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ORIGINAL RESEARCH PAPER

Three-Dimensional Learning through Phenomenon-Based Science Education and Its Application via the Collapsed Container Phenomenon

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Three-dimensional learning, Phenomenon-based science education, Science education standards, 21st century skills, Next Generation Science Standards (NGSS).

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ABSTRACT

This research aims to investigate and explain the three-dimensional learning through the phenomenon-based science education approach. The study employed documentary review research methodology to analyze sources that introduce phenomenon-based science education (including research articles, new science education standards, and Iran's national science curriculum guide). The findings indicate that three-dimensional learning, with its emphasis on disciplinary core ideas, crosscutting concepts, and science and engineering practices, provides a comprehensive framework for understanding and explaining natural phenomena. In this research, the six stages of phenomenon-based science education—including introducing the phenomenon, creating a questions-observations-interpretations table, developing an initial model, exploring the phenomenon, completing a summary table, and proposing a consensus model and explaining the phenomenon—are examined in detail. The research results are embodied in a practical example on the topic of "collapsed container," which demonstrates the phenomenon-based education stages in practice. By connecting theory and practice, this article provides strategies for implementing this approach in the classroom to facilitate its application in the educational system.

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INTRODUCTION

Alongside extensive changes in educational systems, innovative efforts are increasingly being made to create a new perspective on the objectives, functions, and methods of science education. In the new science education standards [14][15] the main goal of science education has evolved beyond "students' proper understanding of scientific concepts" to "helping students explore and explain how and why phenomena occur." Therefore, the primary focus of science education has shifted toward preparing students to observe and explain phenomena in the world around them. From this perspective, the traditional "subject-based teaching" approach, in which different branches and topics of science are taught without any connection to each other, will be ineffective, and students need more powerful tools to explain and interpret phenomena. In these circumstances, the idea of three-dimensional learning has been introduced to equip students with these tools as much as possible.[15]

In three-dimensional learning, students not only acquire appropriate knowledge of scientific content (physics, chemistry, biology, etc.), but also develop skills in the methods or practices used by real scientists and engineers, and gain a broader understanding of concepts that link different areas of science. Three-dimensional learning helps students use science to understand phenomena in the natural or designed world and use engineering methods to solve problems. The three main dimensions of this learning, which are also shown in Figure 1, are: 1. Disciplinary Core Ideas (DCIs), 2. Crosscutting Concepts (CCCs), and 3. Science and Engineering Practices (SEPs). Disciplinary core ideas represent the existing body of knowledge about different branches of the natural sciences (physics, chemistry, biology, earth and space sciences). Crosscutting concepts include patterns, cause and effect relationships, scale and quantity, matter and energy, systems, structure and function, and stability and change. Science and engineering practices include 1) asking questions and defining problems, 2) developing and using models, 3) planning and carrying out investigations, 4) analyzing and interpreting data, 5) using mathematics and computational thinking, 6) constructing explanations and designing solutions, 7) engaging in argument from evidence, and 8) obtaining, evaluating, and communicating information.

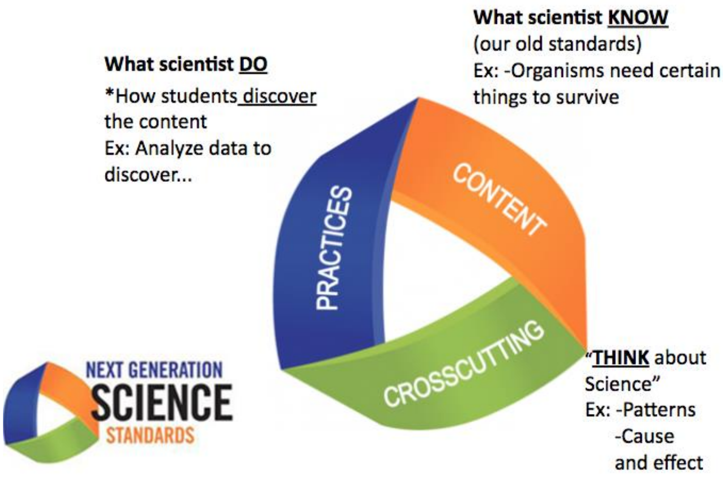


Figure 1. Three-dimensional Learning in the Next Generation Science Standards [13]

This change in perspective regarding the overall goals of science education requires the use of different strategies in teaching science. An instructional strategy that introduces an engaging and educational phenomenon, anchors it in students' minds, and leads to asking questions related to the phenomenon, collecting evidence, analyzing data, explaining, reasoning, presenting an initial model, and finally, after revisions, introducing the final model. Drawing on this idea, Finland introduced the phenomenon-based learning (PhBL) strategy to the world [7]. In the present study, while introducing this strategy and explaining its implementation steps in the classroom, an interesting and educational phenomenon (the collapsed container) is introduced, and its implementation steps in the classroom are described. This applied review article, by addressing both the theoretical foundations and the practical application of this innovative approach to science education, can be an engaging and useful article for those interested in science education.

METHODOLOGY

This research is a documentary review study conducted with the aim of investigating and explaining the three-dimensional learning approach and phenomenon-based science education. In this research, in addition to valid scientific articles, resources and documents related to new science education standards, especially the Next Generation Science Standards [13] and Iran's National Curriculum Guide for Science Education and Learning (2020), have been studied and analyzed.

The research process was conducted in several stages:

A. Search and collection of resources: In this stage, valid scientific and research resources including books, articles, upstream documents, and research reports related to the three-dimensional learning approach and phenomenon-based science education were collected from valid scientific databases and official sources.

B. Refinement and selection of resources: Among the collected resources, those directly related to the research topic were selected and classified. The criteria for selecting resources included scientific validity, recency, and content relevance to the research objective.

C. Analysis and synthesis of findings: The data obtained from studying the resources were qualitatively analyzed, and key concepts, principles, and methods related to three-dimensional learning and phenomenon-based science education were extracted.

D. Development of a theoretical framework: Based on the findings, a theoretical framework for phenomenon-based science education with emphasis on three-dimensional learning was formed, and its implementation steps were explained.

E. Design of a practical example: To concretize and apply the theoretical framework, an educational example on the topic of "collapsed container" was designed, which demonstrates the stages of phenomenon-based education in practice. This research, emphasizing the importance of connecting theory and practice, has sought to explain the theoretical foundations of phenomenon-based science education while providing practical strategies for implementing this approach in the classroom. The documentary research method has allowed the researcher to use diverse and valid sources to provide a comprehensive picture of the three-dimensional learning approach and phenomenon-based science education, and to lay the groundwork for applying this approach in the country's educational system.

RESULTS AND DISCUSSION

Phenomenon-Based Learning

Phenomenon-based learning is one of the prominent approaches to science education in an active and learner-centered manner that focuses on examining real-world phenomena [9]. Finland first began reforming its educational system using phenomenon-based learning (PhBL) in 1970. Schools in this country started experimental implementation of this type of education in 1980, but its official beginning was placed on the agenda of the capital's schools in 2016 and then gradually implemented throughout the country. This approach has been given considerable attention and emphasis as one of the essential teaching-learning strategies in the science education macro-documents of many countries, including Iran's National Curriculum Guide for Experimental Sciences Education and Learning (2020) (Table 1) and also the Next Generation Science Standards in America (2013).

The word phenomenon, derived from the Greek root (fainómenon), means something unusual or interesting that can be seen, felt, tasted, etc. (Cambridge Dictionary). A scientific phenomenon can be defined as an observable event that occurs in the universe around us - an event that we can use our scientific knowledge to explain, interpret, or predict (Lawrence Hall of Science, 2019). In this method, instead of teaching a subject (like energy) in different branches of experimental sciences (such as chemistry, physics, or biology), the focus is on a phenomenon that is affected by this subject. For example, when studying a natural phenomenon like a volcanic eruption, students can simultaneously learn geology, chemistry, and physics. This not only makes learning more efficient but also helps students recognize the interconnection between different branches of experimental sciences and how they collectively contribute to shaping our worldview. NGSS highlights the importance of this strategy by introducing crosscutting concepts (CCCs).

Table 1. Emphasis on the phenomenon-based science education approach in Iran's National Curriculum Guide for Science Education and Learning (2020)

Teaching-Learning Strategy	Essential Stages	Techniques and Methods
Phenomenon-Based	✓ Selecting phenomena from the real world ✓ Creating motivation and capturing attention ✓ Demonstration and observation related to the phenomenon ✓ Posing why, how, and conditional questions ✓ Introducing necessary resources ✓ Evaluation and conclusion	✓ Creating motivation ✓ Brainstorming ✓ Group work ✓ Using various tools and media ✓ Discussion and dialogue ✓ Questioning ✓ Information gathering ✓ Reasoning ✓ Assessment and feedback ✓ Report presentation

Phenomenon-based science learning begins with observing a real-world phenomenon and continues with asking questions, organizing findings, making decisions, and trying to answer the questions [18]. In this process, learners experience the phenomenon and try to benefit from their background knowledge to explain the phenomenon and the science behind it in their own words [10]. Thus, during the learning process, students can think and act like scientists and engineers [5]. Engaging students in seeking natural phenomena and solving real-world problems, like what scientists and engineers do, leads to a deeper understanding of scientific content and enhances their critical thinking skills [12]. This type of learning takes place in a flexible environment where learning objectives are not imposed and definitive, and the learning process is planned with student participation [10].

Phenomenon-Based Learning and 21st Century Skills

Phenomenon-based learning has roots in multiple learning ideas and theories such as constructivism, social constructivism, situated cognition, phenomenology, and emergent learning theory, which together form a comprehensive educational structure [14]. Numerous studies support the effectiveness of phenomenon-based learning in achieving various educational goals, including: phenomenon-based learning improves students' academic performance [4], increases students' teamwork skills [19], helps students develop their creativity and critical thinking skills while working on a real-world phenomenon [13], enhances problem-solving skills in students and helps them better understand physics through problems presented with phenomena [10], and finally leads to improved metacognitive awareness in students and the development of their knowledge about their own learning [2].

In addition to all the above, collaboration and communication are two essential concepts in phenomenon-based learning. This educational approach is deeply collaborative and enhances students' thinking skills through communication and interaction with each other [12]. Students share and develop their ideas while considering all ideas valuable, and create a comprehensive understanding of the subject as a result of group work, not individual effort [8]. Students enjoy participating with peers [6] and feel valued and respected [8]. Dialogue between students is an important challenge in this collaborative process since students have different personalities, background knowledge, experiences, and expectations. In such an equal learning situation, students listen more carefully to their peers, and the retention of content in their minds is greater and longer-lasting [6].

Steps and Stages of Phenomenon-Based Science Education

Science education experts have proposed various steps and stages for designing and implementing this innovative teaching-learning strategy. Among them, Hancock and Lee (2018) describe this strategy as including three stages: 1) selecting a phenomenon and asking questions, 2) extracting students' prior knowledge, and 3) establishing and designing instructions to help students understand and explain the phenomenon. Trauth and Mulvena (2022) look at the steps of phenomenon-based education in more detail and introduce the following six stages:

Step One: Introducing the Phenomenon

Selecting an engaging, relevant, valid, and observable phenomenon that is compatible with the learners' level of knowledge and understanding is the first essential step in phenomenon-based science education. Priority is given to selecting phenomena that have the potential to link different branches of experimental sciences. Also, selecting phenomena from the real world and related to the culture and living environment of learners is strongly recommended. In addition to selecting an appropriate phenomenon, the method of introducing and presenting the phenomenon to learners also requires special attention. The phenomenon can be shown to learners using one or more photos, videos, experiments, etc.

Step Two: Creating a Questions-Observations-Interpretations Table

At this stage, a three-column table for questions-observations-interpretations is drawn by the teacher (facilitator) on the board, and learners have some time to present their observations, questions, and whatever they have understood from the photos or videos to be noted in the table. In some cases, when learners are asked to talk about their observations, they talk about their inferences. It seems that this group of learners makes a mistake in distinguishing between observation and inference. Therefore, there is an opportunity here to discuss the distinction between observation and inference as one of the important components of the nature of science. At this stage, many questions with what, why, how, what factors, etc., are also raised and recorded in the table. Then, with the guidance of the facilitator, the class consensus decides which question(s) to focus on for the continuation of the educational process.

Step Three: Developing an Initial Model

At this stage, learners are asked to present whatever they have in mind as their initial ideas for answering the question(s) of interest. Asking students to design their initial models before any educational activity is done with the aim of extracting students' prior knowledge. Then, through group dialogue and exchange of views, learners suggest various hypotheses related to the phenomenon.

Step Four: Exploring the Phenomenon

At this stage, learners engage in a set of related research activities that are often carefully arranged to help learners understand the scientific concepts and crosscutting concepts related to the phenomenon. At this stage, learners are asked to use patterns such as (if, then, and, but, therefore) to suggest models for testing their hypothesis(es). Then, based on the proposed model and to confirm the hypothesis (to modify or complete it) or reject the hypothesis and present an alternative hypothesis, more evidence is collected. A collection of videos, photos, articles, or various experiments that can provide more evidence and information about each hypothesis will be used at this stage.

Step Five: Completing the Summary Table

Learners prepare their summary table throughout the educational process and note what they learn about the phenomenon at each stage. For this purpose, at the end of each research stage, the facilitator, while summarizing the class discussions, provides sufficient time for learners to add new ideas to the summary table.

Step Six: Proposing a Consensus Model and Explaining the Phenomenon

At this stage, learners, with the help of the facilitator, use information and data from previous investigations and, after discussion and exchange of views, present the class consensus model to answer the original question. To deepen the material, the facilitator can use supplementary sources, simulations, introduction of examples from everyday life, etc.

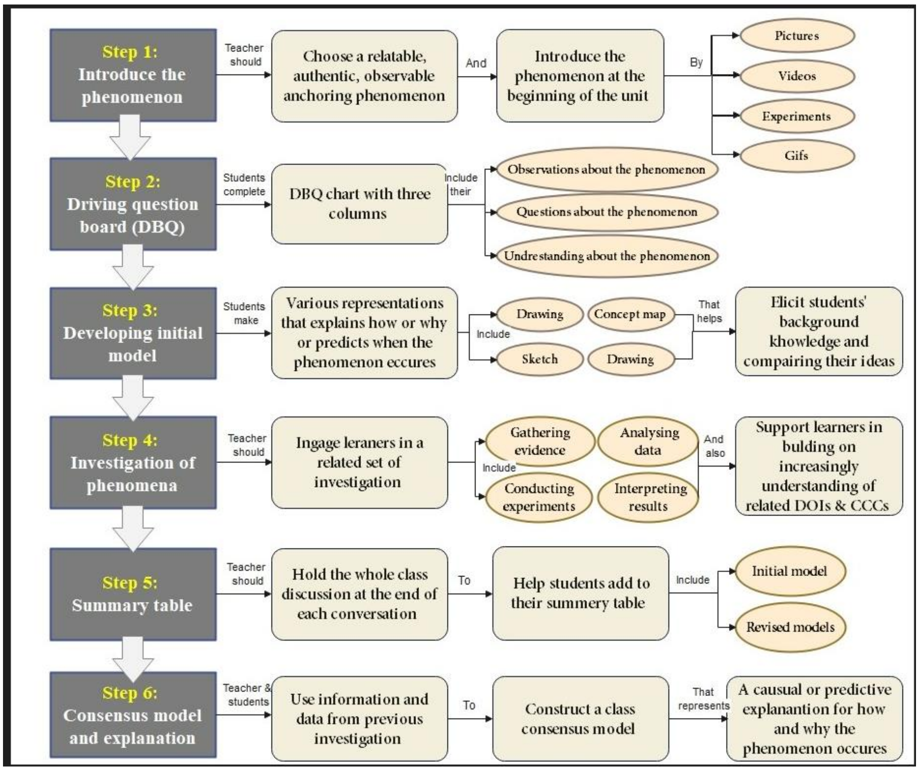


Figure 3. The Six Stages of Phenomenon-based Learning Implementation

Designing Phenomenon-Based Education with the Topic of Collapsed Container

As mentioned earlier, phenomenon-based education is a new method in science education that brings meaningful and deep learning by engaging students in examining real phenomena. Below, a sample of phenomenon-based educational design with the topic of "collapsed container" is presented, which is organized according to the six main steps of phenomenon-based education by Trauth and Mulvena (2022).

Step One - Introducing the Phenomenon: At this stage, the phenomenon of the collapsed container is introduced to students using images. The first image shows a container that was used to transport factory products and was washed every night for the next day's use. The second image shows the same container that factory workers encountered the next morning; a container that has been strangely collapsed. These images are shown in Table 2.

Table 2. Images Used to Introduce the Collapsed Container Phenomenon

Image 1. Container before collapsing	Image 2. Container after collapsing
	

For an engaging introduction of the phenomenon, a narrative approach can be used:

"Imagine that one morning, factory workers come to their workplace as usual to start work, but they encounter a strange scene. The large container that they had washed and prepared for use the night before has strangely collapsed. What caused this incident?"

This narrative, along with showing images of the container before and after collapsing, arouses students' curiosity and motivates them to investigate the cause of this phenomenon. At this stage, students are asked to look carefully at the images and note the notable points.

Step Two: Creating the Questions-Observations-Interpretations Table. After introducing the phenomenon, a three-column table is drawn on the board or in the students' worksheets. This table includes columns for "Observations," "Questions," and "Interpretations." Students are asked to note their observations, questions, and interpretations in this table. Table 3 shows the anticipated observations and questions of students about the collapsed container phenomenon.

Table 3. Anticipated Observations and Questions of Students about the Collapsed Container Phenomenon

Anticipated Students' Observations	Anticipated Students' Questions
- The middle part of the container is collapsed, but its two ends have remained intact. - The area around the container is wet and moist. - The weather appears cloudy and cold. - No large object is seen around the container. - No signs of explosion or external damage are seen.	- What happened? - How was the container collapsed? - Why was the container collapsed? - What factors caused the container to collapse? - Was there an explosion? - Did a heavy object fall on the container? - Did people who were there hear a loud noise last night? - Is there a smell of smoke or burning in the area? - Did the container collapse suddenly or gradually? - Was the air temperature very low last night? - Can we see last night's incident by watching CCTV footage?

At this stage, the teacher guides students to distinguish between observations and inferences. The distinction between observation and inference is one of the important components of the nature of science (NOS) [11] that can be well covered in this activity. The authors' experience from implementing this phenomenon in several student and teacher workshops shows that statements such as "probably something fell on the container," "it seems an explosion occurred," "pressure difference caused the container to collapse," etc., are raised by learners in the observations section, which are all inferences, not observations. Also, after collecting various questions, with the participation of students, the main question is selected, which in this case could be: "What factors caused the container to collapse?"

Step Three - Developing an Initial Model: At this stage, students are asked to propose their initial hypotheses about the cause of the container's collapse. Students use their prior knowledge to express hypotheses. These hypotheses may include:

1. An explosion occurred inside or around the container.

2. A heavy object fell on the container and collapsed it.
3. Someone deliberately damaged the container.
4. A defect in the container's metal structure caused its collapse.
5. Pressure difference caused the container to collapse.

The teacher should create a safe space where students can express their ideas without fear of judgment. Each hypothesis is noted without judgment. Then students are divided into small groups to discuss the hypotheses and find logical reasons for their hypotheses.

Step Four - Exploring the Phenomenon**:** At this stage, students test their hypotheses by collecting more evidence, experimenting, and investigating. This stage includes several activities:

1. Collecting more data: Students look for more evidence to confirm or reject their hypotheses. Actions such as:
   - Reviewing CCTV footage
   - Inquiring from people present at the location
   - Talking to the person responsible for washing the container
2. Discovering new data: At this stage, guided by the teacher, students obtain new data:
   - The washing water temperature for the container was very high.
   - The minimum air temperature last night was very low.
3. Revising hypotheses: Based on new data and watching CCTV footage (which is shown in class), students revise their initial hypotheses. In this footage, it is observed that the container collapses suddenly. Based on the shown footage, hypotheses of explosion and a heavy object falling on the container are rejected, and two new hypotheses are formed:
   - *Hypothesis 1:* The cold air caused the <u>*contraction*</u> of hot air trapped in the container. As a result, the air pressure inside the container became less than the outside air pressure, causing the container to collapse.
   - *Hypothesis 2:* The cold air caused the <u>*condensation*</u> of water vapor trapped in the container. As a result of condensation, the air pressure inside the container became less than the outside air pressure, causing the container to collapse.
4. Designing experiments to test hypotheses: Students, guided by the teacher, design experiments to test their hypotheses:
   - Experiment for Hypothesis 1: They immerse an empty hot can in cold water to see if it collapses.
   - Experiment for Hypothesis 2: They immerse a can containing water vapor in cold water to see if it collapses.
5. Conducting experiments: Students perform the experiments. They discover that the empty hot can gets only slightly compressed when entering cold water, but the can containing water vapor collapses suddenly with a loud noise when entering cold water. This observation confirms the <u>second</u> hypothesis.

At this stage, the teacher and students can review the scientific concepts related to pressure, heat and energy transfer, the effect of heat on volume change of materials, phase changes of matter, condensation, and gas laws, and try to relate them to the phenomenon.

Step Five: Completing the Summary Table. At this stage, students organize their findings and complete the summary table (Table 4).

Table 4. Sample Completed Summary Table to Summarize Students' Learning

Number	Components	Summary of Students' Opinions and Findings
1	Initial Hypotheses	- Explosion in the container - A heavy object falling on the container
2	New Evidence	- CCTV review showed the container collapsed suddenly, without explosion or a heavy object falling - The container washing water temperature was very high - The air temperature last night was extremely low
3	New Hypotheses	- Contraction of hot air inside the container due to cold air - Condensation of water vapor inside the container due to cold air
4	Experiment Results	- An empty (without water) hot can gets slightly compressed when exposed to cold water - A can containing water vapor collapses suddenly when exposed to cold water
5	Conclusion	- The cold air caused condensation of water vapor trapped in the container - As a result of condensation, the internal pressure of the container decreased - The external air pressure on the container caused it to collapse

The teacher, by summarizing the students' findings, helps them understand the connection between scientific concepts and the phenomenon under investigation. The teacher can also link concepts related to educational standards such as matter and its interactions, energy and its transfer, pressure, etc., to this discussion.

Step Six - Proposing a Consensus Model and Explaining the Phenomenon: In the final stage, students, guided by the teacher, present a consensus model to explain the collapsed container phenomenon. This model may include:
Scientific explanation of the phenomenon: "The cold air caused condensation of water vapor trapped in the container. Due to condensation, water vapor turned into liquid and occupied less volume. This decrease in volume causes a sudden decrease in the internal pressure of the container. When the internal pressure of the container becomes less than the external air pressure, the pressure difference between the outside air and inside the container causes the container to collapse."

Connection with the NGSS Three-Dimensional Learning Framework:

a) Disciplinary Core Ideas (DCIs):

- **Matter and Its Interactions**:
  - *Structure and Properties of Matter:* Gases and liquids consist of neutral molecules or atoms that are in motion relative to each other. In a liquid, molecules are constantly in contact with each other; in a gas, they are separated unless they randomly collide. In the collapsed container phenomenon, the

behavior of water vapor molecules and their conversion to the liquid state can be explained based on these principles. The water vapor inside the container is initially in a gaseous state with scattered, distant molecules, but when cooled, it turns into a condensed liquid with close molecules that occupies much less volume.

- *Changes in States of Matter:* State changes that occur with changes in temperature or pressure can be described and predicted using models of matter. In this phenomenon, condensation (conversion of water vapor to liquid) occurs with a decrease in temperature. This process is accompanied by heat absorption from water molecules in the gaseous state, which reduces their kinetic energy and brings molecules closer together. Students can relate this concept to kinetic-molecular theory and the effect of temperature on molecular motion.
- *Designing Solutions (Engineering Application):* Understanding the scientific principles governing this phenomenon, students can design engineering solutions to prevent container collapse, such as: installing ventilation valves to balance pressure, using materials with greater resistance in container construction, or designing internal reinforcing structures to increase container strength against external pressure.

- **Energy**:
  - *Types of Energy:* Energy can exist in various forms such as thermal, chemical, electrical, mechanical, etc. In the collapsed container phenomenon, thermal energy plays a central role. The high temperature of the washing water increases the thermal energy of water molecules and converts them to vapor. Then, with temperature decrease at night, this thermal energy is transferred to the environment, leading to condensation of water vapor.
  - *Conservation and Transfer of Energy:* Energy is never destroyed, but is converted from one form to another or transferred between objects. In the container collapse process, thermal energy is transferred from inside the container to the outside environment. This energy transfer causes a decrease in the temperature of the water vapor inside the container and leads to condensation.
  - *Energy Transfer:* When two objects interact with each other, energy transfer occurs between them. In this phenomenon, the interaction of water vapor molecules with the cold container wall causes thermal energy transfer and consequently condensation. Also, atmospheric pressure (air or atmosphere) does work on the container and causes its deformation.
- **Motion and Stability, Forces and Interactions:**
  - *Forces and Motion*: Atmospheric pressure equals the force exerted per unit area on the external surface of the container. When the internal pressure of the container decreases, this external force remains unopposed and causes the container to collapse.
  - *Types of Interactions*: The interaction between air molecules and the container surface is in the form of continuous collisions that create pressure. These interactions occur at the microscopic level but produce observable macroscopic effects such as container collapse.
  - *Stability and Instability in Physical Systems*: The container is initially in a stable state because its internal and external pressures are approximately equal. But with the condensation of water vapor, this balance is disturbed, and the system moves toward a new state of stability (collapsed container). This is a good example showing that systems react to changes to reach a new equilibrium.

b) Science and Engineering Practices (SEPs):

- Asking questions and defining problems (question about the cause of the container collapse)
- Developing and using models (modeling to explain condensation and pressure)
- Planning and conducting investigations (can experiments)
- Analyzing and interpreting data (examining experiment results)
- Using mathematical and computational thinking (pressure and volume calculations)
- Constructing explanations and designing solutions (providing explanation for the phenomenon)
- Engaging in argument from evidence (using experimental evidence)
- Obtaining, evaluating, and communicating information (presenting findings to the class)

c) Crosscutting Concepts (CCCs):

- Patterns (identifying the pattern of collapse and factors affecting it)
- Cause and effect (relationship between cold, condensation, and collapse)
- Systems and system models (container as a closed system)
- Energy and matter (phase change of matter and thermal energy transfer)
- Stability and change (change in matter state and container shape)

Connection with Nature of Science (NOS) Components:

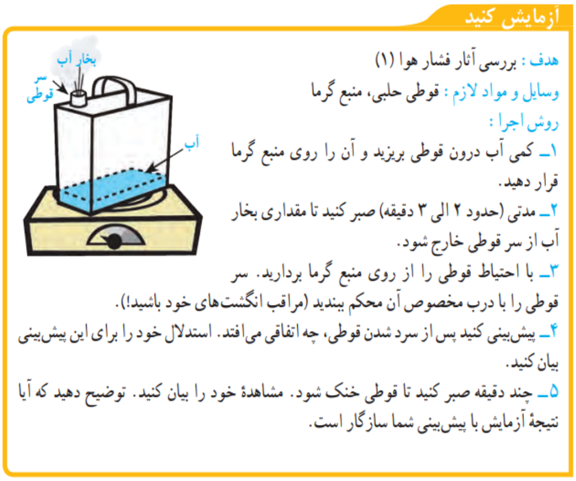
- Diverse methods of scientific investigations: Students understand through observation, hypothesis formulation, experiment design, and evidence collection that scientific methods are diverse and flexible, and not all researchers necessarily follow the same steps.
- Scientific knowledge is based on empirical evidence: Students learn that every scientific claim must be supported by empirical evidence. The designed experiments with cans provide empirical evidence for testing hypotheses.
- Scientific knowledge is revisable in light of new evidence: Students revise their initial hypotheses in light of new data, which shows that science is an ongoing and evolutionary process.
- Scientific models, laws, and theories are for explaining natural phenomena: Students use scientific models like the kinetic molecular theory and gas laws to explain the collapsed container phenomenon.
- Science is a human activity: The role of creativity, subjectivity, and prior knowledge in the scientific process is evident. Students see that different individuals may present different ideas for a single phenomenon.

Connection with Iran's Science Curriculum (Chapter Eight of the Ninth Grade Science Textbook: Pressure and Its Effects)

In one of the important physics chapters of the ninth grade Science textbook, which deals with air pressure and its effects, an experiment is presented on page 90, the image of which is shown in Figure 4.

Objective: Investigating the effects of air pressure
Materials Required: Metal can, Heat source
Procedure:

1. Pour a small amount of water into the can and place it on the heat source.
2. Wait for a while (about 2-3 minutes) until some steam escapes from the top of the can.
3. Carefully remove the can from the heat source. Seal the top of the can tightly with its lid. (Be careful of your fingers!)
4. Predict what will happen after the can cools down. Explain your reasoning for this prediction.
5. Wait a few minutes for the can to cool down. Describe your observations. Explain whether the experimental result is consistent with your prediction.


آزمایش کنید

هدف : بررسی آثار فشار هوا (۱)

وسایل و مواد لازم : قوطی حلبی، منبع گرما

روش اجرا :

۱ـ کمی آب درون قوطی بریزید و آن را روی منبع گرما قرار دهید.

۲ـ مدتی (حدود ۲ الی ۳ دقیقه) صبر کنید تا مقداری بخار آب از سر قوطی خارج شود.

۳ـ با احتیاط قوطی را از روی منبع گرما بردارید. سر قوطی را با درب مخصوص آن محکم ببندید (مراقب انگشت‌های خود باشید!).

۴ـ پیش‌بینی کنید پس از سرد شدن قوطی، چه اتفاقی می‌افتد. استدلال خود را برای این پیش‌بینی بیان کنید.

۵ـ چند دقیقه صبر کنید تا قوطی خنک شود. مشاهدهٔ خود را بیان کنید. توضیح دهید که آیا نتیجهٔ آزمایش با پیش‌بینی شما سازگار است.

Figure 4. "Do the Experiment" in the Ninth Grade Science Textbook on the topic of Examining Air Pressure Effects [1].

In this experiment, a tin can containing some water is placed on a heater until water vapor escapes from the can's opening. Then the can's lid is closed, and students are asked to predict what will happen when the can cools down and to state their reasoning (Ahmadi et al., 2022, p. 90). The experience of the present researchers from teacher training workshops shows that in response to this question, all teachers correctly refer to the pressure difference between the outside air and the inside of the can. In other words, they identify the main factor of the can's collapse as the difference between air pressure and the pressure inside the can. But in explaining the reason for the pressure difference, the only reason mentioned is the cooling of the air inside the can and the contraction of the inside air, while no attention is paid to the main factor creating the pressure difference, which is the *condensation of water vapor* molecules. This is while if the can without water is placed on the heater in this experiment, no matter how much it heats up, it will not collapse after cooling (it will only slightly dent). Therefore, by performing these two experiments (once with a can without water and once with a can containing water), it can be concluded that the main reason for the can's collapse is the condensation of water vapor inside the can. This phase change from gas to solid is accompanied by a significant volume reduction. This volume reduction due to phase change is much greater than the volume reduction that occurs due to the temperature change of the gas inside the can. Therefore, although gas contraction also plays a role in the can's denting, the main role is played by the condensation factor.

Showing scientific educational videos related to the phenomenon to reinforce the material:

In this section, various scientific educational videos related to this phenomenon that provide good explanations in an engaging way can be shown to students to reinforce the material. Images from these videos are shown below. Images from these videos are shown in Table 5. These videos are easily accessible on the internet.

Table 5. Images from Engaging Educational Videos Showing and Explaining the Collapsed Can Phenomenon

Image from Video 1 of soda can collapse	Image from Video 2 of soda can collapse
	

This final step (Step Six) provides an opportunity to integrate concepts, apply learning to real life, and strengthen students' critical thinking. It also shows students the multidisciplinary nature of science (NOS) and familiarizes them with the real process of scientific research.

Assessment Strategies in Phenomenon-Based Science Education

Phenomenon-based science education, with its inquiry-driven and student-centered nature, offers rich opportunities for implementing diverse assessment methods that align with three-dimensional learning goals. Effective assessment in PhBL should evaluate not only content knowledge but also students' development of scientific practices and their ability to connect concepts across disciplines. This section outlines comprehensive assessment strategies that educators can implement throughout the PhBL process.

Formative Assessment Strategies: Formative assessment in PhBL occurs continuously as students progress through the six stages of phenomenon exploration. These assessments provide valuable feedback to both teachers and students, allowing for instructional adjustments and learning improvements in real-time:

1. ***Questions-Observations-Interpretations (QOI) Tables:*** The QOI tables created in Step Two serve as effective formative assessment tools. Teachers can analyze the quality and depth of students' observations, questions, and interpretations to gauge their initial understanding and misconceptions.
2. ***Investigation Planning and Execution:*** During Step Four (Exploring the Phenomenon), teachers can assess students' abilities to design investigations, control variables, and collect relevant data through observation checklists and research journals.
3. ***Classroom Discourse Analysis:*** Teachers can systematically document and analyze classroom discussions using field notes to track student participation, reasoning patterns, and conceptual development throughout the PhBL process.
4. ***Summary Tables and Artifacts:*** The summary tables completed in Step Five provide evidence of students' evolving understanding. Additionally, student-created artifacts such as drawings, diagrams, concept maps, and digital presentations offer insights into how students organize and visualize scientific concepts.

Summative Assessment Strategies: While traditional assessment methods can evaluate content knowledge gained through PhBL, the approach offers opportunities for more authentic summative assessments that evaluate higher-order thinking skills:

1. ***Transfer Phenomenon Assessment:*** Present students with a similar but novel phenomenon and ask them to apply their learning in this new context. For example, after exploring the "candle and water level" phenomenon, students could be assessed on explaining the "egg-in-bottle" phenomenon (where a burning piece of paper inside a bottle creates suction that pulls an egg into the bottle). This approach evaluates students' ability to transfer conceptual understanding across contexts.
2. ***Consensus Model Evaluation:*** Assess the final consensus models (Step Six) using rubrics that evaluate scientific accuracy, integration of disciplinary core ideas, application of crosscutting concepts, and communication effectiveness.
3. ***Phenomenon Explanation Portfolios:*** Students can compile portfolios documenting their journey from initial observations to final explanations, including revised models, evidence collection, and reflections on their changing understanding.
4. ***Performance-Based Assessments:*** Design scenarios where students must apply their understanding to solve related problems or explain real-world applications of the scientific principles explored.

Assessing Three-Dimensional Learning: Effective assessment in PhBL should explicitly address all three dimensions of science learning:

1. ***Disciplinary Core Ideas:*** Assess students' mastery of key scientific concepts and their ability to apply these concepts to explain phenomena.
2. ***Crosscutting Concepts:*** Evaluate students' ability to recognize and use patterns, cause-effect relationships, systems thinking, and other crosscutting concepts across scientific domains.
3. ***Science and Engineering Practices:*** Assess students' proficiency in scientific practices such as asking questions, developing models, planning investigations, analyzing data, and constructing explanations.

The PhBL approach is particularly well-suited for assessing higher levels of cognitive engagement on Bloom's taxonomy, including application, analysis, evaluation, and creation. By incorporating diverse assessment strategies, educators can gain a comprehensive understanding of students' scientific literacy development while providing multiple pathways for students to demonstrate their understanding.

Additional Phenomena for Phenomenon-Based Science Education

While the "collapsed container" phenomenon provides an engaging example for implementing three-dimensional learning through phenomenon-based science education, several other phenomena can also effectively demonstrate these principles. These additional examples offer educators a broader range of applications across different scientific domains and educational contexts.

The Candle and Water Level Phenomenon: The phenomenon of rising water in a jar inverted over a burning candle presents substantial potential for integrating physics and chemistry concepts. When introducing this phenomenon, students observe a burning candle placed in a dish of water, which is then covered with a glass jar. As the flame extinguishes, water rises into the jar, prompting students to ask questions such as: "Why does the flame go out?", "Why does the water rise?", "Is there any oxygen left in the jar after the flame goes out?", and "What factors affect the rise of water inside the jar?"

This comprehensive phenomenon effectively incorporates all three dimensions of learning and nature of science elements within a practical, engaging classroom activity. For more detailed implementation guidance, see Saberi and Nouri [16].

The Lotus Effect Phenomenon: Lotus is rooted in the ancient culture of many countries (such as Iranian, Hindu, and Egyptian) and symbolizes beauty, perfection, and purity. Despite growing in muddy waters and adverse conditions, lotus leaves remain remarkably clean without the slightest trace of mud or pollution. When presented with this phenomenon, students typically raise questions such as:

1. Why lotus leaves are usually clean and free of any contamination despite growing in muddy waters?
2. Why does the surface of the leaf not get wet?

This phenomenon is particularly relevant for coastal regions where context-based science education can connect to students' immediate environment. The lotus effect offers excellent potential for enhancing three-dimensional learning and nature of science understanding. For more implementation details, see Nouri et al. (2024), who explored using this phenomenon to promote science preservice teachers' competencies.

The Color Perception Phenomenon: Another engaging phenomenon involves color perception. When showing students a red apple and asking "What color do you see?" followed by "Why do we see this apple as red?", students typically offer various initial explanations:

- "Because there are red pigments in its skin."
- "Because our eye receptors see it as red with the help of our brain."
- "Because the light hits it and the reflection of the light from the red skin of the apple reaches our eyes."
- "Because when white light hits the apple, it absorbs all colors except red. The red color reflects to our eye so we see it as red."

This phenomenon offers significant potential for integrating physics and biology concepts, allowing students to explore light properties, the physiology of vision, and brain processing of visual information.

Other Potential Phenomena: Other intriguing phenomena that can be implemented at both high school and university levels for preservice teachers (science, physics, chemistry, and biology) include:

- How polar bears survive in harsh arctic conditions
- How a person can lie on the surface of a lake while reading a newspaper

These examples, along with the collapsed container phenomenon detailed in the article, demonstrate how phenomenon-based science education can be applied across diverse scientific domains while effectively incorporating three-dimensional learning and nature of science concepts.

CONCLUSION

In the present research, the three-dimensional learning approach and phenomenon-based science education were examined as innovative strategies in science education. First, the theoretical foundations of three-dimensional learning were explained, focusing on its three main axes including disciplinary core ideas, crosscutting concepts, and scientific and engineering practices. Then, the phenomenon-based science education approach was introduced with emphasis on its role in understanding and explaining natural phenomena. The six stages of phenomenon-based education, including introducing the phenomenon, creating a questions-observations-interpretations table, developing an initial model, exploring the phenomenon, completing a summary table, and proposing a consensus model and explaining the phenomenon, were explained in detail. A comprehensive framework for assessment in phenomenon-based learning was presented, highlighting both formative and summative strategies aligned with three-dimensional learning goals. Finally, a practical example of educational design with a phenomenon-based approach on the topic of "collapsed container" was presented to concretely show how to apply this approach in the classroom.

Potential Challenges and Limitations of PhBL Implementation

Implementing phenomenon-based science education faces several key challenges across different educational contexts. Resource constraints represent a significant barrier, as PhBL often requires materials for experiments, technology for presenting phenomena, and adequate classroom space—creating potential implementation disparities between well-resourced and under-resourced schools. Teacher preparedness is equally critical, as PhBL requires deep interdisciplinary content knowledge, strong inquiry facilitation skills, and comfort with less structured learning environments. Without proper training, teachers may implement PhBL superficially or revert to traditional methods.

Student diversity presents additional challenges, as learners with different language proficiencies, prior knowledge, and cultural backgrounds may experience varied levels of engagement with phenomena. Institutional constraints further complicate implementation, including rigid scheduling that limits extended exploration, curriculum requirements that prioritize content coverage over inquiry, and standardized assessment systems that may not align with PhBL's emphasis on scientific practices and crosscutting concepts.

Implications for Future Research and Practice

This research offers valuable implications for science education stakeholders. For teachers, it provides a practical framework to transform theoretical classrooms into dynamic learning spaces, with the "collapsed container" design serving as an immediately applicable model. For teacher educators, the three-dimensional framework creates opportunities to enrich preparation programs by helping preservice teachers develop integrated understanding of science content, pedagogy, and nature of science. For researchers, several promising directions emerge: longitudinal studies examining PhBL's long-term impact on student learning, cross-cultural research exploring adaptations for different contexts, investigations into effective assessment practices aligned with PhBL's multidimensional goals, and studies of professional development models that support teachers' transition to phenomenon-based approaches. Research on technology integration and PhBL's effectiveness in promoting equity in science education represent particularly valuable future directions. These research avenues would strengthen the evidence base for PhBL while providing practical guidance for its implementation across diverse educational settings.

The physics teachers, student teachers, and physics professors at Farhangian University can use the findings of this research to enrich their teaching and professional development. This approach provides a framework for future research in physics education, potentially leading to innovations that enhance both the teaching and learning of this essential scientific discipline.

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