Jurnal Penelitian dan Pembelajaran IPA JPPI
Vol.10, No.2, 2024, p. 161-189 p-ISSN 2477-1422 e-ISSN 2477-2038

# Remote Chemistry Labs: Academic Success and Opinions of First-Year Science Students Using PDEODE Model

(Received 9 July 2024 Revised 30 November 2024 Accepted 30 November 2024)

**Nehir Özbulut[1], Melis Arzu Uyulgan[2*]**

[1]Institute of Educational Sciences, Dokuz Eylul University, Izmir, Turkey

[2]Department of Chemistry Education, Buca Faculty of Education,
Dokuz Eylul University, Izmir, Turkey
Corresponding Author: *melis.cekci@deu.edu.tr

**DOI: 10.30870/jppi.v10i2.27478**

## Abstract

The PDEODE (Prediction-Discussion-Explanation-Observation-Discussion-Explanation) instructional model, with its structured approach that fosters prediction, discussion, explanation, observation, and subsequent discussions, stands out as a powerful tool for enhancing students' scientific thinking skills and engagement in the scientific process. Research on the implementation and effectiveness of the PDEODE strategy is essential for comprehending its impact on student learning outcomes, conceptual understanding, critical thinking abilities, and social skills within the context of laboratory education. In this paper, we investigated the implementation of the PDEODE in science education within remote learning processes and examined its impact on students' academic success. The results showed a positive improvement in students' academic success over a 6-week period when PDEODE was integrated into laboratory experiments. The model's effectiveness in enhancing students' scientific understanding and thinking was evident through their active participation and discussions. Furthermore, positive feedback from students regarding the model's effectiveness in remote learning environments, as well as their perceptions of improved understanding and enjoyment, further emphasizes the significance of the PDEODE approach in enhancing learning outcomes. This paper suggests that further exploration of the integration of the PDEODE model in various science courses and learning settings could greatly enhance educational experiences.

Keywords: Laboratory experiments, PDEODE model, Science education, University students

## INTRODUCTION

Science educators have long advocated the benefits of engaging students in laboratory activities (Hofstein, 2004; Lunetta et al., 2007). For instance, Tobin (1990) stated, "Laboratory activities provide students with the opportunity to learn by understanding and simultaneously engage in the process of constructing knowledge through doing science." Considering this information, laboratory education should provide students with the opportunity to "practice being a scientist" by questioning, developing, and testing theories (Hofstein & Hugerat, 2021, p. 6). Studies have aimed to explore the effectiveness of laboratory activities in achieving both cognitive and affective gains as proposed in the science education literature (Amolins et al., 2015; Carmel et al., 2019). Laboratory education has the potential to achieve several objectives in scientific understanding, interest, motivation, attitudes toward science, practical skills, problem-solving abilities, scientific thinking habits, understanding the nature of science (NOS), and opportunities for engaging in scientific inquiry (Hofstein, 2004; Lunetta et al., 2007; Naiker et al., 2021).

Research from the past to the present has emphasized the significance of laboratory activities as a crucial and distinctive part of science curricula, highlighting the array of benefits that active engagement in science laboratories offers students (Çıngıl Bariş, 2022; Hofstein & Hugerat, 2021; Lowe et al., 2013; Lunetta et al., 2007; Samsudin et al., 2019; Wang et al., 2014). Particularly, it has been noted that the proper development of research, inquiry, and discussion-oriented laboratory activities has the potential to improve students' meaningful learning, conceptual understanding, and grasp of the nature of science (Russell & Weaver, 2011; Scott et al., 2018). Laboratory work of this kind plays a central role on students' learning in science education. It involves designing problems and scientific inquiries, formulating hypotheses, planning experiments, collecting, and analyzing data, and drawing conclusions about scientific problems or phenomena (Hofstein & Hugerat, 2021).

Effective instruction within laboratory courses requires the use of diverse methods to accommodate the varying learning styles, skill levels, and interests among students. This necessity arises from the recognition that students' diverse attributes require the use of different teaching strategies. This not only fosters a spirit of scientific exploration but also helps students to direct their own learning more effectively. Therefore, in addition to standardized practices in laboratory education, diversity and flexibility in instructional methods are crucial to ensure optimal student engagement (Boyd-Kimball & Miller, 2018; Coştu & Bayram, 2021a; Nicolaidou et al., 2019). Current research emphasizes the essential role of higher-order learning skills in addition to knowledge content in modern laboratory education. Merely memorizing information is no longer sufficient; it is now essential to cultivate and apply higher-order thinking and learning skills. These skills encompass activities such as formulating research questions, solving real problems, argumentation, self-awareness, inference, comparisons, engaging in discussions (Malik & Setiawan, 2016; Simon, 2013). This indicates an environment in which significant learning takes place when students have abundant opportunities to interact and initiate discussions in the laboratory. This shift in laboratory education implies a transition from simply acquiring knowledge to fostering advanced thinking skills (Zoller & Nahum, 2012).

The PDEODE model is an effective instructional method in a laboratory setting. This method facilitates the development of students' scientific thinking skills by providing them with a process for formulating hypotheses. Students are expected to predict potential outcomes before conducting experiments, design the experiment, execute it, carefully observe the results, and finally, analyze their observations and results to provide a scientific explanation (Coştu et al., 2012; Karslı-Baydere, 2021; White & Gunstone, 1992). This approach encourages students to make their own scientific discoveries by guiding them through the scientific process step by step. Moreover, it provides a flexible teaching approach that caters to various learning styles and skill levels, enabling each student to learn at their own pace and in their preferred manner. Widely used in laboratory education, this approach improves students' cognitive abilities and equips them with skills in scientific thinking and analysis (Alsalamat, 2012; Dipalaya & Corebima, 2016).

Aligned with the PDEODE instructional model, Francis Bacon's emphasis on critical thinking resonates deeply in the realm of scientific exploration (Aminudin et al., 2019). Bacon, a pioneering proponent of the scientific method, emphasized the significance of systematic inquiry and skepticism in the quest for knowledge (McMullin, 2009, p. 15). The PDEODE model's structured approach, which encourages students to predict, experiment, observe, and analyze, aligns seamlessly with Bacon's philosophy. By promoting a culture of inquiry and thoughtful analysis, this approach not only helps students navigate the practical aspects of experimentation but also imbues them with Baconian principles of critical thinking, enhancing their capacity to examine, interpret, and draw meaningful conclusions from their scientific pursuits.

In recent times, the PDEODE has been utilized in various studies as a modified version of the POE (Predict-Observe-Explain) method. It is supported by discussions conducted both before and after the 'observation' stage of the conventional POE method (Abdullah et al., 2017; Coştu, 2008; Demircioğlu, 2017; Halimah et al., 2019; Savander-Ranne & Kolari, 2003). The key difference between this method and the POE approach is its emphasis on encouraging student participation in scientific discussions. Students present their experiment findings to the class and receive feedback from a variety of perspectives. These discussions enable students to delve deeper into their own observations, thereby enhancing their scientific thinking skills. Moreover, examining different hypotheses and explanations enhances students' critical thinking abilities, leading to a more comprehensive understanding of the scientific process (Aminudin et al., 2019; Dipalaya & Corebima, 2016; Mailani & Syafii, 2020). In this way, the PDEODE, enriched with discussions, encourages students to develop scientific thinking skills and actively participate in the scientific community.

The first stage of the PDEODE is the Prediction (P) step. At this stage, students are encouraged to make predictions about a specific activity or event and to explain the reasoning behind their predictions. Activities designed to provoke cognitive dissonance encourage each student to formulate their own predictions. During the discussion (D) stage, students discuss their thoughts in groups. In the third stage, known as the Explanation (E) stage, students within each group discuss and evaluate the outcomes of their predictions. They attempt to find common solutions through mutual problem-solving and reasoning, and subsequently present their conclusions in front of the class (Savander-Ranne & Kolari, 2003). In the Observation (O) stage, students are required to observe and take notes on the events or activities they were asked to predict in the initial stage. Students observe potential events that could provide evidence and inferences for the results. At this stage, students are encouraged to observe all aspects of the activity. In the next discussion (D) stage, students collaborate to connect and reconcile their observations with their initial predictions. They discuss observations, debate the relevance of predictions, and develop a new understanding by comparing it with their prior knowledge. Throughout the course, students analyze, compare, and critique their own thoughts alongside those of their peers. In the final stage, the Explanation (E) stage, students identify discrepancies between their predictions and observations and provide explanations for contradictory situations. Presentations in front of the class serve as a platform for discussing with other groups. If a group encounters disagreement, other groups can communicate the results of their discussions. After the presentations are completed, teachers encourage and emphasize whether students have embraced or adopted a new cognition (Coştu, 2008).

The PDEODE strategy, like POE, is effective in fostering a scientific mindset and enhancing students' skills in the scientific process. The scientific process involves students engaging in an integrated learning process that includes discovery, observation, hypothesis formulation, and inference processes. In contrast to POE, PDEODE involves two additional processes: discussion and explanation. These processes foster skills in students, such as scientific thinking, empathy, critical thinking, and the ability to articulate and defend their own thoughts (Cholisoh et al., 2015; Savander-Rane & Kolari, 2003). The PDEODE strategy is designed to facilitate disciplined progress in the learning process for both educators and students. Questions and problems utilized in this instructional approach, which emphasizes collaborative learning and peer interaction, should prompt students to initiate discussions, ask questions, consider various perspectives, constructively object, and present diverse solution methods (Savander-Rane & Kolari, 2003). The integration of classroom activities using the PDEODE, and similarly, discussion-supported POE studies, has shown effectiveness in correcting conceptual misconceptions and enhancing academic achievement compared to traditional instructional programs (Sıriş, 2022). Moreover, instructional methods grounded in this approach for laboratory activities have been shown to be more effective in enhancing students' scientific process skills, addressing real-life problems, and improving conceptual understanding (Coştu & Bayram, 2021a; Ernawati et al., 2019; Hardianti & Permatasari, 2023; Wati & Novita, 2021). Coştu and Bayram (2021b), conducted a study with pre-service science teachers, revealing that discussion-supported PEODE-based laboratory activities contributed more to the development of pre-service science teachers' scientific process skills compared to traditional (cookbook) laboratories. In their study, Widyastuti et al. (2019a) concluded that the incorporation of PDEODE activities supported by PhET simulations led to the enhancement of higher-order thinking skills among students. Ekawati (2018) examined the impact of blended learning using the Edmodo application based on the PDEODE on the topic "Nature of Light" and found a positive enhancement in students' achievements. Similar research findings, such as those referenced in these studies, have highlighted the positive impact of the PDEODE not only on academic achievement and conceptual understanding, but also on social skills, critical thinking, effective debate and questioning, teamwork, and communication abilities (Gustiani, 2013; Wulandari et al., 2021). Furthermore, Wulandari et al. (2021) emphasized the importance of improving critical thinking skills, especially in reflective and impulsive cognitive styles, by using the PDEODE strategy in online education. However, the number of studies investigating the role of this method in the laboratory activities is quite limited. With this research, an attempt was made to contribute to this gap in the literature.

This study aimed to investigate the change in academic achievement of first-year science education students during a semester in practical sessions using PDEODE-based chemistry laboratory activities. In addition, students' experiences of the PDEODE activities were also investigated. To achieve this goal, the researchers conducted various chemistry experiments throughout the semester as part of the Chemistry 2 course in remote education process. Students' academic success was assessed at the end of each chemistry experiment and their progress was evaluated by analysing their development throughout the process. Our research questions are the following:

Q1. How does the academic success of students in chemistry laboratory experiments change while using PDEODE activities during remote education?

Q2. What are the students' experiences on engaging PDEODE activities in chemistry laboratory experiments during remote education?

## METHOD

### Research Design

In this study, we utilized a qualitative approach, specifically employing the case study method to fulfill the research aims. Case study is a research method aimed at comprehending a situation, providing explanations to questions of "what, how, why" about the situation, and comprehensively assessing the situation (Yin, 2011). In case studies, addressing complex and challenging situations involves examining the situation in detail and providing necessary explanations. These explanations are supported using multiple data collection tools.

**Sample of the Study**

The study was conducted during the spring semester of the 2020-2021 school year. The study's sample comprises students enrolled in the Chemistry 2 course offered by the Department of Science Education at a state university in the west part of Turkey. The sample selection was conducted using purposive sampling. The choice of this sampling method enables a thorough examination and exploration of a group or event that is believed to hold detailed information about a particular situation (Yin, 2011, p.88). 38 first-year students enrolled in the Department of Science Education were selected in alignment with the research aims. Among the participants, 7 (18.4%) were male and 31 (81.6%) were female.

**Data Collection Tools**

The data were collected using two different data collection tools. Using multiple data collection instruments facilitated diversifying the data in the research.

**PDEODE Activity Sheets for Chemistry Laboratory Experiments**

The activity sheets used in the study were created by the researchers in line with the PDEODE model. During the preparation of these activities, we sought the opinions of three field experts. Within the scope of the study, a total of six activity sheets were created for experiments (see Appendix for a sample of the PDEODE activity sheet). Open-ended questions were used in these sheets to evaluate the academic success of the students in the sample. Initially, the activity sheets presented students with pre-assessment questions pertaining to the experiment. The questions, designed to relate to daily life scenarios, aimed to encourage students to reflect, focus on the topic, and ensure a more effective and successful execution of the experiment, prompting them to enter the prediction stage. At this stage, students' predictions were elicited through a visual experiment provided on the activity sheet and a directive related to the experiment. Following the prediction stage, whole-class discussions were conducted to encourage students to share their predictions and provide justifications. During the observation stage, an experimental video created by the researchers was shared with the students during live sessions for simultaneous viewing. Students recorded their observations on the activity sheets. During the discussion stage following the observation, students were encouraged to share their opinions on whether there was any difference between their predictions and observation notes. In whole-class discussions, students presented their reasoning behind their ideas. Following this discussion, in the explanation stage, students were encouraged to address cognitive contradictions and provide scientific explanations. Finally, at the end of the activity sheet, students were also asked to write a brief paragraph about the changes occurring in their thoughts before and after the experiment.

**Structured Interview Form**

In the study, a structured interview form was used as the second data collection tool to assess the effectiveness of Chemistry Laboratory applications conducted with the PDEODE activities and to measure students' experiences. The form comprised a total of 5 questions about PDEODE activities and students' academic success in the chemistry laboratory. To evaluate the clarity of the questions and establish the duration of the interview, a pilot study was conducted with five students not part of the sample group. Based on expert feedback and the results of a pilot study, the structured interview form was refined. Example of a question from the structured interview form are provided below:

"Could you please share your experiences on the activities conducted using the PDEODE strategy in chemistry experiments?"

Although responding to the interview form was voluntary, all students in the sample responded to the questions after the implementation of the PDEODE activities. The structured interview form was distributed to students during a synchronous session in the final week of the implementation process. Students were asked to personally complete the form and send it to the researchers within the 50-minute duration of the class session. The interview form was never used for grading purposes, and students were encouraged by the researchers to express their experiences openly and honestly.

**Instruction Process**

Due to the outbreak of the Covid-19 virus, classes during the instruction period were conducted remotely. Lessons were conducted live in real time through an online education platform. All students registered on this platform using their school number and name. The implementation, including the data collection process, was completed in a total of 9 weeks. The experiments were conducted over a period of 6 weeks, spanning from the 2nd to the 7th week, as part of the Chemistry 2 course. According to the curriculum, the Chemistry 2 course consists of a total of 4 class hours per week, comprising 2 hours of theory and 2 hours of practice. The PDEODE activities were conducted during the two-hour practical session of this course. In the online classes, the duration of a single class ranged from 25 to 45 minutes. Detailed information about the experiments selected for the research and the instruction process is presented in Table 1.

Table 1. The Instruction Process

| Weeks | Activities | Data Collection Tool | Course Hours | Contents |
|---|---|---|---|---|
| 1 | Pre-Introduction to the PDEODE | Introduction to a Sample PDEODE Activity Sheet | 2 | Providing information about the research process |
| 2 | Dissolving Experiment | PDEODE Activity Sheet 1 | 2 | Explanation and application of dissolution and solubility concepts |
| 3 | Crystallization Experiment | PDEODE Activity Sheet 2 | 2 | Explanation and application of separation of mixtures |
| 4 | Heat Conduction Experiment | PDEODE Activity Sheet 3 | 2 | Explanation and application of heat conduction |
| 5 | Titration Experiment | PDEODE Activity Sheet 4 | 2 | Explanation and application of acid, base, and concentration concepts |
| 6 | Determination of Water Hardness Experiment | PDEODE Activity Sheet 5 | 2 | Explanation and application of permanent hardness, temporary hardness, and substances causing water hardness |
| 7 | Electrolysis Experiment | PDEODE Activity Sheet 6 | 2 | Explanation and application of electric current, electrochemical cell, and electrolysis of water |
| 8 | General Evaluation of the PDEODE | - | 2 | General evaluation of the research process |
| 9 | Interview | Structured Interview Form | 2 | Obtaining students' opinions about the PDEODE model |

The flowchart in Figure 1 illustrates the step-by-step implementation of the experimental activities developed using the PDEODE through the online education platform.
The students individually shared the activity sheets used during the experimental sessions with the researchers within the designated time frame provided through the online platform. Furthermore, the students' opinions, especially during the discussion stages I and II, were collected through vocal participation and written

comments in the general chat section on the platform. A sample screenshot from the educational platform during the experimental activity is shown in Figure 2.

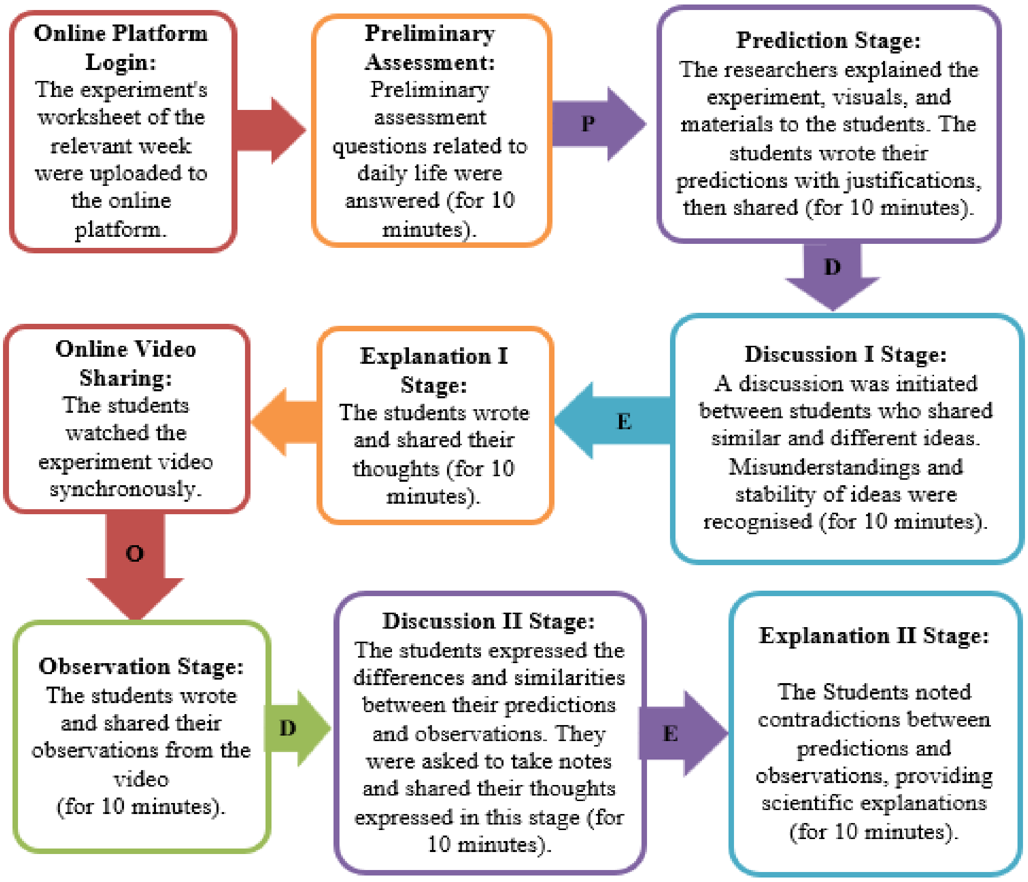


Figure 1. The Flowchart of the PDEODE Model

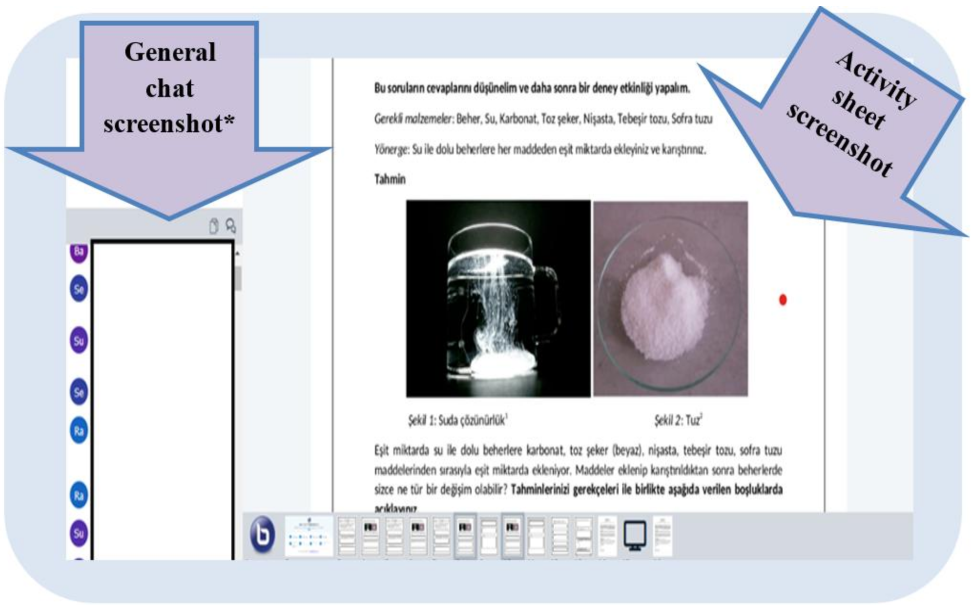


Figure 2. A Sample Screenshot of the Educational Platform During the Research Process

*Note.* *The student responses shared in this screen were concealed due to containing personal data

## Data Analysis

The students were asked to individually complete the PDEODE stages in the activity sheets. The discussion I and explanation I stages following the prediction stage in the activity sheets were not applied separately to obtain more detailed data from the students. Instead, they were combined and applied as a single discussion I-explanation I stage. In the quantitative analysis of the data, the students' responses to the questions in the activity sheets were scored as 0, 1, and 2 based on the rubric. A score of 1 point obtained from students' answers indicates a partially or inadequately addressed aspect of the given PDEODE stage, while a score of 2 points signifies the ability to provide the definite and complete answer required for the relevant PDEODE stage. Conversely, irrelevant, or incorrect responses were assigned a score of 0 points. The rubric for POE (TGA in Turkish) activities, developed by Kozcu-Çakır et al. (2017), was adapted for PDEODE and utilized by the researchers in this study (see Table 2).

Table 2. Rubric Used in the Evaluation of PDEODE Stages

| PDEODE Stages | Score | Criteria |
|---|---|---|
| Prediction | 0 | There is no prediction sentence, or it is left blank. |
| | 1 | The number of prediction sentences is one. |
| | 2 | The number of prediction sentences is two or more. |
| Discussion I and Explanation I | 0 | Predictions lack explanation, with no connection to in-class discussions. |
| | 1 | Predictions partly explained, partly linked to in-class discussions. |
| | 2 | Fully explained predictions directly linked to in-class discussions. |
| Observation | 0 | The observation statements lack connection to the prediction sentences. |
| | 1 | The observation statements partly connected to the prediction sentences. |
| | 2 | The observation statements fully aligned with the prediction sentences. |
| Discussion II | 0 | Reasons lack of association with in-class discussions and not explained. |
| | 1 | Reasons partly associated with the in-class discussions and partly explained. |
| | 2 | Reasons thoroughly associated and fully explained during in-class discussions. |
| Explanation II | 0 | The association of the experiment with the prediction and observation statements is scientifically incorrect, or no explanation. |
| | 1 | The association of the experiment with prediction and observation statements is scientifically partly correct. |
| | 2 | The association of prediction and observation statements with the experiment is scientifically accurate. |

Considering the criteria shown in Table 2, the stages of each student in the PDEODE activity sheets were evaluated. In this manner, the analysis aimed to determine if there was any change in the students' academic success.

Each stage in the activity sheets was presented in individual rows within specific boxes. This minimized the influence of students' previous answers and ensured high reliability. To ensure the reliability of the data, the researchers and a field expert independently scored the students' responses to assess the reliability of the scoring (Miles & Huberman, 1994). The inter-rater reliability was calculated to be 84% for 6 activity sheets. The scoring reliability of 70% and above is considered acceptable.

After implementing the experimental activities developed based on the PDEODE, the students' written responses to the questions in the structured opinion form were descriptively analyzed. The process of descriptive analysis involves initial data reading, independent theme generation, and consensus building (Boyatzis, 1998). The researchers first read all the data. In the next stage, the analysts independently gathered the opinions under themes and sub-themes. A consensus was reached by coming together to discuss the generated themes. The themes and sub-themes identified through consensus were organized into categories, and direct quotations from the students' opinions were included. The students' quotations were coded as S1, S2, ..., S38. These quotations were then analyzed. The reliability between the researchers was calculated at 97%.

**Validity and Reliability of the Study**

In this study, data triangulation was used to ensure internal validity. Data were collected using two different tools and evaluated quantitatively to assess the change of the students' academic success. Expert opinions were utilized in developing activity sheets, planning, selecting experiments, and analyzing data, enhancing internal validity (Merriam, 1998). Participants voluntarily engaged in all activities, and their experiences were gathered during practice courses. Efforts were made to ensure applications were non-intimidating, promoting active participation and motivation. To enhance internal reliability, a field expert assisted in the data evaluation process (Merriam & Grenier, 2019).

Lincoln and Guba (1985) emphasized credibility over validity and reliability in case studies. To demonstrate credibility, student statements were quoted, and the entire research process was reported clearly and comprehensively.

**Role of the Researchers**

Due to the Covid-19 pandemic, face-to-face education was not possible. Researchers recorded chemistry laboratory experiments using the

PDEODE model and uploaded the videos to an online platform. The PDEODE activity sheets connected the experiments to daily life, encouraging comprehensive thinking and raising awareness. Online courses ensured active participation in all PDEODE stages (pre-assessment, prediction, discussion I-explanation I, observation, discussion II, and explanation II). Researchers observed the process without interfering with students' thoughts and provided guidance during the final explanation stage to clarify any contradictions.

**Ethics**

In this study, research ethics principles were observed, and the necessary ethics approval was obtained from the University Legal Consultancy Department (E-87347630-640.99-33366).

## RESULTS AND DISCUSSION

### Results of the PDEODE Activity Sheets

The students' responses to the central question for each PDEODE stage were assessed using a rubric, and the results are presented in the Table 3 as percentages corresponding to each experiment. Furthermore, separate graphs were generated for each PDEODE stage to facilitate clear visualization of score variations (Q1).

Table 3. Percentage Distribution of Weekly Score Change for the PDEODE Stages

| The PDEODE Stages | Score | Experiments/Weeks 1st % | 2nd % | 3rd % | 4th % | 5th % | 6th % |
|---|---|---|---|---|---|---|---|
| Prediction | 0 | 0 | 0 | 0 | 0 | 0 | 2.6 |
| | 1 | 76.3 | 55.3 | 42.1 | 44.7 | 42.1 | 42.1 |
| | 2 | 23.7 | 44.7 | 57.9 | 55.3 | 57.9 | 55.3 |
| Discussion I and Explanation I | 0 | 2.6 | 5.3 | 0 | 0 | 0 | 1.8 |
| | 1 | 71.1 | 52.6 | 36.9 | 15.8 | 26.3 | 34.2 |
| | 2 | 26.3 | 42.1 | 63.2 | 84.2 | 73.7 | 63.2 |
| Observation | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 1 | 52.6 | 29.0 | 44.8 | 26.3 | 15.8 | 39.5 |
| | 2 | 47.4 | 71.1 | 55.3 | 73.7 | 84.2 | 60.5 |
| Discussion II | 0 | 7.9 | 2.6 | 0 | 0 | 0 | 0 |
| | 1 | 63.2 | 36.8 | 42.1 | 36.8 | 34.2 | 44.7 |
| | 2 | 29.0 | 60.5 | 57.9 | 63.2 | 65.8 | 55.3 |
| Explanation II | 0 | 0 | 0 | 0 | 2.6 | 0 | 0 |
| | 1 | 34.2 | 29.0 | 29.0 | 55.3 | 23.7 | 50.0 |
| | 2 | 65.8 | 71.1 | 71.1 | 42.1 | 76.3 | 50.0 |

When considering the changes in the students' scores at the prediction stage throughout the process, it can be observed that the scores are generally increasing. The percentage of correct answers increased from 23.7% in the first week to 57.9% in the fifth week and 55.3% in the sixth week. This change is a result of the increase in the number of fully correct answers provided by the students, which in turn reflects the improvement in the accuracy of their scientific explanations. The change for this stage can be seen more clearly in the Figure 3. The graph illustrates a significant increase between the experiments conducted in the first and third weeks, while scores remained consistent during the experiments in the fourth and sixth weeks.

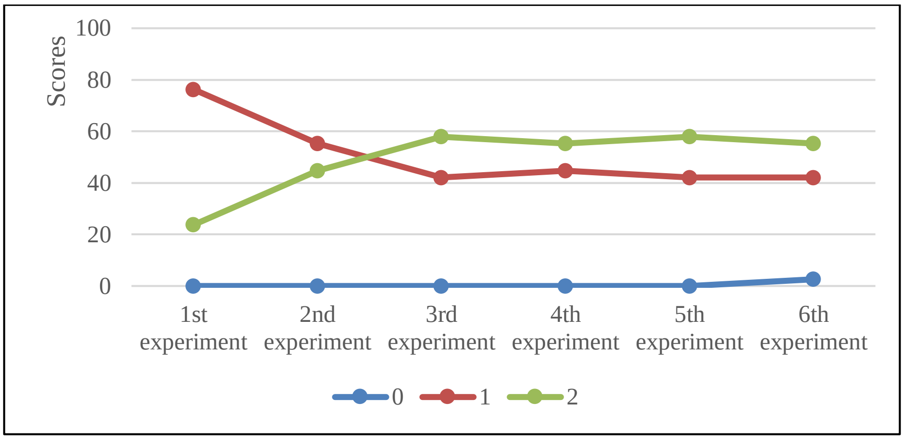


Figure 3. Scores from the Prediction Stage

When the scores related to the stage in which the students discussed and explained their predictions immediately after the prediction stage were evaluated, it can be said that there is an increase in the scores. While the percentage of fully correct answers determined in the first week was 26.3%, it increased to 84.2% in the 4th week, and was found to be 73.7% in the 5th week, and 63.2% in the 6th week. The change for this stage is shown in the Figure 4. When we examine the graph in the Figure 4, it is evident that the scores increased significantly, particularly during the experiments in the 1st and 4th weeks.

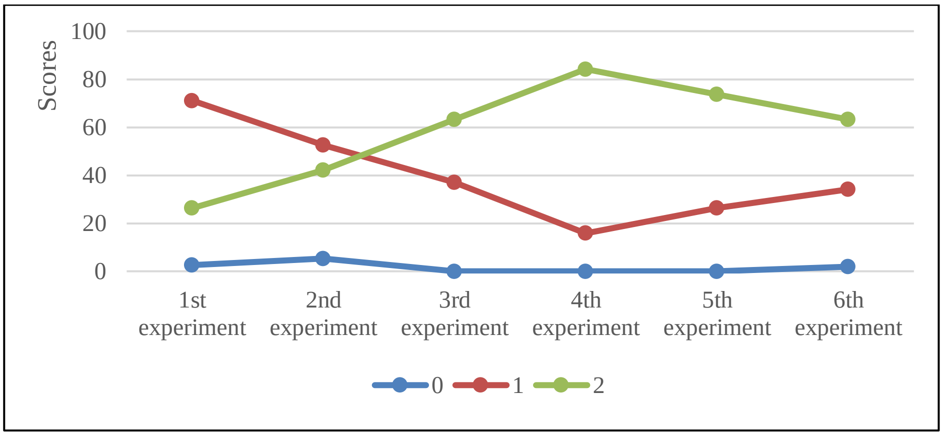


Figure 4. Scores from the Discussion I and Explanation I Stage

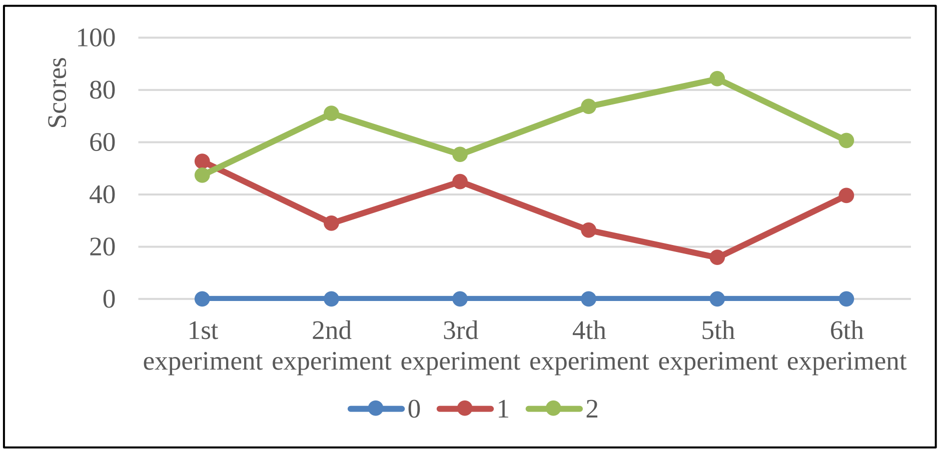

Figure 5. Scores from the Observation Stage

We observed an increase in the scores during the observation stage, particularly between the 1st and 5th weeks, as shown in Figure 5. However, there was a partial decrease in fully correct responses in the 6th week. During the discussion II stage, following the observation stage, the scores increased, and the change in the process was determined. At this stage, the students provided 29% correct answers in the first week of the experiment, and this percentage increased to 65.8% by the end of the 5th week.

Figure 6 shows a significant increase, especially between the 1st and 2nd weeks. In the subsequent weeks, the changes show similar values in the upward direction.

The score changes in the explanation stage, which is the final stage of the PDEODE activities, followed the same increasing trend as in the other stages. The percentage of fully correct answers in the scores started at 65.8% in the first week and reached its highest value of 76.3% at the end of the 5th week. Graphical changes in scores are shown in the Figure 7. Figure 7 shows that partial decreases were observed in the 4th and 6th weeks.

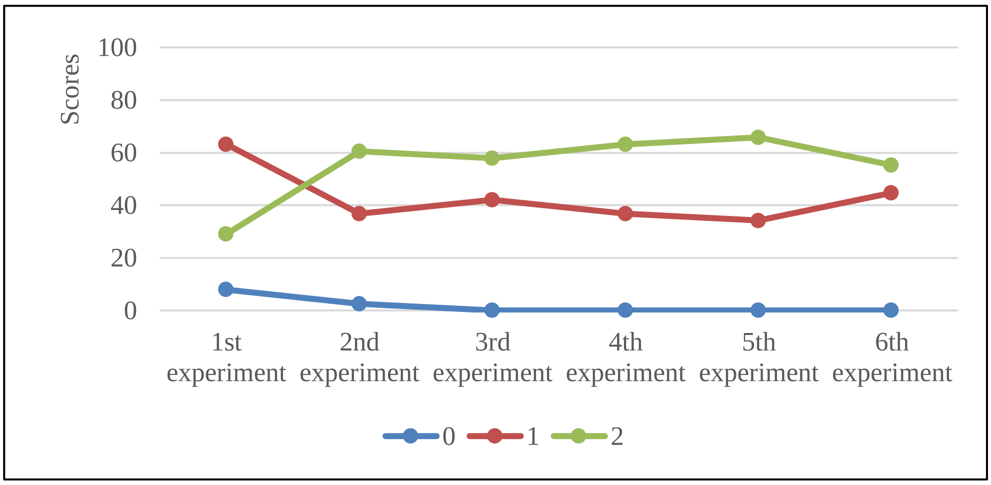


Figure 6. Scores from the Discussion II Stage

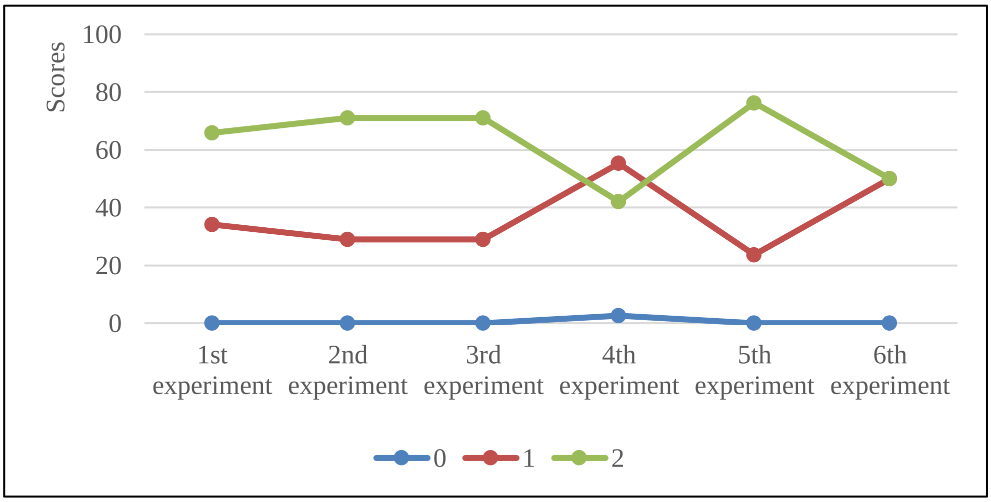


Figure 7. Scores from the Explanation II Stage

Overall, we found that the scores of students at all stages of the PDEODE activities showed a positive improvement throughout the process. On the other hand, we determined that students were able to justify and explain their answers by supporting them with scientific explanations, especially during the discussion and explanation stages of the PDEODE activity sheets.

These findings suggest that the structured nature of the PDEODE activities, which require students to predict, discuss, observe, and explain, helps reinforce their learning and fosters deeper comprehension. The observed improvements in the students' scores can be attributed to the iterative learning process inherent in the PDEODE model, where continuous feedback and opportunities for reflection play crucial roles.

### Results of the Structured Interviews

The responses were analyzed based on three sub-themes: (1) positive reflections, (2) challenges, and contradictions in the learning process, and (3) PDEODE model in the remote education process (Q2). Sample quotations from the student responses were included.

### Positive Reflections on the Learning Process

This sub-theme aims to highlight the students' positive thoughts of the activities conducted using the PDEODE model in the learning process. As a result of the analysis of the responses, it was evident that the students largely expressed that the PDEODE provided an effective learning environment. They reported that it prompted them to reassess their prior knowledge, address misunderstandings, and acquire new information.

S4: "In my opinion, the PDEODE was a very beneficial activity that offered us the opportunity to make predictions, observations, engage in discussions, test our knowledge, and conduct research. At times, I have had the opportunity to recognize that I had misunderstood previously learned information and to correct it. At other times, this method has created a learning environment by conducting extensive research on subjects that were previously unfamiliar to me."

S6: "The PDEODE activities were both instructive and enjoyable. In other words, we conducted numerous experiments and learned many things. They were very helpful to initially make predictions about what we had learned, to either confirm our predictions or to learn the correct information when we were wrong."

In this process, where there was no opportunity to conduct experiments in remote education conditions, the students who participated in the research stated that they had the opportunity to observe the experiments through PDEODE activities, albeit remotely, and expressed positive opinions.

S16: "During the pandemic, we were unable to conduct the practice course in person. However, we conducted useful, developmental, and thought-provoking chemistry experiments in our online courses with the PDEODE model. I believe I gained experience with this method, even though it was done remotely. After the remote education process ends, I will be able to focus more quickly on my lessons when I return to face-to-face learning, and I will strive to improve myself."

### Challenges, and Contradictions in the Learning Process

This sub-theme aims to uncover the challenges and contradictions that students experience during the learning process while engaging in activities using the PDEODE model. In most of these responses, we found that students expressed difficulties in the prediction stage and the pre-assessment questions preceding it, citing a lack of prior knowledge as the reason for making incorrect predictions.

S33: “The pre-assessment was challenging for me because you had to examine your knowledge while explaining the causes of events and situations that we encounter in daily life. I can say that I had more difficulty in making correct predictions in these parts.”

When the students’ responses regarding the contradictory situations between prediction and observation were analyzed, we determined that the students mostly expressed experiencing contradictory situations between the prediction and observation stages due to a lack of understanding. They also indicated that this information was forgotten or remembered very little after a certain period because a lasting connection between theoretical knowledge and practical courses was not established, leading to a lack of permanent learning.

S4: “Most of the activity sheets contain either missing predictions or contradictory situations. I believe the contradiction arises from the fact that subjects like chemistry, biology, physics, and mathematics are taught solely in theory, without being reinforced by experiments or activities before moving on to the next topic. Furthermore, the absence of experiments or activities for us to observe and reinforce this subject can lead to misunderstanding or forgetting the material. For instance, we have been theoretically studying electrolysis for a long time. After a period of 3 months, we tend to forget most of the knowledge about the subject. Because we can only access theoretical information on the internet or in books. For these reasons, our predictions may be inaccurate or incomplete because we may have forgotten the knowledge we learned previously, which contradicts our observations.”

**PDEODE Model in Remote Teaching of Chemistry Laboratory Experiments**

This sub-theme aims to identify the role that differentiate PDEODE activities in remote teaching of chemistry laboratory experiments from other methods. The analysis of the students’ responses was revealed that the students mostly indicated that a permanent learning was achieved through engaging in discussions and actively participating in every stage of the PDEODE model.

S26: “The most important aspect of these activities is that it allows us to make a prediction initially and then; after observing the experiment, it provides an opportunity to compare the prediction with the experimental results. In addition, they were also significant in this regard as the class discussed their predictions, which increased our participation in the lesson."

However, the results showed that the students mostly reported a positive impact of the method on their academic careers and noted a distinct experience.

S7: "I have gained knowledge about the nature of academic study. It enhanced my understanding and practical skills, including assessing prior knowledge, making predictions, conducting observations, fostering a discussion environment, and preparing a report on the experiment. It helped me to gain an understanding of the potential path ahead if I pursue this study in the future."

In addition, the results show that some students stated that they learned the experiments more effectively with the PDEODE model.

S30: "It has contributed to presenting new experiments to us during the remote education process and making the experiments fully understandable. We shared and discussed various opinions on the experiments, which proved to be an effective learning activity for us."

**Discussion**

The main purpose of this study was to examine how the activities conducted with the PDEODE contributed to changes in students' academic success. First-grade students in the department of Science Education participated in the online implementation of the PDEODE model in the Chemistry 2 course during the remote education process. Furthermore, we analyzed students' opinions regarding the PDEODE model. The contribution of the PDEODE activities on students' academic achievements was evaluated using activity sheets. As a result of these evaluations, we concluded that integrating PDEODE activities in chemistry laboratory experiments had a positive connection on students' academic success over a 6-week period. In their research, Coştu and Bayram (2021a) indicated that discussion-enriched POE-based laboratory studies were effective in enhancing prospective teachers' scientific process skills and improving their academic achievements. This finding supports our results. Since the PDEODE represents an enriched version of the POE through discussions, the contribution of the POE to academic success in learning environments can also be attributed to the PDEODE model. The significant improvement in students' academic success and interest at every stage of the PDEODE can be interpreted as enhancing both their interest in the subject and their subsequent academic achievement. In line with this finding, numerous studies have demonstrated the positive results of implementing the POE process and its various versions in laboratory experiments, leading to improved academic success in laboratory activities (Ajayi, 2019; Barut & Sert-Çıbık, 2022; Candra et al., 2018; Erdem-Özcan & Uyanık, 2022; Gernale et al., 2015; Hilario, 2015; Kozcu-Çakır et al., 2017).

The PDEODE model actively involves students in hands-on activities, particularly observation, to substantiate their predictions and explain observed phenomena. This approach is instrumental in fostering conceptual change, supported by Weaver (1998) who highlighted that experimental learning, when coupled with discussions and reflection, facilitate this change. Students' success in transitioning from their prior conceptions to scientifically appropriate concepts can be attributed to specific factors within the PDEODE approach. Firstly, engaging in PDEODE activities prompts students to bring forth their prior knowledge, predictions, and explanations, which are then openly discussed within groups or classes, leading to constructive exchanges and revisions (Wati & Novita, 2021). Secondly, this process often leads students to reassess their existing knowledge and acquire new perspectives during discussions, compelling them to conduct observations aimed at refining their explanations. Ultimately, by iteratively discussing their predictions alongside observations and reinforcing them through subsequent discussions, students transform their understanding into a more scientifically grounded concept. This is consistent with the conceptual change model proposed by Posner et al. (1982) and emphasizes the connection between the PDEODE approach and the improvement of academic success.

Engaging in the stages of PDEODE enables students to discuss, explain, and observe a given subject. Following the observation stage, students proceed to discussion activities where they re-explain, fostering their ability to ask and respond to questions. This active participation encourages meaningful learning, ultimately empowering the development of critical thinking skills, which is essential for fostering academic success (Wulandari et al., 2021). Although there are limited studies examining the relationship between PDEODE and academic achievement, the findings of these studies are consistent with our results. According to Coştu et al. (2012), the PDEODE learning strategy proves effective in rectifying students' misconceptions due to its six-step process, aiding students in evaluating their misconceptions and revisiting ideas through both small and large group discussions in class. Demircioğlu (2017) further suggests that once students grasp the correct concept, they connect these new concepts with relevant ideas, thereby making the learning experience more meaningful. In another similar study, Samsudin et al. (2021) suggested that students' academic success improved by evaluating their previous knowledge, rechecking their ideas in their own groups or in whole-class discussions, and creating new concepts in their minds, in PDEODE*E tasks. The PDEODE model can help students learn to develop scientific concepts by encouraging independent thinking and active communication, enabling them to interactively share their thoughts with other students. Through the implementation of PDEODE, students' writing abilities are honed, they engage in interactive discourse with fellow students, they have hands-on experience with conducting and observing experiments, they categorize and analyze experimental results, and they clarify their understanding (Demircioğlu, 2017; Hidayati et al., 2019; Lathifa, 2018; Nawafleh & Muheedat, 2020). By establishing connections between new concepts and their existing knowledge, this learning method helps students enhance their comprehension and broaden their knowledge. In this regard, our weekly quantitative findings and the students' statements about conceptual development and reaching full understanding align with the findings of these studies. Furthermore, our findings emphasize the positive connection between the implementation of the PDEODE model and improved academic success of the students.

Another important finding in this study was the positive feedback from students regarding their ability to visually observe PDEODE activities and participate in experiments during remote learning. In light of this result, post-pandemic, students have had the opportunity to visualize chemistry experiments before conducting them in the laboratory, effectively learning the procedures. Consequently, they were expected to carry out these experiments with fewer errors and less time lost in subsequent periods. The positive effect of using educational videos to illustrate experiments, as highlighted by Uyulgan and Akkuzu (2018), aligns with findings emphasizing how visual representation aids effective learning in chemistry education and optimizes time utilization (Kennepohl, 2001; Pekdağ & Le Maréchal, 2010). The study by Irwanto (2018) supports these observations and shows that virtual labs improve students' problem-solving, critical thinking and scientific process skills. Several studies, including those by Diani et al. (2018), Ekawati (2018), Samsudin et al. (2019), Serevina and Arianti (2021) and Widyastuti et al. (2019a), also confirm our findings by indicating that the PDEODE model significantly improves student learning in virtual lab experiments. Taken together, these studies emphasize the significant contribution of the PDEODE model to improving students' learning experiences in virtual laboratory settings.

We analyzed the students' opinions on the use of PDEODE activities in chemistry experiments to address the second research question. The analysis revealed that students had a positive experience with the PDEODE application process and expressed favorable opinions about the activities. They found the activities to be informative, enjoyable, and entertaining. Students additionally stated that courses would be more efficient and enjoyable if more subjects incorporated the PDEODE model. Mohammed (2020) affirmed that using the PDEODE in science education had a positive effect on students' attitudes toward learning. Additionally, in various other studies students reported that using PDEODE activities in the laboratory made the learning environment enjoyable, enhanced their research motivations, aroused curiosity, and instilled a desire to pay careful attention and exert effort, using positive expressions (Cholisoh et al., 2015; Hidayati et al., 2019; Nawafleh & Muheedat, 2020; Widyastuti et al., 2019b). These positive perspectives from students provide the evidence to support our findings.

Furthermore, the students also stated that they corrected misunderstandings about the PDEODE and acquired new knowledge. Students stated that their understanding became more meaningful and permanent through their research and active participation in the learning environment, leading to the acquisition of new knowledge. Research has shown that students can acquire new information and address gaps in their knowledge by engaging in collaborative learning with their peers, observing events in a stimulating laboratory environment, and devising solutions to problems that interest them (Coştu, 2008; Wulandari et al., 2017).

The distinguishing features of the PDEODE model, which set it apart from other methods, include the creation of a discussion environment where students actively engage, comment on their peers' ideas, and defend their own perspectives. These characteristics are considered important for fostering students' self-confidence and facilitating meaningful learning. The research confirmed the positive enhancement on students' academic success, supported by both student opinions and quantitative findings. Students reported that PDEODE activities significantly contributed to their academic progress during the period of remote education, providing them with a unique learning experience. An important finding was that the discussions before and after the observation stage enabled students to reconsider their own ideas and explore diverse perspectives from their peers. Additionally, students emphasized that creating a discussion environment within the PDEODE and their active involvement in every stage of this method ensured a lasting impact on their learning. This result is also consistent with findings of other studies in terms of supporting the idea that the PDEODE model makes learning permanent (Coştu, 2008; Coştu et al., 2012; Coştu & Bayram, 2021a; Demircioğlu, 2017; Dipalaya & Corebima, 2016; Savander-Ranne & Kolari, 2003).

## CONCLUSION

This study demonstrated that incorporating the PDEODE model into chemistry laboratory experiments in remote education had a positive enhancement on students' academic success. PDEODE activities have been found to enhance the learning process through active participation and discussions. Based on the interview results, students' feedback indicated that PDEODE activities made their understanding more meaningful and increased their interest in learning. Additionally, the opportunity to visually observe the experimental procedures in remote education significantly enhanced their performance in the laboratory and helped address their misunderstandings. It is highlighted that students generally hold positive opinions about PDEODE activities. Therefore, incorporating these activities into various courses could enhance the effectiveness of learning, as suggested by current research. These findings underscore the need for further exploration of PDEODE's potential benefits across different educational settings.

Finally, additional research could be conducted to develop educational materials and teaching strategies for the effective implementation of PDEODE. This could enhance students' learning experiences and improve the effectiveness of science education, including remote learning.

## REFERENCES

Abdullah, MNS, Mat Nayan, NA, & Mohamad Hussin, F 2017, 'A Study on addressing students' misconceptions about condensation using the predict-discuss-explain-observe-discuss-explain (PDEODE) strategy', in M Karpudewan, AN Md Zain, & AL

Chandrasegaran (eds.), *Overcoming students' misconceptions in science,* Springer, pp. 51-69.

Ajayi, VO 2019, 'Effects of predict-explain-observe-explain and vee heuristic strategies on students' achievement, metacognitive awareness and self-efficacy belief in organic chemistry in Ekiti State, Nigeria', PhD thesis. Benue State University, Makurdi.

Alsalamat, MK 2012, 'The effectiveness of using (PDEODE) strategy among higher basic stage students on their achievement of physics concepts and scientific thinking', *An-Najah University Journal for Research-B (Humanities),* vol., 26, no. 9, pp. 2041-2064.

Aminudin, AH, Rusdiana, D, Samsudin, A, Hasanah, L, & Maknun, J 2019, 'Measuring critical thinking skills of 11th grade students on temperature and heat', *Journal of Physics: Conference Series,* vol.,1280, no. 5, pp. 052062.

Amolins, MW, Ezrailson, CM, Pearce, DA, Elliott, AJ, & Vitiello, PF 2015, 'Evaluating the effectiveness of a laboratory-based professional development program for science educators', *Advances in physiology education,* vol.,39, no. 4, pp. 341-351.

Barut, DB, & Sert Çıbık, A 2022. The effect of 'POE activities supported by concept networks on laboratory attitudes, anxieties and scientific process skills of pre-service science teachers', *Hacettepe University Journal of Education,* vol.37, no. 4, pp. 1303-1316.

Boyatzis, RE 1998, *Transforming qualitative information: Thematic analysis and code development.* Sage.

Boyd-Kimball, D, & Miller, KR 2018, 'From cookbook to research: Redesigning an advanced biochemistry laboratory', *Journal of Chemical Education,* vol. 95, no. 1, pp. 62-67.

Candra, LP, Rintayati, P, & Poerwanti, JIS 2018, 'The improvement of experimental skills by implementing predict, observe, explain (POE) learning model in learning science', *Social, Humanities, and Educational Studies (SHEs): Conference Series,* vol. 1, no. 1, pp. 450-460.

Carmel, JH, Herrington, DG, Posey, LA, Ward, JS, Pollock, AM, & Cooper, MM 2019, 'Helping students to "do science": Characterizing scientific practices in general chemistry laboratory curricula', *Journal of Chemical Education,* vol., 96, no. 3, pp. 423-434.

Cholisoh, L, Fatimah, S, & Yuniasih, F 2015, 'Critical thinking skills in integrated science learning viewed from learning motivation', *Jurnal Pendidikan Fisika Indonesia,* vol. 11, no. 2, pp. 134-141.

Coştu, B 2008, 'Learning science through the PDEODE teaching strategy: Helping students make sense of everyday situations', *Eurasia Journal of Mathematics, Science & Technology Education,* vol., 4, no. 1, pp. 3-9.

Coştu, B, & Bayram, H 2021a, 'The effect of enriched with discussion predict-observe-explain (POE) based science laboratory applications on pre-service science teachers' academic achievement' *YYU Journal of Education Faculty,* vol. 18, no. 1, pp. 1161-1190.

Coştu, F & Bayram, H 2021b, 'The effectiveness of Predict-Explain-Observe-Discuss-Explain

(PEODE) Based Laboratory Works Activities on Pre-Service Science Teachers' Science Process Skills', *Mimbar Sekolah Dasar*, vol., 8, no. 1, pp. 21-40.

Coştu, B, Ayas, A, & Niaz, M 2012, 'Investigating the effectiveness of a POE-based teaching activity on students' understanding of condensation', *Instructional Science*, vol. 40, no. 1, pp. 47–67.

Çıngıl Bariş, Ç 2022, 'The effect of the 'predict-observe-explain (POE)' strategy in teaching photosynthesis and respiration concepts to pre-service science teachers' *Journal of Biological Education*, pp. 1-18.

Demircioğlu, H 2017, 'Effect of PDEODE teaching strategy on Turkish students' conceptual understanding: Particulate nature of matter' *Journal of Education and Training Studies*, vol. 5, no. 7, pp. 78-90.

Diani, R, Latifah, S, Anggraeni, YM, & Fujiani, D 2018, 'Physics learning based on virtual laboratory to remediate misconception in fluid material', *Tadris: Jurnal Keguruan Dan Ilmu Tarbiyah*, vol. 3, no. 2, pp. 167-181.

Dipalaya, T, & Corebima, AD 2016, 'The effect of PDEODE learning strategy in the different academic abilities on students' critical thinking skills in senior high school' *European Journal of Education Studies*, vol. 2, no. 5, pp. 60-78.

Ekawati, N 2018, 'Application of blended learning with Edmodo application based on PDEODE learning strategy to increase student learning achievement' *Jurnal Ilmiah Pendidikan MIPA*, vol. 8, no. 1, pp. 7-16.

Erdem-Özcan, G, & Uyanık, G 2022, 'The effects of the "predict-observe-explain (POE)" strategy on academic achievement, attitude and retention in science learning', *Journal of Pedagogical Research*, vol. 6, no. 3, pp. 103-111.

Ernawati, E, Andriani, S, Farida, F, & Sri Anggoro, B 2019, 'Analisis Miskonsepsi Matematis: Dampak Strategi Pembelajaran Predict Discuss Explain Observe Discuss Explain Desimal', *Jurnal Matematika*, vol. 2, no. 3, pp. 259–269.

Gernale, J, Duad, D, & Arañes, F 2015, 'The effects of predict-observe-explain (POE) approach on the students' achievement and attitudes towards science', *The Normal Lights*, vol. 9, no. 2, pp. 1-23.

Gustiani, I 2013, 'Students' conceptual change and science process skills acquisition on separation of mixture concept through predict-discuss-explain-observe-discuss-explain (PDEODE) method', S1 thesis, Universitas Pendidikan Indonesia, Bandung.

Halimah, M, Langitasari, I, & Solfarina, S 2019, 'Application of PDEODE learning model to increase student's KPS in buffer solution' *Jurnal Profesi Keguruan*, vol. 5, no. 1, pp. 15-22.

Hardianti, RD, & Permatasari, IU 2023, 'Promoting Students' Science Process Skills Through Predict Discuss Explain Observe Discuss Explain Implementation', *Unnes Science Education Journal*, vol. 12, no. 1, pp. 1-6.

Hidayati, AZ, Basuki, I, & Buditjahjanto, IA 2019, 'The effect of PDEODE learning model on competency of electronic and electronic basics lessons reviewed from the ability of formal reaching students of class X TITL A in Raden Rahmat Mojosari vocational school', *International Journal for Educational and Vocational Studies,* vol. 1, no. 6, pp. 604-608.

Hilario, JS 2015, 'The use of predict-observe-explain-explore (POEE) as a new teaching strategy in general chemistry laboratory' *International Journal of Education and Research,* vol. 3, no. 2, pp. 37-48.

Hofstein, A 2004, 'The laboratory in chemistry education: Thirty years of experience with developments, implementation, and research' *Chemistry Education Research and Practice,* vol. 5, no. 3, pp. 247-264.

Hofstein, A, & Hugerat, M 2021, *Teaching and Learning in the School Chemistry Laboratory*. Royal Society of Chemistry.

Irwanto, I 2018, 'Using virtual labs to enhance students' thinking abilities, skills, and scientific attitudes', *The 5th International Conference on Educational Research and Innovation (ICERI 2017),* Yogyakarta, Indonesia.

Karslı-Baydere, F 2021, 'Effects of a context-based approach with prediction–observation–explanation on conceptual understanding of the states of matter, heat and temperature', *Chemistry Education Research and Practice,* vol. 22, no. 3, pp. 640-652.

Kennepohl, DK 2001, 'Using computer simulations to supplement teaching laboratories in chemistry for distance delivery', *The Journal of Distance Education,* vol. 16, no. 2, pp. 58-65.

Kozcu-Çakır, N, Güven, G, & Özdemir, O 2017, 'A study on the efficiency of TGA strategy on general biology laboratory applications' *Abant Izzet Baysal University Journal of Faculty of Education,* vol. 17, no. 4, pp. 2014–2035.

Lathifa, U 2018, 'Correcting students' misconception in acid and base concept using PDEODE instruction strategy' *Unnes Science Education Journal,* vol. 7, no. 2, pp. 170-177.

Lincoln, Y. S., & Guba, E. G 1985, Naturalistic inquiry, Newberry Park.

Lowe, D, Newcombe, P, & Stumpers, B 2013, 'Evaluation of the use of remote laboratories for secondary school science education' *Research in Science Education,* vol. 43, no. 3, pp. 1197-1219.

Lunetta, VN, Hofstein, A, & Clough, M 2007, 'Learning and teaching in the school science laboratory: An analysis of research, theory, and practice' in N Lederman, & S Abel (eds.), *Handbook of research on science education*, Lawrence Erlbaum, pp. 393-441.

Mailani, T, & Syafii, W 2020, 'Development of the PDEODE-WEB model in blended learning to improve the students critical thinking skills' in *Journal of Physics: Conference Series,* IOP Publishing, vol. 1655, no. 1, pp. 012054.

Malik, A, & Setiawan, A 2016, 'The development of higher order thinking laboratory to improve transferable skills of students' in *2015 International Conference on Innovation in Engineering and Vocational Education* Atlantis Press, pp. 36-40.

McMullin, E 2009, ‘Hypothesis in early modern science’ in M Heidelberger and G Schiemann (eds.), *The significance of the hypothetical in the natural sciences,* De Gruyter, pp. 7-38.

Merriam, SB 1998, *Qualitative research and case study applications in education. Revised and expanded from “case study research in education.”.* Jossey-Bass Publishers.

Merriam, SB, & Grenier, RS (eds.) 2019, *Qualitative research in practice: Examples for discussion and analysis.* John Wiley & Sons.

Miles, MB, & Huberman, AM 1994, *Qualitative data analysis: An expanded sourcebook*. (2nd ed.). Sage.

Mohammed, S 2020, ‘The effect of using constructive (PDEODE) strategy in developing some science process skills “a field study among basic education schools in Tartous city"”’, *Tishreen University Journal-Arts and Humanities Sciences Series,* vol. 42, no. 4, pp. 703-723.

Naiker, M., Wakeling, L., Johnson, J., & Brown, S. (2021). Attitudes and experiences among first-year regional Australian undergraduate students toward the study of chemistry. *Journal of University Teaching & Learning Practice,* vol. 18, no.4, https://ro.uow.edu.au/jutlp/vol18/iss4/15

Nawafleh, WH, & Muheedat, RM 2020, ‘The effect of using six dimensional strategy PDEODE in teaching science on the basic eighth grade students' achievement and their attitudes towards it’, *Journal of Educational and Psychological Studies [JEPS],* vol. 14, no. 3, pp. 417-436.

Nicolaidou, V, Nicolaou, P, & Nicolaou, SA 2019, ‘Transforming a cookbook undergraduate microbiology laboratory to inquiry based using a semester-long PBL case study’, *Advances in Physiology Education,* vol. 43, no. 1, pp. 82-92.

Pekdağ, B, & Le Maréchal, JF 2010, ‘An explanatory framework for chemistry education: The two-world model’, *Education and Science,* vol. 35, no. 157, pp. 84-99.

Posner, GJ, Strike, KA, Hewson, PW, & Gertzog, WA 1982, ‘Accommodation of a scientific conception: Toward a theory of conceptual change’, *Science Education,* vol. 66, no. 2, pp. 211-227.

Russell, CB, & Weaver, GC 2011, ‘A comparative study of traditional, inquiry-based, and research-based laboratory curricula: Impacts on understanding of the nature of science’, *Chemistry Education Research and Practice,* vol., 12, no. 1, pp. 57-67.

Samsudin, A, Kaniawati, I, Suhandi, A, Fratiwi, NJ, Wibowo, FC, Malik, A, & Costu, B 2019, ‘Unveiling students’ misconceptions through computer simulation-based PDEODE learning strategy on dynamic electricity’, *Journal of Physics: Conference Series,* vol. 1280, no. 5, pp. 1-8.

Samsudin, A, Afif, N, Nugraha, M, Suhandi, A, Fratiwi, N, Aminudin, A, … & Coştu, B 2021, ‘Reconstructing students’ misconceptions on work and energy through the PDEODE*E tasks with think-pair-share’, *Journal of Turkish Science*

*Education*, vol. 18, no. 1, pp. 118-144.

Savander-Ranne, C, & Kolari, S 2003, 'Promoting the conceptual understanding of engineering students through visualization', *Global Journal of Engineering Education*, vol. 7, no. 2, pp. 189-199.

Scott, PH, Veitch, NJ, Gadegaard, H, Mughal, M, Norman, G, & Welsh, M 2018, 'Enhancing theoretical understanding of a practical biology course using active and self-directed learning strategies', *Journal of biological education*, vol. 52, no. 2, pp. 184-195.

Serevina, V, & Arianti, S 2021, 'Development of online learning devices based on PDEODE (predict-discuss I-explain I-observe-discuss II-explain II) on the material doppler effect in the covid-19 pandemic era', *Journal of Physics: Conference Series,* vol., 876, no. 1, pp. 1-12.

Sırış, AB 2022, 'Tahmin – gözlem – açıklama – tartışma – açıklama (TGA-TAA) destekli öğretimin öğrencilerin akademik başarılarına ve kavram yanılgılarının giderilmesine etkisi (The effect of predict – observe – explain – discuss – explain (POE-DE) supported education on the academic success of students and elimination of misconceptions)', MBA thesis, Yıldız Technical University, Istanbul.

Simon, NA 2013, 'Simulated and virtual science laboratory experiments: Improving critical thinking and higher-order learning skills', PhD thesis, Northcentral University, Arizona.

Tobin, KG 1990, 'Research on science laboratory activities: In pursuit of better questions and answers to improve learning', *School Science and Mathematics,* vol. 90, no. May-June, pp. 403-418.

Uyulgan, MA, & Akkuzu, N 2018, 'Educational short videos to utilize in the biochemistry laboratory: Opinions of university students', *Journal of Baltic Science Education,* vol. 17, no. 3, pp. 496-523.

Wang, CY, Wu, HK, Lee, SWY, Hwang, FK, Chang, HY, Wu, YT, ... & Tsai, CC 2014, 'A review of research on technology-assisted school science laboratories', *Journal of Educational Technology & Society,* vol. 17, no. 2, pp. 307-320.

Wati, W, & Novita, D 2021, 'Mereduksi miskonsepsi materi kesetimbangan kimia melalui penerapan strategi predict discuss explain observe discuss explain (PDEODE)', *Jurnal Pendidikan Kimia Undiksha,* vol. 5, no. 1, pp. 1-10.

Weaver, GC 1998, 'Strategies in K-12 science instruction to promote conceptual change', *Science Education,* vol. 82, no. 4, pp. 455-472.

White, R, & Gunstone, R 1992, 'Prediction-observation explanation' in R White, and R Gunstone (eds.), *Probing understanding,* Routledge, pp. 44-64.

Widyastuti, F, Helsy, I, Farida, I, & Irwansyah, F S 2019a, 'Implementation of PDEODE (predict, discuss, explain, observe, discuss, explain) supported by PhET simulation on solubility equilibrium material', *Journal of Physics: Conference Series,* vol. 1155, no. 1, pp. 1-5.

Widyastuti, R, Lestari, WA, Fadhilah, U, Nurfarida, R, Rosidin 2019b, 'The ability to understand students' mathematical concepts through the PDEODE cooperative learning model based on assessment for learning (AFL)', *Journal of Physics: Conference Series*, vol. 1155, no. 1, pp. 1-6.

Wulandari, TSH, Astuti, HP, & Cintamulya, I 2021, 'Analysis of students' critical thinking abilities using the PDEODE strategy in terms of cognitive style through online learning', *Procedia of Social Sciences and Humanities,* vol. 1, pp. 19-26.

Wulandari, TSH, Amin, M, Zubaidah, S, & IAM, MH 2017, 'Students' critical thinking improvement through PDEODE and STAD combination in the nutrition and health lecture', *International Journal of Evaluation and Research in Education,* vol. 6, no. 2, pp. 110-117.

Yin, RK 2011, *Qualitative research from start to finish,* The Guilford Press.

Zoller, U, & Nahum, TL 2012, 'From teaching to know to learning to think in science education' in BJ Fraser, KG Tobin, & CJ McRobbie (eds.), *Second international handbook of science education,* Springer, pp. 209-229