	Intuition	Expert opinion
Ela	X	X						X
Elif	X			X			X	X
Sumay	X	X		X				X
Burcak	X			X			X	
Sevgi	X	X		X				X
Tuba	X			X				X
Beray	X	X		X				X
Sude	X	X		X				X
Havva	X			X				X

majority of participants required assistance from computer scientists when they encountered difficulties, especially in tasks such as establishing cable connections or coding, which were necessary to activate an LED light or a piezo buzzer. Another aspect of this strategy is using the Internet to pose specific questions, such as, "How did you determine the type of gas detected by your device?" "What concentration of this gas in the air constitutes an explosion hazard?" "Where did you obtain this precise information?" "What constitutes the threshold point for your vehicle?" "On what basis did you choose this point?" The following quotes contain explanations from Sude's interview:

> Sude: Before designing the detector, I researched the gas type and its threshold points on the internet. I found that it should be between %12.5 - %75. I then defined three tiers with two threshold points...During the designing phase, I tested it, but it did not work. I rechecked it, but it still did not work. I consulted the computer scientist for assistance; then he identified a mistake in the cable connections. After fixing the issue, it started working correctly. (The interview)

Case-based reasoning is one of the most preferred strategies. It encompasses employing a similar approach to one encountered previously to solve a problem. The participants were assigned to Task 4 after completing Task 1, Task 2, and Task 3. Task 1 requires participants to use an algorithm with one threshold point, a two-tier algorithm. In contrast, participants need to use a three-tier algorithm with two threshold points for Task 2 and Task 3. These tasks have three intervals, each requiring specific reactions.

Most participants adopted an algorithm in Task 4 that utilizes a two-tier hierarchy, similar to the one used in Task 1. The participants utilized a two-tier algorithm employed in Task 1, which involves designing a plant watering system where, if the soil moisture value drops below a specific threshold, the system is triggered to release water to the plant. If the moisture value exceeds the threshold, the system closes the tap, preventing the release of water to the plant. For Task 4, the participants employed nearly identical logic to solve the problem. For example, the following quotes highlight the characteristics of this strategy, as illustrated in an interview with Elif and the presentation she delivered (see Fig. 3). It features a threshold point, below and above which the device triggers different responses.

> Elif: I used an algorithm where no warning mechanism is activated when the value falls below 100. The piezo begins to function and an LED lights up once the value reaches the threshold of 100, with a minimum value set at 85 and a maximum at 375. (The interview)

Some participants used three-tier algorithms similar to those in Task 2 and Task 3. Task 2 incorporates a monitoring system to maintain a predefined temperature for a goldfish. The task encompasses two threshold points, each prompting distinct reactions: below the minimum value, between the minimum and maximum values, and exceeding the maximum value. Two participants utilized Task 2 as a reference

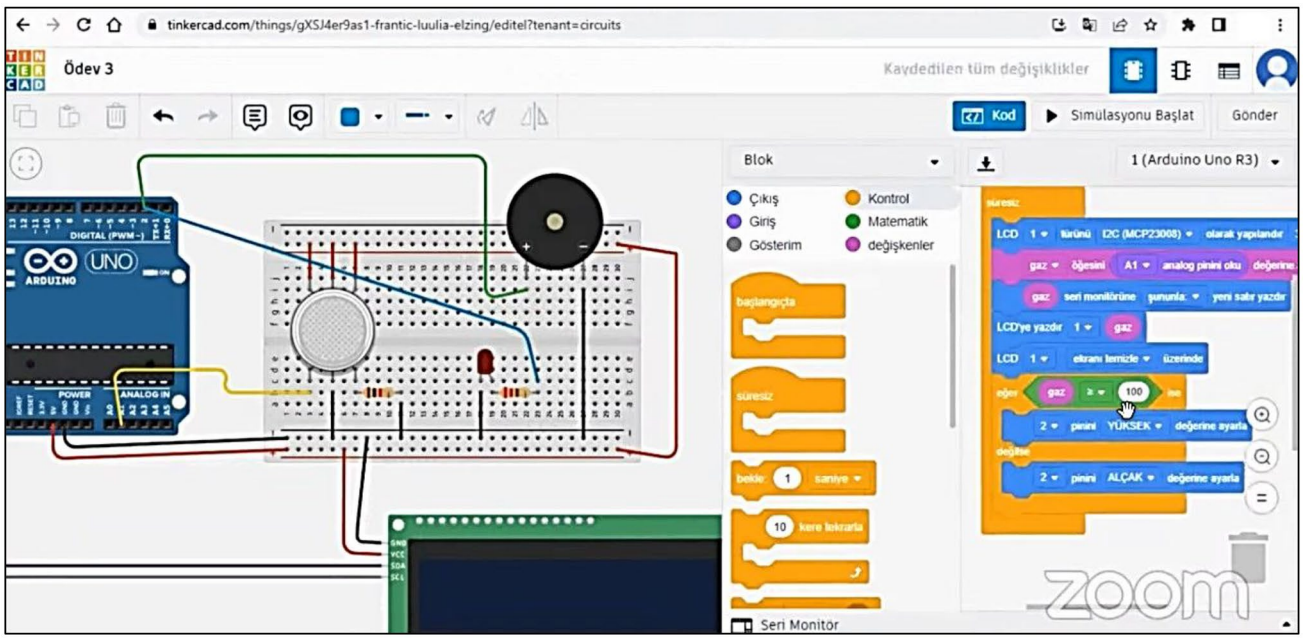


Fig. 3 The artifact from Elif's presentation for task 4 illustrating a two-tier algorithm

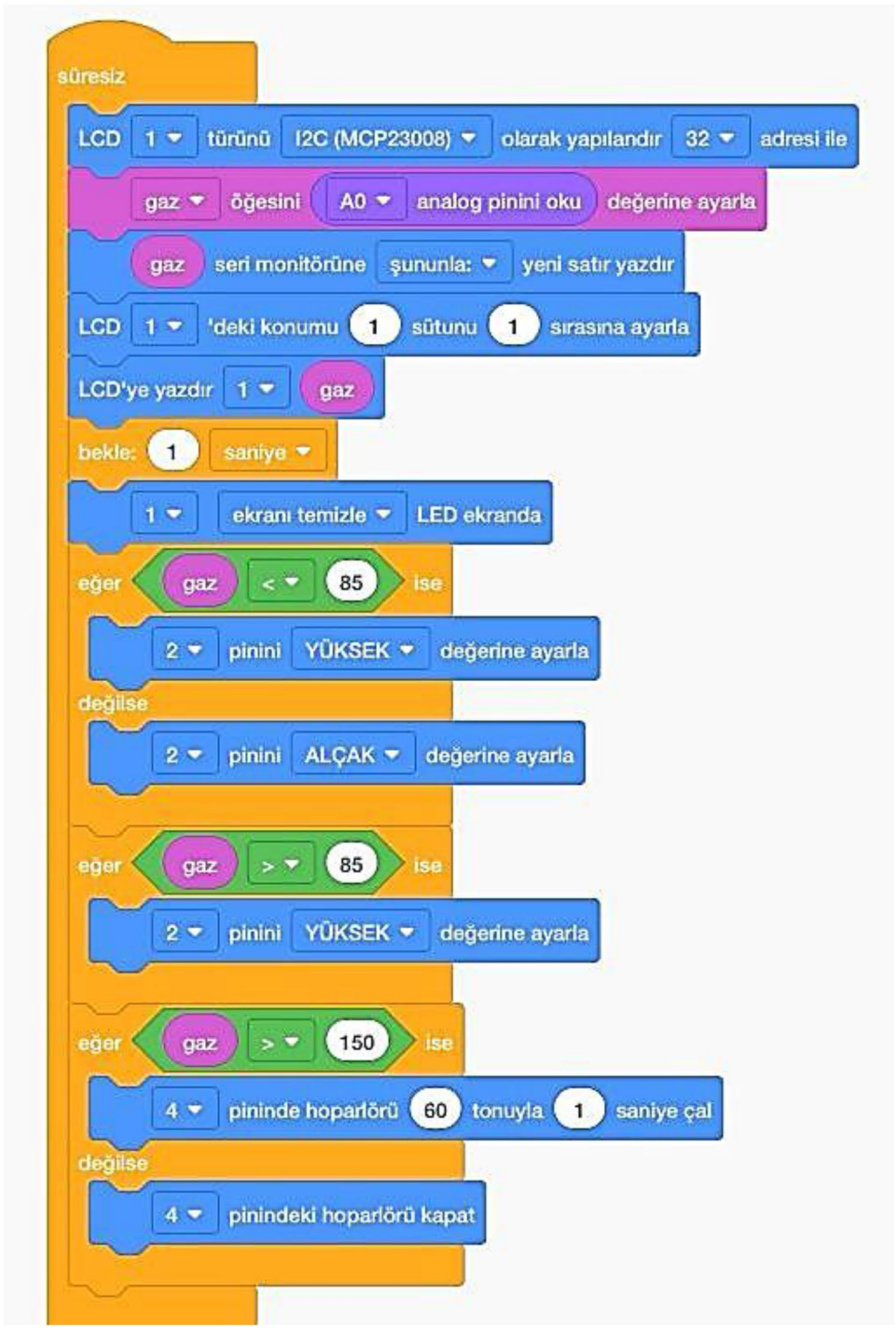


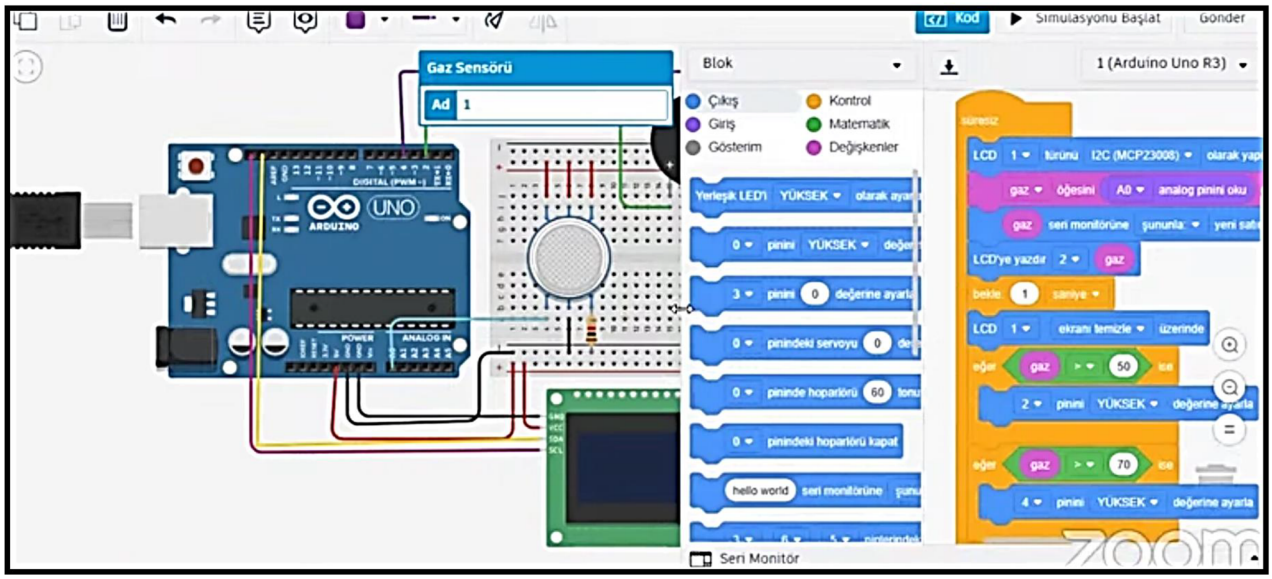
Fig. 4 The artifact from Sude's presentation for Task 4 illustrating the three-tier algorithm

case, resulting in algorithms that exhibit similarities to it. The exertion from Sude's presentation described a three-tier algorithm with two threshold points, as seen in Fig. 4.

Sude stated in the interview that below 85, no alert is triggered. The LCD light is activated within the range of 85 to 150. Beyond 150, the light and the piezo are initiated simultaneously, with the threshold value set at 150. The participants used an algorithm similar to the ones in Task 2 and Task 3.

The heuristic approach was employed by five participants. They investigated threshold points and struggled to incorporate them into the device; however, they refrained from making any conversions. They employed the values exactly as they appeared in the actual readings. For instance, Ela found that the danger level arises between 50 and 70%, with 70% marking the threshold point for a potential gas explosion. These points were then integrated

(a)



(b)

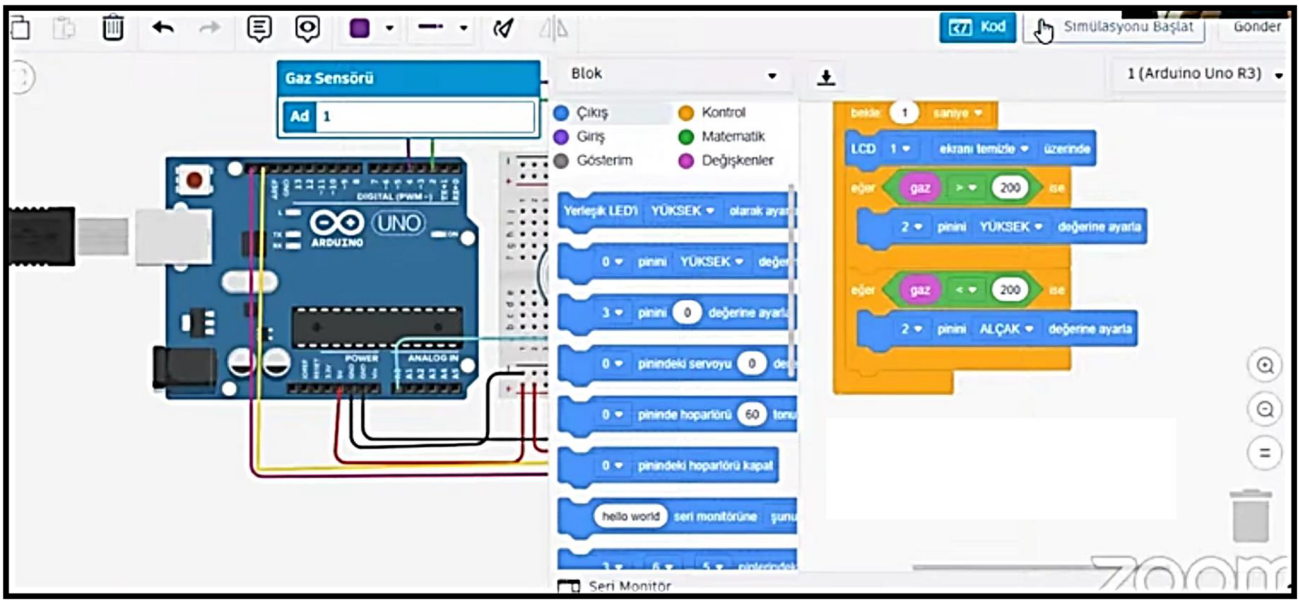


Fig. 5 **a** Ela's segment of a gas detector illustrating the minimum and maximum threshold points at 50 and 70, **b** along with the 200 as threshold point for Task 4

into the design as 50 and 70% (see Fig. 5a). When asked about the rationale behind these values, she responded, "I attempted to incorporate scientific knowledge into the design, but it was ineffective." However, Ela overlooked that the gas detector's operational range was between 85 and 375, placing her selected values outside this interval, resulting in the device not functioning as intended. To determine the corresponding values, she should have applied the following formula: $((375-85)\ /\ 100)\times 50$, yielding 145 for the minimum, and $((375-85)\ /\ 100)\times 70$, yielding 205 for the maximum. However, Ela did not employ these calculations; instead, she used the criterion that gas values below 200 would activate the piezo, and those above 200 would trigger the LED (see Fig. 5b). This value was chosen intrinsically, and as it turns out, the device functioned as intended.

Two of the nine participants utilized preliminary threshold points without relying on explicit knowledge; instead, they intuitively defined these points, and this way was called intuition. For example, during the artifact presentations, when questioned about the rationale behind selecting the value 200, Burcak explained, "I established the threshold value as 200 based on personal judgment, lacking any specific criteria. I tried it, and it worked."

Discussion and Conclusions

This study aims to uncover preservice science teachers' problem-solving strategies when assigned to create a post-earthquake gas detector for rescue teams within a PD course.

Previous research on teaching earthquakes with college students, e.g., Ardianto et al. (2019) or Kuester and Hutchinson (2007) examined various methods, such as STEM activities or virtual reality, and tools within courses in PD settings. In this present study, the primary objective of PD was to offer preservice science teachers a chance to integrate ER into their understanding of earthquakes. This integration was then applied practically through a specific gas detection task.

The study demonstrates that almost all participants successfully completed the task involving creating a gas detector through Tinkercad. They built the detector and explained its functionality, incorporating both their science and robotics knowledge. This would be interpreted as a positive outcome for using ER as a tool for teaching earthquakes. Existing research that explores the incorporation of ER into science education has identified evidence that employing ER enables teaching concepts such as simple machines (An et al., 2022), force and speed (Fakaruddin et al., 2023), reaching food resources (Fridberg et al., 2022), and titration for high school chemistry laboratories (Verner & Revzin, 2017). Others leverage robotics as an effective environment for problem-solving, where learners can apply their scientific knowledge, e.g., Jaipal-Jamani and Angeli (2017). This current study expanded our perspective by introducing a new concept, "earthquake," to the existing literature on utilizing ER in science education.

Prior investigations into the realm of ER within science education have yielded conclusions centered on problem-solving skills (Barak & Zadok, 2009; Castledine & Chalmers, 2011). Researchers have emphasized that effective problem-solving demands abilities that extend beyond mere knowledge acquisition; these abilities encompass understanding strategies and their application. A few research studies have reported several problem-solving strategies separately within the existing literature. For instance, Barak and Zadok (2009) classified them as heuristics and trial and error. Building upon this foundation, the present study synthesized the problem-solving strategies into a comprehensive framework and used the framework as a coding scheme (see Table 1). This framework contributes to delineating problem-solving processes within the context of ER. Doing so offers a structured approach to defining and understanding problem-solving within the ER problem-solving environment.

As highlighted in the relevant studies on problem-solving strategies in ER settings by Castledine and Chalmers (2011), Barak and Zadok (2009), and An et al. (2022), this study has found that trial and error is the most preferred strategy among participants. Previous literature also concluded that students or teachers initially utilized trial and error, followed by heuristics. The participants in this study favored using case-based reasoning and expert opinions. Considering the problem-solving process, trial and error and case-based reasoning require using experience. It may stem from the participants' intrinsic motivation, meaning they first attempt to solve the problems they encounter during ER situations. If unsuccessful, they then consult an expert or employ other heuristic methods.

A problem consists of an obstacle (a task) and an objective (Watts, 1991). Solving a problem also requires applying knowledge in new situations through mastering problem-solving skills, as highlighted by Dewey (1938), Jonassen (2011), and the OECD (2023). Although several studies, including those by Zhang and Zhu (2022), Dorotea et al. (2021), Norton et al. (2007), and Hussain et al. (2006), have explored problem-solving skills in ER settings, it is the strategies within this problem-solving process that reveal the foundation of this focus. Methods such as trial and error, case-based reasoning, and expert opinion could serve as catalysts for further enhancing problem-solving skills. Modifying these methods could also assist PD developers or teachers.

Implications for Future Studies

The study's emphasis on integrating problem-solving strategies with ER in PD settings reveals several implications for future research and educational practices. The findings highlight the potential applications of ER in science education and underscore the significance of problem-solving strategies.

The first implication concerns PD designers: problem-solving strategies should be considered in courses that extend beyond science and robotics content knowledge. Moreover, case-based reasoning represents a problem-solving approach in which participants apply experienced methods within the course. Therefore, PD designers must carefully select tasks in the PD course to ensure problems are solved effectively.

For researchers, the connection between problem-solving skills in ER settings and broader problem-solving

capabilities warrants further exploration. Drawing includes the actual connections between skills, and problem-solving methods are recommended. We recommend this coding scheme for researchers aiming to construct an instrument to measure problem-solving strategies in ER settings. We developed and applied this coding scheme in our study, which suggests that there was only one code/strategy, namely expert opinion, in ER settings. This could serve as evidence that the strategies were effectively scaffolded and could be utilized in subsequent studies.

Appendix 1

The Interview Protocol

This interview protocol is focused on exploring the problem-solving strategies of pre-service science teachers participating in an ER-enriched earthquake-oriented teaching course. The specific context involves their engagement in devising a gas detection task (Task 4) using Tinkercad.

Date & Time:_____ Place:_____

Interviewee:_____ Interviewer:_____

Below, we outline the problem simulated in Task 4 for your consideration.

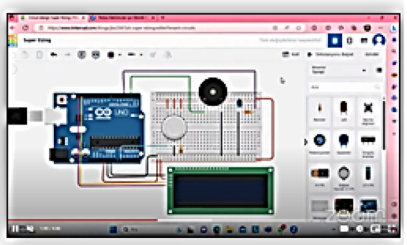


During search and rescue operations, teams use drills and diggers to locate people trapped beneath collapsed buildings. However, one of the major challenges in such situations is the risk of explosions due to gas leaks from damaged pipes. Even a small amount of released gas can lead to a dangerous explosion when using drills or diggers. One effective solution to mitigate this risk is using gas detectors, which can identify the presence of gas and prevent explosions before rescue operations commence.

Our task today is to construct a device capable of detecting gas emissions following an earthquake. Please share the artifact with us and present it on the Zoom platform.

We've also included a video recording featuring your presentations on the Tinkercad design created in response to this problem. Click below to enjoy watching.

https://drive.google.com/drive/folders/1RbkHEam6F6_pss98QKWsRzIpmHiE1FpG?usp=sharing



Interview Questions:

Please provide comprehensive answers to the following questions, which explored the specifics of your artifact:

1. What were your actions before you began working on your artifact?

2. Could you create a sketch that illustrates the artifact you were planning to make and explain the details of this sketch?

3. Were you able to create the artifact requested in Task 4? Did it work? Can the artifact you designed be used for earthquake search and rescue operations? Could you explain in detail?

Please give thorough responses to the following questions, which address your problem-solving process for selecting your design and programming tools:

4. How did you ascertain the type of gas that your device detects?

5. What percentage of this gas must be in the air to explode? How did you obtain this specific information?

6. What are the minimum and maximum values registered by the gas detector you created? And how did you establish these ranges?

7. What is the threshold point for your vehicle? How did you select this point?

8. What reactions did your gas detection device display in various intervals, and how did you determine these responses?

Please provide detailed answers to the following questions, which explore the obstacles you encountered while tackling Task 4 and how you overcame them:

9. What problems did you encounter during the design of the device?

10. How did you address the problems? Please describe the methods you used to handle the problems.

11. Why did you choose these ways to solve the problems?

12. Did you achieve a solution by selecting the method you used?

Thank you to the participant/interviewee for contributing to the study, aiming to reveal the problem-solving strategies of pre-service science teachers. We appreciate your allowing us data and assure you that additional interviews may be conducted if necessary during the data analysis process.

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Author Contribution Dr. Mirac Aydin (corresponding author) and Salih Cepni conceptualized and designed the study, led the data acquisition process, conducted the primary data analysis and interpretation, and played a pivotal role in drafting and revising the manuscript critically for important intellectual content. Dr. Aydin also ensured the accuracy and integrity of all parts of the work and agreed to the final approval of the version to be published.

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Availability of Data and Materials The current study's dataset generated and analyzed is not publicly available due to the fact that the dataset constitutes an excerpt of research in progress but is available from the corresponding author on reasonable request.

Declarations

Ethical Approval The authors confirm that all procedures performed in the study involving human participants were according to the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Informed Consent The authors affirm that informed consent was obtained from all individual participants included in the study.

Statement Regarding Research Involving Human Participants and/or Animals Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Competing Interests The authors declare no competing interests.

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