Activating the Student´s Prior Knowledge in the Learning of Third Newton Law trough a P.O.E. ("Predict-Observe-Explain") Strategy

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Abstract

Laboratory experiments are commonly used in the teaching of experimental science. They have proven beneficial when they are designed to demonstrate concepts previously explained by the teacher. However, they often fail short when used to introduce the explanation of a new concepts. There is a necessity of designing new lab experiments that activate the student´s prior knowledge in pursuit of more efficient learning when introducing new scientific concepts for the first time. The constructivist principles of learning are grounded in the notion that learning constitutes an internal reorganization process of the student´s mental frameworks, which undergo more significant modifications when learners encounter discrepancies with their prior ideas. Hence, many constructivist learning strategies place emphasis on leveraging students' prior knowledge as a fundamental starting point. A method to translate this approach into the teaching of science involves the utilization of P.O.E. strategies (Predict, Observe, Explain). In this work, we present several P.O.E. experiences employing counterintuitive experiments based on third Newton´s Law. These experiments were specifically designed to challenge students' predictions and uncover common misconceptions in comprehension of the Newtonian mechanics. Specifically, scenarios such as the behavior of an analog scale when a person raises on tiptoes; and the movement of a ship propelled by its own fan often contradict many student predictions, including those of prospective secondary school educators. These experiences also highlight the importance of the capacity of students for scientific abstraction and the correct use of rational argumentation to correctly explain the counterintuitive experiments and to argue against their own previous predictions. The P.O.E. experiences were tested with prospective secondary school educators to assess the level of significative learning facilitated by this constructivist approach.

Keywords: *Constructivist, Predict-Observe-Explain, P.O.E., Newton´s Law, Prior-Knowledge.*

1. Introduction

Traditional approaches for laboratory activities usually focus on verification work, with students following handouts or lab manuals that provide detailed instructions for both the design and the procedure of the experiments(Saunders, 1992). While these activities have proven to be undoubtably fruitful for learners to assimilate the phenomena under study(Hofstein & Kind, 2012), they often exhibit poor impact in learning when introducing a new topic for the first time(Pickering, 1988). One of the reasons is the lack of specific design for hand-on laboratory activities aimed to introducing students to a new topic or explaining a new phenomenon for first time(Eubanks, 2015).

Constructivist principles of learning are grounded in the notion that learning constitutes an internal reorganization process of the student´s mental frameworks, which undergo more significant modifications when learners encounter discrepancies with their prior ideas(Ausubel, 1968). Hence, many constructivist learning strategies emphasize leveraging students' prior knowledge as a fundamental starting point(Driver et al., 1994).

A method to translate this approach into the teaching of science involves the utilization of P.O.E. strategies (Predict, Observe, Explain)(White & Gunstone, 1992). A P.O.E. strategy in education is a formal instructional approach designed to enhance critical thinking and conceptual understanding among students. This pedagogical method typically unfolds in three key stages(Yang & Chen, 2023):

Predict: In the initial phase, students are prompted to make predictions or hypotheses about the outcomes of an experiment, a scientific phenomenon, or a problem-solving scenario. This encourages students to tap into their prior knowledge and form initial expectations.

Observe: Following the prediction stage, students engage in hands-on or observational activities to gather data, observe outcomes, or conduct experiments. This empirical phase allows students to compare their predictions with real-world observations, fostering a direct connection between theoretical concepts and practical experiences.

Explain: The final stage involves students articulating their observations and connecting them to underlying scientific principles or theoretical frameworks. This step encourages students to reflect on their predictions, assess the accuracy of their initial hypotheses, and refine their understanding based on the observed outcomes. Additionally, it provides an opportunity for classroom discussion and collaborative learning as students share and compare their explanations.

The P.O.E. strategy is particularly effective in science and mathematics education, by promoting active engagement, inquiry-based learning, and the development of analytical skills(Suryamiati et al., 2019). Through the incorporating of prediction, observation, and explanation into the learning process, educators aim to deepen students' understanding of complex concepts and foster a more robust grasp of the underlying principles within a given subject area(Astiti et al., 2020).

When designing a P.O.E. strategy, the selection of the experimental activities become crucial, as traditional hands-on laboratory experiences often fall short in provoking significant learning of new scientific concepts(Liaw et al., 2021). Experimental activities in the P.O.E. strategy should be as counterintuitive as possible because deeper conceptual changes in the student´s mind occur when new learning contradicts their prior knowledge(Gok & Goldstone, 2022).

This paper presents two P.O.E. activities to teach Newton´s third law. The P.O.E. strategy was tested with students from the Master's degree in Secondary Education Teaching (n= 29). All students held a degree in a scientific discipline; but no specific review of the Newton´s laws was conducted before this pilot experience. The activity aimed to provide a first-person experience for future teachers, triggering a conceptual change through a strong contradiction with their prior knowledge. Additionally, it served to assess the suitability of the experiences for implementing a P.O.E. strategy.

2. Methodology

The pilot experience was performed without any previous explanation of the P.O.E. strategies and without a review of the Newton's laws. Students were tasked with predicting the outcome of two counterintuitive experiments:

Experiment 1: Behavior of a scale when a person raises on tiptoes.
Experiment 2: Movement of a sailship propelled by its own fan.

2.1. Prediction

It is crucial for the efficiency of the P.O.E. strategy to incorporate the prediction of experiments 1 and 2 discreetly among other, more intuitive yet challenging questions related to the same topic. To elicit the prior knowledge of the students effectively, it is necessary for them to express their more natural and intuitive answers for the predictions. Teachers should avoid the perception that the prediction task is a "tricky" question to avoid overthought answers from the students.

Table 1 and 2 show the questions used to mask the predictions that will be tested through observation in the next step of the P.O.E. strategy. As shown in Figure 2, the large majority of the students failed in their predictions of question 5 of table 1 and question 2 of table 2.

Predictions related with experiment 1	
1	Does the scale show the same, more, or less weight if you step on it with one foot compared to stepping on it with both?
2	If you were to step on the scale on the Moon, would it indicate more, less, or the same weight?
3	Would your mass on the Moon be the same, more, or less than on Earth?
4	Does the scale show the same, more, or less weight if you lean on a

	friend?
5	**If you stand on tiptoes on the scale, does it always show the same weight?**

Table 1. *Selection of questions to cover up the prediction of experiment 1. Question #5 was the relevant question to test through P.O.E. strategy.*

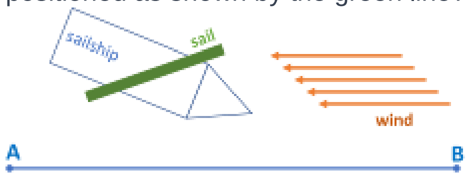
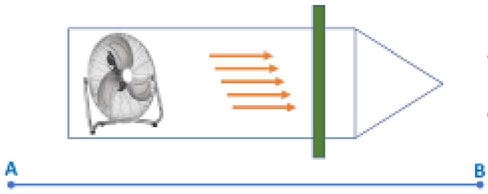
Predictions related with experiment 2		
1	Which way would a sailboat move with the wind against it if the sail is positioned as shown by the green line? 	a)It would approach point B b) It would approach point A c) None of the above
2	**If on a day with little wind, a giant fan located at the back of the boat is turned on, sending air towards the sail, how does the boat move?** 	a)It would approach point B b) It would approach point A c) None of the above

Table 2. *Questions related with experiment 2. Question #2 was the relevant question to test through P.O.E. strategy.*

2.2. Observation

As next step, students were invited to enter the lab to test their predictions through hand-on experience. Special attention was given to carefully annotating their observations. They tested the scale standing on one leg and leaning on a colleague, confirming their predictions for these situations. However, they were very surprised when they noticed that scale´s needle moved rapidly in both directions when they raised themselves on tiptoes over the scale.

Additionally, students assembled a toy car with a built-in fan pointed to its sail, as shown in Figure 1. Contrary to their previous predictions, it was unexpected that the toy car did not move when the fan was tuner on.

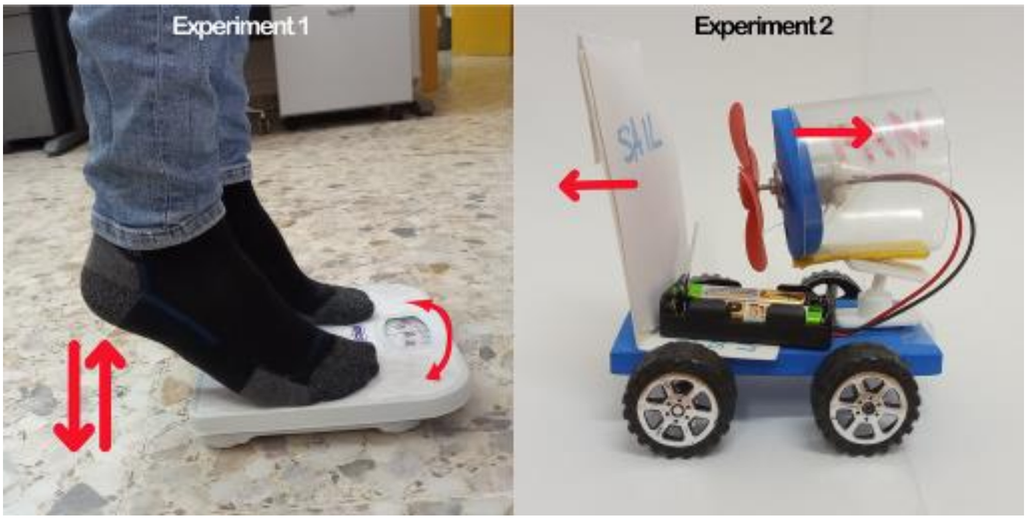


Figure 1. Sytudents were tasked with predicting, observing and explaining the behavior of a scale when a person raises on tiptoes (experiemnt 1) and theovement of a sailship propelled by its own fan.

Even though students may tend to improvise hypotheses and potential explanations during the experiments, teachers should maintain the discussion focused on the experimentation and the annotation of their observation, leaving the argumentation for the next and final step of the P.O.E. strategy.

2.3. Explanation

After the experimentation in the lab, students collaboratively worked in groups of four on the detailed scientific argumentation to explain the unexpected observations. More importantly, they aimed to identity counterargument against their initial predictions. This is a key aspect of the P.O.E. strategy because provoking the detection, understanding and correction of their own prior Knowledge triggers a deeper conceptual change and a more lasting assimilation of the new scientific concept(Erdem Özcan & Uyanık, 2022). During their deliberation, students were not allowed to use smartphone or computer because. Although it is not easy to find correct explanations for these experiments in internet and even AI chatbots like ChatGPT have failed in their predictions, it is more desirable for students to focus their reasoning on their annotations and the debate of their hypothesis.

2.3.1.The third Newton´s law: “To every action there is always an equal and opposite reaction.”

Most all the secondary physics textbooks illustrate the third Newton´s Law with very similar examples: a gun firing a bullet pushes back the gun backwards, jumping from a boat to land pushes back the boat to the sea or a garden hose moving while expelling water. This limited scope hardly helps students to grasp the idea that our daily life if surrounded by action-reaction forces. Nature manifests forces always in pairs. A particularly surprising fact for students is that even gravitational forces are manifested by a pair of action-reaction forces. For instance, when an apple (~200 mg) falls from a tree attracted by a gravitational force of F=mg ~ 1,96 N., the apple also attracts the Earth with equal reaction force in the opposite direction. So, theoretically, the apple fails into the Earth; and the Earth also falls toward the apple. The scientific concept is very similar to two separated strong magnets of opposite sign. Once that we are released, they will move forward to each other and meet in a middle point. However, in practice, the Earth does not actually move towards the apple dur to two reasons: other objects are pushing Earth in other directions; and the displacement of the Earth is so small that it is imperceptible. Doing the math could be a good exercise for students: considering that the Earth´s mass is 5.9·1024 Kg, the second Newton’s law can be applied to calculate the acceleration of Earth as a=F/m. Assuming a null initial velocity for our planet, the displacement of the Earth by the attraction of the apple is $\sim10^{-24}$ meters. This is less than 500 millionth of the size of an electron. At this distance, even uncertainty principle from quantum theory would prevent us from making any claim about the displacement of Earth.

When we stand on a scale, gravity pulls us down on with force mg (where m is our mass) and the scale pushes up on us with the same force, resulting in a net force of zero on us. This force pushing up against us is what the scale actually measures, and this is what tralates as our weight. When the students raised themselves on their tiptoes, they accelerated their bodies up by applying an extra force against the scale, primary executed by the calf muscle (Parker, 2001). According with third Newton´s law, the scale reacts pushing their bodies back in the opposite direction, causing the scale to register a higher weight. Just before reaching the maximum height on tiptoes, they had to deaccelerate before stopping This is archived by the calf muscle applying an extra force in the direction of the scale, which sum up with the weight of the students. This translates in the scale manifesting a lower reaction force, and registering lower weight(Lewin & Goldstein, 2011). The rapid acceleration and deceleration occurring within a short duration create the perception that the scale's needle behaves erratically when raising on tiptoes.

A similar line of reasoning can be applied to explain experiment 2 with the sailship. A force is generated when the fan pushes air in the direction of the sail. Following the third Newton´s law, the air pushes the fan in the opposite direction and with the same force. Since both the fan and the sail are anchored to the same toy car, the net force on the car is zero and, therefore, no movement.

3. Results

To evaluate the efficiency of these two P.O.E. strategies on provoking a significant learning in the students of Master's Degree in Secondary Education Teaching, a feedback survey was conducted two weeks after the activity. The large majority of them (95%) considered the experiment 2 (sailship) useful for a deeper comprehension of the third Newton´s law, while 58% considered the experiment 1 (scale) effective. When asked about their preference, a mayoralty of 58% of the students prefers the Experiment 2 to produce a significant learning.

We attribute this difference in the perceived efficiency of the experiments to the fact that Experiment 1 (scale) appears to be more challenging for students with less training in abstract thinking, mainly students with background in biology, nutrition, veterinary science, or other related subjects. However, students who fully understood the scale experiment, mainly with background in chemistry, engineering, or mathematics, seem to grasp a deeper understanding of the action-reaction effect. This is reflected in a 21% of the students who still prefer the scale experiment to produce a conceptual change. These results suggest that the scale experiment may be better suited for advanced courses in secondary education while the sailship experiment could be effective for introducing the Newton's laws at the initial courses of secondary education.

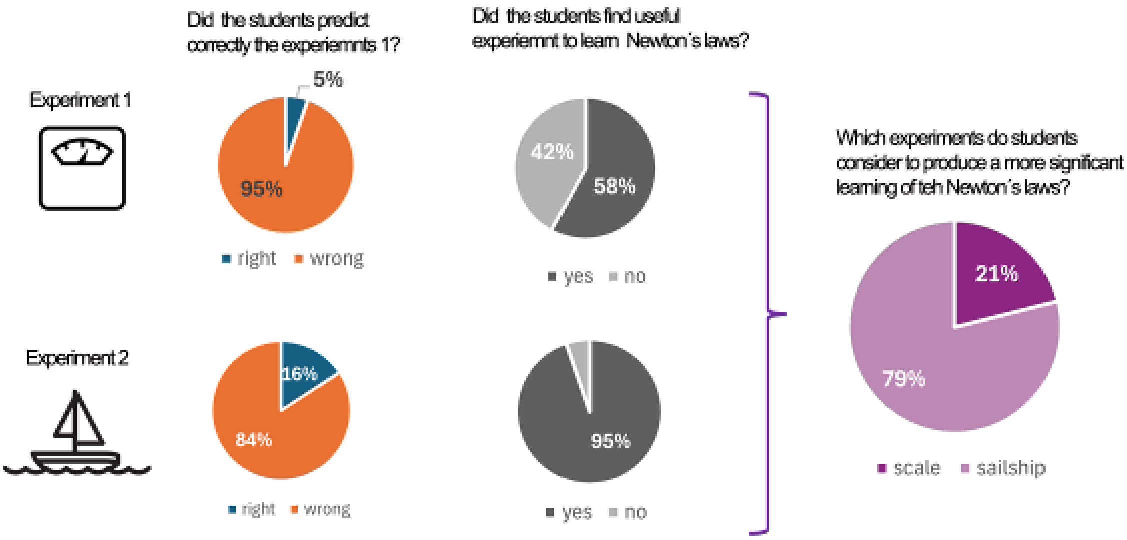


Figure 2. Results of the survey to evaluate the efficiency of the two experiment to teach third Newtown's law using P.O.E. strategy.

4. Conclusions

As traditional laboratory activities often focus on verifying previously explained phenomena, there is a growing need to design new hand-on experimental activities to activate prior knowledge. The constructivism view of education suggests that more significant learning occurs when hand-on activities contradict prior knowledge of learners, triggering a conceptual change in their minds.

To challenge prior knowledge about third Newton´s law of the students of master's degree in Secondary Education Teaching, two counterintuitive experiments were presented: one was based on the behavior of a scale when a person raises on tiptoes, and the other on the movement of a sailship propelled by its own fan.

Both experiments successfully demonstrated unexpected outcomes for the students and Prediction-Observation-Explanation strategies seem to translate the constructivist approach by helping learners to provoke conceptual changes and a more significant learning. The results suggest that the sailship experience would be significantly useful in introducing the third Newton's law at the initial coursers of secondary education. On the other hand, the scale experiment would contribute to a deeper understanding of the action-reaction law in more advanced courses.

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