The influence of active physics learning on reasoning skills of prospective elementary teachers: A short initial study with ISLE methodology

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Abstract

Pre-service elementary teachers, who have not studied physics for four years, face difficulties when they learn abstract concepts because their formal reasoning skills are not developed enough. To measure these skills, the "Test of logical thinking" (TOLT) has been used. Physics contents have been presented following an active physics learning methodology (Investigative Science Learning Environment, ISLE), in which students observe, explain and test their explanatory models through predictions and posterior observations. In the study 29 students participated. The TOLT has been applied before and after the active learning activities to measure the changes in the abstract reasoning skills. In general, the effects have been positive. The results were compared with the results found in other similar studies.

Keywords: Logical reasoning, ISLE, elementary teachers.

Resumen

Los futuros maestros de primaria no han estudiado física durante cuatro años y se enfrentan a dificultades cuando aprenden conceptos abstractos porque sus habilidades de razonamiento formal no están suficientemente desarrolladas. Para medir estas habilidades, se ha utilizado la "prueba de razonamiento lógico" (TOLT). Los contenidos de física se han presentado a raíz de una metodología activa de aprendizaje (Entorno de aprendizaje investigativo de ciencias, ISLE), en la que los estudiantes observan, explican y prueban sus modelos explicativos a través de las predicciones y observaciones posteriores. En el estudio participaron 29 estudiantes. El TOLT se ha aplicado antes y después de las actividades de aprendizaje activo para medir los cambios en las habilidades de razonamiento abstracto. En general, los efectos han sido positivos. Los resultados se compararon con los resultados encontrados en otros estudios similares.

Palabras clave: Razonamiento lógico, ISLE, maestros de primaria.

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I. INTRODUCTION

It is well known that students reveal numerous signs that they do not understand scientific concepts being unable to apply them in out-of-school contexts. In addition, the students use intuitive knowledge about science phenomena that makes very difficult and sometimes impossible to learn scientific concepts. That intuitive knowledge, based on routine activities and superficial thinking, is made of alternative conceptions or preconceptions [1, 2]. In a try to remediate this troubling situation, many countries of the European Union (EU) are investing money in science education introducing new teaching methodologies which promote active learning experiences and take into account how people learn [3].

To reach this goal, it is necessary to modify the training of the prospective teachers. Special attention should be given to those teachers who will teach science in elementary grades because they do not have good understanding of science, in general, and of physics, in particular. This group is important because they have to teach key concepts to the young pupils whose knowledge is a base for understanding physics in next stages [4, 5].

Concerning the contents, most of the prospective elementary teachers did not study physics during a period of four years. Therefore, it is difficult that they remember what they have already "learned" what shows that they have not understood well enough the key concepts in previous schooling. In addition, they have to study simultaneously different subjects in the same semester, like mathematics and language, physics and history.

To add more complications to the situation, some studies report that most of the in-service elementary teachers admit that they try to avoid the topics of physics due to a lack of confidence at the moment of explaining them [6, 7, 8]. In fact, the memories they have of science classes at school are related to textbooks and answers to the questions at the end of every chapter [9]. Nevertheless, there are also a few teachers who enjoy teaching science and do several experiences that are based on the research [4].

The research in science learning introduces the importance of the argumentation [10, 11]. In the science learning, the argumentation is necessary to discover and discuss inconsistencies between ideas and evidences [12]. Nevertheless, to argue well in the science learning one also needs logical or abstract reasoning. In fact, the development of these skills facilitates the physics concepts understanding. Namely, it is possible to think about a positive correlation between the abstract reasoning and the understanding and application of the basic concepts [13, 14, 15]. These abstract reasoning skills have been studied according to the age. There is no general agreement about the age by which the development of these skills is completed. The studies agree that the building pace of these skills depends on each person and they are usually developed from 11 to 21 years [16, 17, 18, 19].

In this study, we will focus on the logical reasoning and its possible improvements by using classroom-based active physics learning sequences. More precisely, we are interested to answer the research question:

Does and how much teaching methodology, called Investigative Science Learning Environment (ISLE), affect logical reasoning skills?

II. WHAT IS THE ISLE?

It is a system of active physics learning which seeks that the students acquire skills necessary for scientific thinking about the real world physical phenomena. In general terms, the students are given designed learning opportunities to know, practice and improve the processes that the physicists have used to construct the physics knowledge. The teachers are not supposed to give lectures but main their teaching goal is that the students construct and assess their knowledge. Every learning activity develops according to the cycle: observation, qualitative explanation, physical representation, test, quantitative explanation, multiple representations, test and applications [20].

In this process it is important that the students reveal what they know and how they got the knowledge they believe in. To make it possible, students have to work cooperatively, sharing their ideas the partners in learning groups. Students first observe the studied phenomenon and propose some possible explanations for its course and characteristics. To compare these explanations, students have to derive from each one a logical consequence which is testable. These consequences are predictions whose validity can be evaluate by making test experiments [21]. In this part of the class, the students have to use the hypothetical-deductive reasoning to make the predictions and to assess the results of the experiment [22].

III. THE FORMAL REASONING AND PHYSICS LEARNING

In general, the skill of formal reasoning is important not only at the moment of making and testing the predictions but also at every moment of learning physics. It is also true that the previous knowledge of every person and the effective use of logical rules of reasoning have a great effect in the learning [23, 24, 25]. In addition, there is also a partial dependence between the procedures of learning and the conceptual content [26]. Therefore, the abstract reasoning is the skill that goes beyond the particular case and it is important to learn and understand, specially the abstract concepts [27].

Several programs, for instance "Cognitive Acceleration" [28, 29, 30] and "Thinking in Physics" [31], have been designed with the goal to develop this skill. The last program utilized Lawson's Classroom Test of Scientific Reasoning (LCTSR) to assess the improvement of logical reasoning. This test has been long used both in biology education [32, 33] and in physics education [34, 35, 36].

To get the measures of abstract reasoning levels and their changes, we applied the Test of logical thinking (TOLT), designed by Tobin and Capie [27]. In this study, the Spanish version of that test was used. The translation was done by the "Seminario Permanente de Investigación en Didáctica de las Ciencias" in Cadiz [37].

The test consists of ten tasks, related to proportionality, control of variables, probability, correlation and combinatorial operations. The first eight questions have two levels: answer and reason, they are multiple choice, both the answer and the reason. The two questions have to be answered correctly in order to be considered correct. The questions fit with the standard errors [38, 39]. On the other hand, the last two questions are relating to combinatorial analysis, they are opened semi-structured answer. To avoid the introduction of a new variable we will use the Spanish version, validated in a previous study [40].

The TOLT, the Spanish and the original version, has been used in several investigations. Acevedo and Oliva [40] measured the formal reasoning of 1400 students from 13 to 21 years. Valanides [41, 42] used the test with students from 13 to 17 years. The TOLT has been also applied to engineering students [43], chemistry students [44] and pre-service science secondary teachers [45]. In an experiment with in-service elementary teachers, carried out to develop their formal reasoning, the researchers used another test of logical thinking inspired by the TOLT, called the GALT [46]. There was also a research which had the goal to compare the effects in formal reasoning skills between a group with lab instruction and another one with traditional methodology [47].

According to the level of formal reasoning, there are different ways of division. Some researchers consider that concrete level corresponds to a score from 0 to 3, transitional level from 4 to 6 and formal level 7 to 10 [48-50]. Valanides [42] distinguished four levels: concrete (punctuation of 0 or 1), transitional (2 or 3), formal (4 to 7) and rigorous formal (8 to 10). The comparison is shown in the table 4. Surprisingly, Valanides [41] made another division: concrete (0 and 1), transitional (2 and 3) and formal (from 4 to 10).

IV. SAMPLE, SCORING AND PROCEDURE

The sample of the experiment has been 29 pre-service elementary teachers, which did not study physics during previous four years, the ages of the students were from 19 to 21 years old. In these years, they have only studied some mathematical contents and several humanities subjects. We wanted to measure up the changes of formal reasoning levels and if the students were able to reach the formal reasoning level.

According to the score in the TOLT, we used the following classification: concrete reasoning level, from 0 to 3 points, transitional level, from 4 to 6 points, and formal level, from 7 to 10 points.

Procedure

The students did the TOLT as a pretest and posttest. During the experiment, the teacher – researcher (David Méndez Coca) did eleven physics experiments, some of them were done in the classroom or some were shown by videos. The time spent were six 90-minute sessions.

The sessions started with the observation of an experiment. After that, the teacher gave a paper with some explanatory and predictive questions. The students predicted what it would happen and wrote down these predictions. Later they discussed the hypotheses and predictions in small groups of three or four people. The discussion lasted up to thirty minutes. After it, they shared the answers with the whole class, the predictions were tested and they had to rethink if they were mistaken. It is true that, in all the cases there was at least one correct answer.

The experiments were about atmospheric pressure, heat and electricity. Six experiments were carried out by the professor in the classroom and six were presented in the video format. At the end of the class, the final comments were done by the professor if some student still had doubts.

The experiments, carried out by the teacher, were the following:

1. A postcard covers a glass filled with water. The glass is turned upside down, but the postcard is kept stuck preventing the water to flow down.
2. Cover a syringe with a finger. It is possible to experience that the piston cannot be moved very much in spite of doing a lot of force.
3. A plastic bag is situated inside a plastic container stuck to the interior walls, without glue, and tied to the mouth of the bottle with an elastic gum. Though the students pull strongly the bag but they do not manage to take it out of the bottle.
4. An opened bottle with a hole at the bottom was filled with water. The students observe the jet of the water. Later the bottle is closed and the jet stops. In another situation, the opened bottle is thrown up and finally, the opened bottle is let to fall down. In both cases, the jet stops.
5. A globe tied to the mouth of a bottle, the bottle does not have base, it has been removed. The professor introduces this system in a container with water; in fact the professor can only introduce a part of the bottle because the volume of the air decreases and the globe is inflated by the air.
6. A closed bottle is inside the refrigerator, later it is opened and a globe sticks to the mouth, now the bottle warms up and the students observe that the globe inflates.

The six video experiments were the following:

1. A globe is placed on a candle and it explodes.
2. A globe with water is placed on a candle and it does not explode.
3. How can I break a ruler at one stroke using only a few sheets of paper? They had to design and do this experiment and later they observed it.
4. They observe a tin with a bit of water warming up very much, the tin is moved to a place with cold water and it contracts.
5. A system is connected with a potential source and a ball of aluminium moves or stops depends on the circumstances. It is based in electrifying by contact and by induction.
6. A few glasses of paper are connected with a potential source and the glasses jump.

We will illustrate the common steps and questioning strategy in every experiment by the example of the plastic bottle with a hole filled with water. Students saw the opened bottle with water falling down in the form of a jet. The teacher asked the students several questions:

Why does the water flow down?

What would happen with the water if the bottle was closed? The water would fall down or not? Why?

What would happen if the bottle was moved freely up, the water would fall down or not? Why?

What would happen if the bottle falls freely down, the water would fall down or not? Why?

The students had to write down their answers on their work-sheets. Later the teacher did the experiment. They saw if their predictions were good or not. The teacher asked the students why happened what they had just seen and they had to give the reasons of this behavior. With all these answers, the teacher could learn about the knowledge of the students and help them to improve it.

V. RESULTS

The general results are the following:

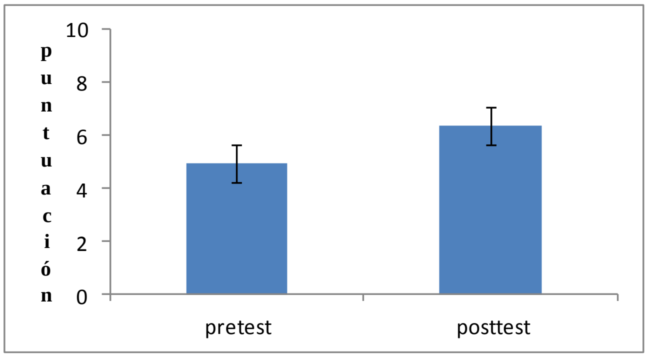

FIGURE 1. Mean and standard deviation of the pretest and posttest scores of the students in the TOLT.

The results of the posttest are better than the pretest. In the pretest the mean is 4.93 and the standard deviation is 2.30, in the posttest the mean is 6.35 and the standard deviation is 2.61. Therefore, the results have improved with the ISLE methodology. With these results, the gain [51] is 0.33+0.28. Only one student has a negative gain and seven do not have gain.

The general results divided in the parts of the TOLT are:

TABLE I. Mean of each part of the TOLT in the pretest and posttest.

Part of TOLT	Pretest	Posttest
Proportions	0.63	0.73
Control of variables	0.57	0.75
Probabilities	0.46	0.46
Correlations	0.50	0.73
Combinations	0.31	0.52

The results of the posttest are clearly better than the prestest in four areas, nevertheless there is no change in probabilities. The theoretical value of $\chi 2$ (0.01) is 58.301, the value calculated with the data is 80.712. Therefore, the difference is significant.

As for the classification of the students according to the level of formal reasoning, concrete from 0 to 3, transitional from 4 to 6 and the formal from 7 to 10, the results are given in the Table II.

TABLE II. Distribution of the students according to the level of formal reasoning in the prestest and posttest.

Formal reasoning level	Pretest (%)	Posttest (%)
Concrete	34	17
Transitional	31	24
Formal	34	59

The students' distribution has moved towards higher levels of formal reasoning. In fact, four have changed from concrete to transitional; one student has changed from concrete to formal and six from transitional to formal. Five have kept in the concrete, three in the transitional and ten in the formal. No student has changed to a lower level of formal reasoning according to the results of the TOLT.

Therefore, 62% of the students have kept in the same level and 38 % has changed to a higher level. The students who have kept their level have achieved an improvement in the punctuation of 0.66 and those who have changed to a higher level have got 2.63. It causes a gain for those who have kept in the same level of 0.25 and for those who have changed level of 0.46.

As it has been said above, the teacher could learn about the knowledge of the students. Being so, it would be possible to make many comments on students' performances, but it is not the aim of the article. In order to illustrate what the students' ideas and thinking were, we expose some of them related to the experiment of the bottle with the hole filled with water.

When the students were asked what would happen when the bottle is closed, their answers were:

"The water will fall down because there is nothing that does pressure on the hole."

"The gravity will do that the water falls down."

"The inertia does that the water goes out of the bottle."

"The atmospheric pressure is less than the one that exists inside the bottle".

When the students were asked about what would happen if one lets the opened bottle to fall freely, the students answered:

"The particles increase the movement, the pressure will increase too, and, therefore, the water will go out with more force."

"The pressure of the air is less than that of the water. Therefore, the water goes out of the bottle.

"The water will go out because of the gravity."

From these answers, one concludes that the prospective teachers, who participated in the study, have conceptual problems with atmospheric and hydrostatic pressure and weightlessness.

VI. DISCUSSION

When one has to evaluate the size of the effects gain in an educational experiment on physics teaching, comparisons with the results of other studies are useful. In our study, the mean is 4.93 in the prestest. In Acevedo and Oliva's study [40], the mean score was 3.7. With students of 16 and 17 years, it was 5.59 [41]. The first year engineering students' have mean score of 5.60. It should be expected because they have to use habitually the formal reasoning and it should be more developed [43]. The mean of pre-service secondary teachers is 6.74. This group has the formal reasoning more developed than elementary teachers because they have done science studies [45]. With chemistry university students, the results are clearly higher, the mean score is 7.73 [44]. Therefore, the mean score of our prospective teacher in the pretest is rather. However, the posttest mean score is 6.35, being close to the mean score of secondary science teachers. Such a change should be considered as a success.

Valanides [42] distinguishes four levels of formal reasoning while the students are growing from 13 years to 15. The comparison is shown in the table below.

TABLE III. The distribution of students in four levels of formal reasoning according to the results of pretest and posttest and the results of Valanides [42].

Formal level	13 years	14 years	15 years	Pretest	Posttest
Concrete	54.2	47.3	33.4	10.3	6.9
Transitional	28.8	26.5	25.7	24.1	10.3
Formal	15.5	22.1	30.7	55.6	44.9
Rigorous formal	1.4	4.1	10.2	10.3	37.9

It can be noticed the change between the prestest and posttest, the improvement is more than the improvement between 13 years to 14 or 14 to 15. Therefore, it is a significant change.

If the results are compared with another study of Valanides [41], now he classifies in three levels of formal reasoning. The results were:

TABLE IV. Results of the prestest, posttest and a sample 16-17 years according to the classification of Valanides [41].

Formal level	16-17 years	Pretest	Posttest
Concrete	4.4	10.3	6.9
Transitional	22.8	24.1	10.3
Formal	72.2	65.6	82.8

With these results as reference, the reasoning skills' change of the prospective elementary teachers is important. In the pretest they got worse than the 16-17 years old students, but in the posttest their results are better. This important change was caused by the ISLE methodology.

It is possible also to make a comparison with first year engineering and 15-16 years old students [43, 52]. The data are distributed in the same levels that appears in the Table 2.

TABLE V. Results of 15-16 years old and first year of engineering and the prestest and posttest according to the classification of Table II.

Formal level	15-16 years	First year of engineering	Pretest	Posttest
Concrete	51	36	34	17
Transitional	30	24	31	24
Formal	19	40	34	59

The students of engineering are of similar age as the prospective elementary teachers. In addition, they should have a more developed formal reasoning. This statement is correct at the beginning, because the results of the elementary teachers are low. Nevertheless, the formal reasoning has developed so much that the prospective elementary teachers have achieved better results than the engineering students. When the comparison is with the 15-16 years old students, the elementary teachers have developed more the formal reasoning because they are older.

And there is another interesting comparison, the development of logical reasoning between two groups of in-service elementary teachers: one followed a traditional methodology and other one followed a lab instruction for twelve weeks and three hours each week. The gain was in the first case -0.08 and in the second case 0.29 [47]. It shows that our experiment with prospective elementary teachers has had a very positive effect. Namely, they get a little better gain in 9 hours than students who participated in lab instruction during 36 hours.

Finally, there is a study [35] which explored the effect of three different teaching designs on the improvement of logical reasoning, meassured by the LCTSR. The experiment was 16 weeks long (12 weeks for learning and 4 for testing, one 45-minute session per week). The students were 17-18 years old. The methodologies were traditional methodology (TM), experimenting and discussion (ED) and Reading, presenting and questioning (RPQ). The levels of logical reasoning are similar as with the TOLT.

TABLE VI. Results of improvement in comparison with ISLE according to the methodology followed by Marusic and Slisko [35]. The numbers are percentages of the students being at certain reasoning level.

Levels of reasoning	TM		ED		RPQ		ISLE	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Concrete	31	29	27	15	26	24	34	17
Transitional	50	52	53	46	57	47	31	24
Formal	19	19	20	39	17	29	34	59

The results of ISLE are better than the traditional methodology and reading, presenting and questioning, however they are really similar to the results of experimenting and discussion.

VII. CONCLUSIONS

The formal reasoning is an important skill for learning abstract scientific concepts. Specially, it is very needed and useful in physics learning. As it is show in this and other studies, an adequate design of learning experiences can improve this skill significantly. Due to the lack of such experiences, this skill is not usually very developed in the students who are preparing to be elementary teachers. Namely, they have not studied physics in the last four years. To improve that situation, it is necessary to follow an active learning methodology, as ISLE, which can help them to develop necessary reasoning skill.

With the results of the pretest, it is possible to show that the prospective elementary teachers had underdeveloped formal reasoning. Nevertheless, by implemented ISLE methodology during only six 90-minute sessions, a positive change has been produced.

While 38% of students got a change of level (from concrete to transitional or formal, from transitional to formal) and 62% of them has been kept in the same level (although many with a better score).

Therefore, the ISLE methodology has facilitated the improvement of formal reasoning which is very useful for development of other learning skills, like building explanatory and predictive models. The students have learnt a good methodology to develop these skills in their pupils, when they start to teach physics concepts in their future job.

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