Enhancing Self-Efficacy for Learning and Performance in High School: a Simulation-Enhanced Predict-Observe-Explain Intervention

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Abstract. To foster student motivation, it is crucial to infuse learning with enjoyment during the educational process. The advent of information and communication technologies has made access to digital tools increasingly convenient. Teachers frequently employ free digital resources, such as simulations, pictures, videos, and games, in their teaching-learning process. By incorporating simulations in the Predict-Observe-Explain (POE) method, the POE method can positively impact student success, particularly in bolstering students' belief in their ability to learn and perform well in chemistry courses. This study aimed to examine the impact of a simulation-supported POE intervention on high school students' self-efficacy for learning and performance. The study randomly selected two groups of students as the experimental and control groups. While the experimental group received lessons using the POE method supported by simulations, the control group was taught using the teacher's conventional method. The Self-Efficacy for Learning and Performance scale, one of the subscales of the Motivated Strategies for Learning Questionnaire (MSLQ), was used to assess the self-efficacy levels of high school students. The findings indicated that simulation supported POE led to a significant increase in student self-efficacy. The results of this study suggest that employing the POE method with digital tools such as simulations in teaching-learning environments can enhance teachers' effectiveness in teaching chemistry compared to the control group.

Keywords: Self-Efficacy, Predict-Observe-Explain, Simulation, Chemistry, High School.

1 Introduction

To foster student motivation, it is crucial to infuse learning with enjoyment during the educational process. In this context, using technological innovations can be particularly effective. Teachers frequently employ free digital resources, such as simulations, pictures, videos, and games, in their teaching. These resources facilitate visualization of the microscopic level events, which is crucial in chemistry learning. There are three levels of thinking in chemistry learning: macroscopic, microscopic, and symbolic [1, 2]. At the heart of learning chemistry is the development of relationships between representations at these levels [3]. It is necessary to develop a comprehensive understanding at the micro level, especially to understand the issues summarized at the macro and symbolic level [4]. In other words, teaching about the particulate nature of matter helps students establish relationships among the three levels at which chemistry can be both taught and understood [5]. Since many chemistry concepts require visualization at the microscopic representation level, it is accepted that they pose difficulties for students to learn, which can also lead to misconceptions [6, 7]. For this reason, it is recommended to use three levels of representation simultaneously in chemistry learning activities and to emphasize their relationships with each other [1]. Therefore, simulations that support the relationship between multiple representations are considered very important for chemistry educators and researchers [3, 4, 8]. PhET simulations, one of these applications, allow students to explore multiple representations covering microscopic, symbolic, and macroscopic levels [3]. However, since simulations provide only a part of the learning experience, they should be integrated into methods that support learning activities [9]. Among the methods that can be used accordingly is Predict-Observe-Explain (POE). In addition, the literature suggests that the POE method is effective in science education and achieving the comprehensive change required to eliminate misconceptions.

The POE method, extensively detailed by White and Gunstone [10], has been lauded as an effective tool for uncovering students' prior knowledge and fostering discussions around their ideas. In this method, researchers prompt students to make predictions by presenting a demonstration experiment or a problem scenario. Subsequently, they observe the students' predictions and then present a comparison highlighting the similarities and discrepancies between the predictions and the actual observations [11]. This method empowers students to delve into their own individual conceptions, irrespective of whether it is implemented as individual or group work. Furthermore, even if discrepancies arise between the predictions and observations, it allows for the reconstruction of students' initial ideas [11, 12].

Integrating simulations and the POE method can simultaneously present the three essential levels of representation for effective chemistry learning, facilitating students in establishing connections between them. Extant research demonstrates that both the POE method and simulations contribute to students' skills, attitudes, motivation, achievements, and conceptual understanding [13, 14, 15, 16, 17, 18]. Additionally, studies have shown that the combined application of simulations and the POE method is an effective strategy for improving students' conceptual understanding [9, 10, 12, 19, 23]. Therefore, we posit that the integrated approach of simulations and the POE method will also influence students' self-efficacy for learning and performance. Accordingly, our study investigates the effect of the POE method developed in conjunction with PhET interactive simulations on students' self-efficacy for learning and performance in the subject of States of Matter. To align with our research goals, our research question is:

Does the POE method supported by PhET interactive simulations influence students' self-efficacy for learning and performance? The following hypotheses were tested to assess group differences and the effect of the intervention:

H1. There is no statistically significant difference in pre-test scores between the experimental and control groups.
H2. There is no statistically significant difference in post-test scores between the experimental and control groups.
H3. The POE+Simulation intervention does not have a statistically significant effect on the pre-test and post-test scores of the experimental group.
H4. There is no statistically significant difference between the pre-test and post-test scores within the control group.

2 Methodology

2.1 Experimental design

This study adopted a quasi-experimental non-equivalent control group design. To assess self-efficacy for learning and performance, we employed the Self-Efficacy for Learning and Performance Scale [20], adapted for the Turkish chemistry course by Şen et al. [21]. The implementation process is detailed in Table 1.

Table 1. Application Process of the Study

Group	Pre-test	Process	Post-test
Experimental group	Chemistry Self-Efficacy Scale	Prediction-Observation-Explanation method supported by PhET interactive simulations	Chemistry Self-Efficacy Scale
Control Group	Chemistry Self-Efficacy Scale	Teacher-centered teaching method	Chemistry Self-Efficacy Scale

2.2 Population and sample

The research was conducted during the spring semester of the 2023/2024 academic year. The study employed a convenience sample, a non-random sampling method. Two intact ninth-grade classes from a high school in Ankara's Çankaya district participated, with one assigned to the experimental group and the other to the control group. While aiming for random selection, due to limitations, the experimental and control groups were formed from the existing four ninth-grade classes. The study ultimately involved 38 students, with 20 in the experimental group and 18 in the control group.

2.3 Instrument

Self-Efficacy for Learning and Performance Scale. The Motivated Strategies for Learning Questionnaire (MSLQ) [20] was employed to assess both the motivation levels and learning strategies used by university students in classroom settings. This instrument comprises two main sections: motivation and learning strategies. This study focused specifically on the Self-Efficacy dimension (Self-Efficacy for Learning and Performance) within the motivation section. In this study, the Turkish adaptation for chemistry developed by Şen et al. [21] was utilized. This adaptation demonstrated a Cronbach's Alpha (α) internal consistency coefficient of .87.

2.4 Treatments

The same teacher instructed both the experimental and control groups. In the control group, the teacher delivered the topic of physical states of matter by adhering to the established curriculum and textbook materials. This involved presenting and explaining the concepts, followed by student completion and discussion of textbook study questions. The instruction primarily relied on direct explanation and question-and-answer methods. To ensure consistency across groups, the teacher also posed some questions to the control group that were originally prepared for collaborative activities in the experimental group.

The experimental group utilized PhET simulations, a free online library accessible at https://phet.colorado.edu/en/simulations/browse. This library offers numerous interactive simulations particularly useful for science and mathematics education. Prior to implementing the POE method with PhET simulations, students received a one-hour training session to understand the method and expected group behaviors. Additionally, the researcher interviewed the main teacher, familiar with this particular group for a longer period, to gather information on students' academic performance, interest, motivation, and success in science courses. In collaboration with the teacher, students were then grouped based on achievement levels (lower, middle, higher) into collaborative heterogeneous teams. The researcher further ensured gender and academic balance when forming these five, four-person teams. Each group received a computer and worksheets guiding them through the POE steps throughout the intervention. The worksheets used in the experimental group can be found in Appendix 1 and Appendix 2.

During the observation stage of the POE method, students in the experimental group engaged with the "States of Matter: Basics" simulation from PhET Interactive Simulations. This simulation comprises two sections: "States" and "Phase Changes". Each section was utilized in separate lessons, accompanied by specific worksheets guiding students through the POE steps. A summary of the utilized simulations is provided in Table 2.

Table 2. Simulations Used in Teaching the State of Matter

Simulation	Simulation Name	Learning Objectives
Simulation 1	States	* Explains the properties of solids, liquids, and gases. * Compares the arrangement and movement of particles in each state. * Explains freezing and melting at the molecular level. * Discovers that different substances have different melting, freezing, and boiling points.
Simulation 2	Phase Changes	Predicts how changes in temperature or pressure affect the behavior of particles (e.g., causing phase changes).

The Simulation 1 aimed to visualize the particle structure of solids, liquids, and gases at the microscopic level. By comparing the arrangement and movement of particles in each phase, students could investigate the properties of the three states of matter. Additionally, the simulation allowed exploration of freezing and melting processes at the molecular level, highlighting how different substances exhibit varying melting points, boiling points, and freezing points. The Simulation 2 focused on predicting how changes in temperature or pressure affect the behavior of particles, ultimately leading to phase changes. Figure 1 presents examples from both simulations.

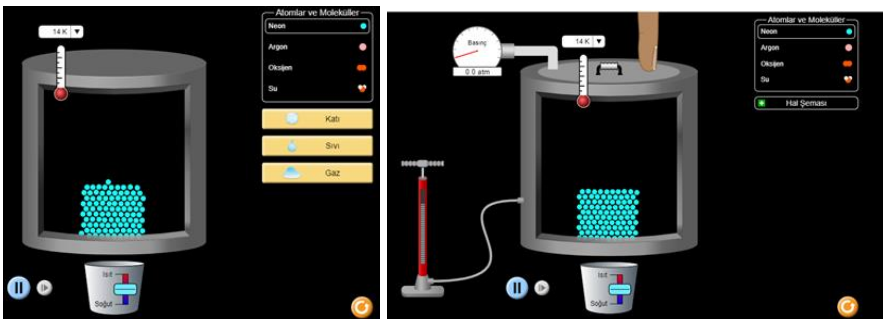

Fig. 1. The first part of the 'States of Matter: Basics' simulation is the 'States' simulation and the second part is the 'Phase of State' simulation. https://phet.colorado.edu/tr/simulations/states-of-matter-basics.

3 Data analysis and results

Descriptive statistics for the Self-Efficacy for Learning and Performance pretest and posttest scores for the control and experimental groups are presented in Table 3.

Table 3. Descriptive statistics about pre-test and post-test scores for each group

	Control groups		Experimental groups	
	Pre-test	Post-test	Pre-test	Post-test
N	18	18	20	20
Mean	33.66	33.83	36.45	43.50
Standard Deviation	11.832	11.768	10.091	8.623
Skewness	-.133	-.176	-.598	-.744
Kurtosis	-.204	-.123	.773	-.344

The dependent variable in the study is self-efficacy, while the independent variable is the teaching method used (the Prediction-Observation-Explanation method developed with PhET interactive simulations and the teacher-centered teaching method). The Mann Whitney U test, a non-parametric test, was performed to determine whether there was a statistically significant difference between the pre-test and post-test scores of the experimental and control groups, depending on the sample size. This was because Ravid [22] stated that if measurements of a feature of interest are obtained from a small group ($n < 30$), there will be deviations from the normal distribution. To determine whether there was a statistically significant difference between the pre-test and post-test scores of each group, the Wilcoxon signed-rank test, another non-parametric test, was used. The findings obtained are presented in Tables 4 and 5

Table 4 Mann Whitney U test results

	Group	**N**	**Mean Rank**	**Sum of Ranks**	**U**	**p**
Pre-test	Experimental	20	20.85	417.00	153.00	.430
	Control	18	18.00	324.00		
Post-test	Experimental	20	23,98	479.50	90.50	.009
	Control	18	14.53	261.50		

According to the results presented in Table 4, Hypothesis 1 was accepted, while Hypothesis 2 was rejected. It is observed that there is no statistically significant difference in the pretest scores of the experimental and control groups (U=153.00, p=.430). However, a statistically significant difference is noted in the post-test scores of the experimental and control groups (U=90.50, p=.009).

Table 5 Wilcoxon signed-rank test results.

		Mean Rank	Sum of Ranks	p
Experimental	Negative Ranks	7.64	53.50	.054
	Positive Ranks	12.04	12.04	
Control	Negative Ranks	9.78	9.78	.913
	Positive Ranks	9.22	9.22	

According to the results presented in Table 5, Hypothesis 3 was rejected, while Hypothesis 4 was accepted. It is observed that there is a statistically significant difference in terms of pre-test and post-test scores of the experimental group (p = .430). However, no statistically significant difference is noted in terms of pre-test and post-test scores of the control group (p = .913).

4 Discussion

The findings indicate that simulation-supported POE significantly increases students' self-efficacy. This finding aligns with prior research highlighting the benefits of integrating POE and simulations in chemistry education (e.g., [19, 23, 24, 25]). However, this study is unique in its examination of their effect on self-efficacy. Based on researchers' experiences and students' opinions, we recommend initiating teaching with real-life events and enriching the method with simulations in the explanation part. This approach will make the course more engaging, allow for the visualization of chemistry concepts at the microscopic level of representation, and we hypothesize that this would influence students' self-efficacy. Indeed, the results of this study support this hypothesis. Additionally, this study contributes to the existing literature by demonstrating the effectiveness of the TGA method supported by simulations in increasing students' self-efficacy for learning and performance.

This study has a sample of 9th grade students and limits the generalizability of the findings to other populations. Additionally, this study focused on the states of matter. Examining the POE method enriched with simulations in chemistry learning in terms of other aspects such as student achievement, conceptual understanding, attitude, and scientific process skills in other subjects will contribute to the field.

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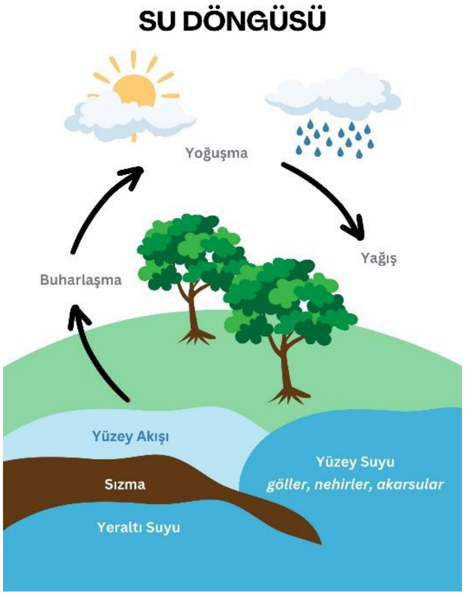
Appendix 1 POE process using States Simulation

PREDICT:



Water in seas and lakes evaporates when the temperature rises, forming water vapor and clouds in the atmosphere. Water droplets in the clouds descend to the earth as rain, snow, and hail, depending on the temperature. The cycle of water between the earth and the atmosphere, involving changes in its state, is referred to as the water cycle. Accordingly, please provide your responses to the questions below.

- What physical states are present for water in the water cycle, and how do the properties of these physical states compare?
- Which phase transitions occur in the water cycle, and can you explain these phase changes at the molecular level?
- How does temperature influence the cycles of different substances?

OBSERVE:

In this section, open the 'States' simulation (access https://phet.colorado.edu/tr/simulations/states-of-matter-basics) and follow the instructions given below.

- Examine the particle structures of each substance (Neon, Argon, Oxygen, and Water) in solid, liquid, and gaseous states.
- Select a substance and compare its properties (shape, inter-particle space, inter-particle interactions, regular structure, compressibility, particle movement) in solid, liquid, and gas states.
- Illustrate the melting and evaporation events at the particle level.
- Determine and compare the temperatures of each substance in its solid, liquid, and gaseous states.

EXPLANATION:
Are there any differences between your predictions and the observations obtained from the simulation? Please explain your thoughts and answer the questions below.
• Which properties of the three physical states of matter change, and how do they change?
• Can you explain the processes of freezing and melting at the molecular level?
• Do the phase change properties of different substances vary?

Appendix 2 POE process using Phase Change Simulation

PREDICT:

The pressure cooker operates on the principle of using steam power to cook food quickly. This concept emerged from the relationship between pressure and the boiling point of water. Since the pressure cooker prepares the food at a high temperature and in a completely sealed environment, the cooking time of the food is minimized. Accordingly, please provide your responses to the question given below.
• How does pressure influence the boiling point of water?

OBSERVE:
In this section, open the 'State changes' simulation (accessible at https://phet.colorado.edu/tr/simulations/states-of-matter-basics) and follow the instructions given below.
• Select the initial temperature in degrees Celsius for each substance (Neon, Argon, Oxygen, and Water) and identify their physical states by observing their particle structures.
• Determine the temperature values at which phase changes occur by applying pressure separately to each substance (Neon, Argon, Oxygen, and Water).
• Compare the phase change temperatures you obtained with your observations in the 'States' simulation.

EXPLANATION:
Are there any differences between your predictions and the observations obtained from the simulation? Please explain your thoughts and answer the question below.

- What is the impact of pressure on the phase change temperature?