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DEVELOPMENT OF SCIENTIFIC REASONING IN PHYSICS CLASSROOM WITH HIGH SCHOOL STUDENTS FROM MARGINALIZED CONTEXTS

Abstract.
The importance of studying scientific reasoning is crucial for various reasons, ranging from the unsatisfactory outcomes of standardized tests at both national (planea) and international (Pisa) levels that govern the quality of learning to the classroom level where there is often a preference for covering a thematic content program rather than encouraging reasoning per se. Due to this, the present article aims to establish the variations in scientific reasoning that occur during the teaching of physics at the high school level categorized as high marginalization. To achieve this, the scientific reasoning in the classroom test by lawson was used, where a pre-test and post-test were administered to two groups, one control and one experimental. In the experimental group, a didactic intervention focused on the use of concepts such as magnitude, unit, and variable was carried out, as teachers had reported that students struggled to relate these concepts, leading to confusion when completing exercises. In contrast, the control group received the class as it is typically conducted. However, the results obtained in the post-test of both groups indicate that there were no statistically significant variations in either the experimental or control group. Despite these results, it was found that students remained in empirical-inductive reasoning during the first part of the Physics course. Therefore, a challenge in educating students under similar conditions would be designing activities that contribute to the transition toward hypothetical-deductive reasoning.
Key words: scientific reasoning, high school students, physics, high marginalization, teaching-learning strategies.

Introduction.

Studying reasoning as a core component in the teaching-learning processes of high school students is relevant because it enables the development of critical thinking, fosters the comprehension of natural phenomena, and cultivates analytical skills among other attributes [1]. Therefore, the purpose of this study is focused on identifying potential variations in scientific reasoning within high school Physics classes, particularly in contexts where learning can be hindered by environmental conditions, such as a high degree of marginalization. Thus, pinpointing the level of scientific reasoning that students develop can prove beneficial for educators when designing class activities.

Consequently, studying reasoning, especially within the adolescent population, is valuable since, as referred to by Moshman (2013), reasoning represents "self-control of thought" as students channel their thinking to arrive at a true or justifiable conclusion. This definition is supported by Kellogg (2020), as it underscores reasoning as a cognitive process through which people start with certain information and reach conclusions that transcend this information. In this context, reasoning nourishes formal thinking. It implies that high school subjects must be capable of making deductions, formulating conclusions, and establishing hypotheses without the need for direct observation. This means that in formal thinking, it becomes possible to imagine things that have not been seen or experienced [2].

Given the aforementioned considerations, scientific reasoning can be defined as a cognitive process that logically and systematically analyzes understanding in problem-solving where empirical evidence, experimentation, deductive and inductive logic are employed to formulate hypotheses, inferences, and generalizations [3], [4]. In this vein, considering the starting point of Physics classes in high school, it could be assumed that promoting meaningful learning in young students would be facilitated if their reasoning processes exhibit the formal thinking characteristics described earlier. In this way, when approaching phenomena studied within this discipline (such as electromagnetic phenomena, hydraulics, types of motion, among others), experimentation wouldn't be a prerequisite for understanding the phenomenon itself. This is because it would not be sufficiently necessary for achieving meaningful learning, as formal thinking entails reflecting on one's own thoughts and behaviors [5].

Nevertheless, standardized tests such as the Programme for International Student Assessment (Pisa) or the National Plan for Learning Assessment (planea) in Mexico, which evaluate scientific reasoning, yield results demonstrating unsatisfactory levels of performance among high school students. Only around 1% of those who took these tests managed to achieve the highest levels.

Consequently, it becomes apparent that there is an issue that remains unresolved, suggesting that perhaps the problem lies beyond teaching methods and the content itself. Hence, a possible approach to addressing the causes of this unsatisfactory performance in such tests could involve diagnosing the level of scientific reasoning with which students embark on their classes, particularly in the field of Physics. According to Yediarani, Maison, & Syarkowi (2019), this area requires the interpretation of information, classification of elements, and, notably, reasoning skills such as inductive thinking and deductive analysis to explain events occurring in nature, both qualitatively and quantitatively.

Furthermore, it has been demonstrated that scientific reasoning strongly correlates with learning outcomes, particularly in science-related fields such as Physics. This is because it enables students not only to think logically about concrete objects but also to comprehend verbal representations of phenomena [6], [7]. This, in the classroom setting, would have advantages. During the course of class activities, it becomes evident that there is a difficulty in assimilating theoretically presented phenomena. This hindrance not only obstructs understanding but also impedes learning itself. Additionally, certain environmental factors can further complicate matters, potentially favoring or even inhibiting learning, particularly in contexts characterized by marginalization, as is the case with the population under investigation.

For example, the effects of social marginalization persist from childhood to later stages of psychological development. It has also been shown that individuals facing social disadvantages tend to exhibit lower intelligence test scores and performance compared to their peers without such disadvantages. Cognitive development differences in these social groups are even greater than differences in physical health [8], [9].

Finally, within the context of low performance on standardized tests that evaluate learning quality, it's imperative to emphasize contextual nuances to prevent them from diminishing the teaching-learning processes. As lawson (1977) suggests, making an effort to teach physics through its interaction with the community could contribute to the shift from concrete to formal thinking. Thus, the significance of this article lies in the fact that scientific reasoning comprises various forms of reasoning, which, once identified, can be incorporated into didactic planning to promote teaching-learning processes more effectively. These forms of reasoning, according to Lawson (1977), are as follows:

1. Combinatorial reasoning: the individual considers all possible theoretical or experimental relationships without the need for direct observation in nature.
2. Variable control: hypotheses, whether true or false, are established based on the recognition of variables.
3. Concrete reasoning about constructs: the individual conducts reasonable classifications or series of patterns of concepts and properties.
4. Functional relationships: dependencies between variables in different situations are recognized and interpreted.
5. Probabilistic correlations: the subject acknowledges that natural phenomena are random by considering multiple variables. However, they can correlate variables with a higher probability of occurrence.

Materials and methods of research.

According to Lawson (1977), studying reasoning is especially relevant when applied in sciences like Physics, as it promotes scientific and mathematical reasoning to analyze a situation and solve a problem. Hence, the purpose of the classroom test of scientific reasoning (ctsr) is to measure concrete and formal operational reasoning based on Piagetian stages [10]. The test applied here is a Spanish version designed for high school and secondary school students, focusing on the following categories:

1. Physical concepts
2. Proportions
3. Understanding of variables
4. Probability
5. Capacity for observation and hypothetical-deductive thinking.

These categories, in turn, indicate the level of reasoning through the following abilities:

Table 1 - Levels of reasoning evaluated by items according to their thematic axis

Theme	Abilities	Items
Conservation of physical magnitudes	The student applies the reasoning of conservation of perceptible objects and their properties	1, 2, 3, 4
Proportional Thinking	The student recognizes and interprets numerical relationships through observable variables	5, 6, 7, 8
Identification and control of variables	The student recognizes the need to consider all possible causal variables and design an experiment where they control all variables except the one being investigated	9, 10, 11, 12, 13, 14
Probabilistic thinking	The student recognizes phenomena of a probabilistic nature and evaluates the probability of certain assumptions remaining true in the design of an experiment	15, 16, 17, 18,
Combinatorial and correlational thinking	The student considers experimental combinations, even if some do not occur in nature; and despite random fluctuations, the student recognizes causes or relationships of a phenomenon under study.	19, 20, 21, 22, 23, 24
Note: It is important to point out that some items exhibit a transitional nature towards other levels of thinking, as seen in the case of items 11 to 14, where probabilistic thinking is included, and items 23 and 24, where hypothetical-deductive reasoning is reached. Own elaboration.		

Lastly, based on the reviewed content, it's important to remember that the lawson classroom test of scientific reasoning (ctsr) aims to evaluate the following forms of reasoning:

1. Empirical-inductive reasoning (0-4 pairs): Students are unable to test hypotheses based on observable causal agents, but they can engage in mental experiments. In other words, they possess concrete thinking, meaning they relate to objects rather than verbalized hypotheses.

2. Transitional between reasonings 1 and 3 (5-8 pairs): Concrete thinking has been established, but validation of verbalized hypotheses has not yet been achieved, showing inconsistency.

3. Hypothetical-deductive reasoning (9 and 11 pairs plus 2 independent responses): Individuals are capable of testing hypotheses related to both observed and unobserved elements. In other words, they possess formal thinking, meaning they can formulate and test hypotheses.

These reasoning are distributed across 24 multiple-choice items, grouped into 11 pairs, with items 23 and 24 being independent. In other words, responses are only marked as correct when both items in a pair are correct, except for the last two items.

Additionally, the author emphasizes the importance of teachers' involvement in the development of these skills. This involvement can encompass their teaching practices and the implementation of strategies like the one presented here.

Lastly, the instrument has been validated and translated into Spanish in Mexico by Dr. Genaro Zavala and the physics education research and innovation Group (PERIG) at Tecnológico de Monterrey, Monterrey Campus. This group is responsible for updating and improving teaching methods used by instructors in the Physics Department, ensuring a high reliability (Cronbach's alpha of 0.78).

Test Administration. For the fieldwork application of the CTSR, a convenience sample of 66 students (n=66) from a public high school in Zapopan, Jalisco, Mexico, was considered. The school is located in an area characterized by high marginalization, according to the Institute of Statistical and Geographic Information (2010). This population was divided into two groups: the 3rd-C class as the control group (n=30) and the 3rd-A class as the experimental group (n=36), following the inclusion criteria below:

a. Adolescents aged 15-18 years b. Graduates from a public middle school located in the Mesas area c. Public high school students d. Enrolled in the 3rd semester e. Have taken a previous Physics course f. Reside in areas near the school g. The school's location should exhibit a high degree of marginalization h. Exclusion criteria: i. Did not complete the entire questionnaire.

Now, since the objective of this research has been to establish variations in scientific reasoning among high school students whose contextual conditions can be defined as marginalized, in order to identify the types of reasoning necessary for achieving Physics learning outcomes and potentially serve as references for teachers' didactic design, the study was conducted by implementing both a pre-test and a post-test. Only in the experimental group was a didactic intervention carried out, aimed at promoting the use of Physics concepts for understanding uniform rectilinear motion (urm) and uniformly accelerated rectilinear motion (uarm), such as unit, magnitude, and variable. On the other hand, the control group conducted their classes with the teacher as per usual, without emphasizing these concepts.

Results and its discussion.

In Table 2, the statistical results of the pre-test of the lawson classroom test of scientific reasoning for both groups can be identified. As for Figure 1, it becomes evident that, for the 3rd-A group, 88.88% (32 students) fall within the empirical-inductive reasoning level, while 11.12% (4 students) are in a transitional stage towards hypothetical-deductive reasoning. On the other hand, the 3rd-C group displays similar figures, with 93.33% (28 students) positioned at the empirical-inductive reasoning level and 3.33% (1 student) in transition towards hypothetical-deductive reasoning. Only the remaining 3.33% (1 student) is positioned at the hypothetical-deductive reasoning level. In other words, the majority of students initially positioned themselves within concrete thinking, as depicted in Figure 1, which shows a concentration of responses between 1 and 4.

Table 2 - CTSR pre-test result

				Total
		3rd-A	3rd-C	
CTSR pre-test result	Empirical-inductive reasoning	11	12	23
	Empirical-inductive reasoning	10	4	14
	Empirical-inductive reasoning	7	8	15
	Empirical-inductive reasoning	4	4	8

	Transitional inductive and hypothetical-deductive	1	1	2
	Transitional inductive and hypothetical-deductive	1	0	1
	Transitional inductive and hypothetical-deductive	1	0	1
	Transitional inductive and hypothetical-deductive	1	0	1
	Hypothetical-deductive reasoning	0	1	1
Total		36	30	66
Note: Own elaboration				

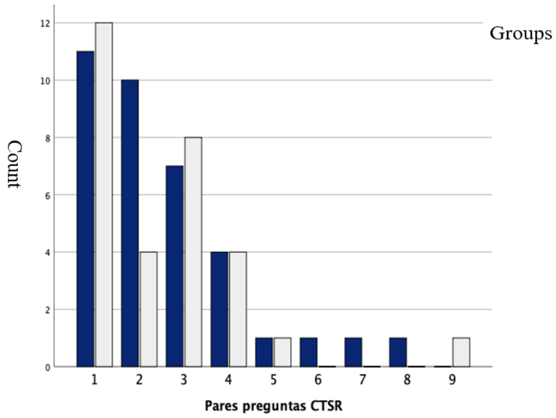

Figura 1 - Results of the pre-test administration of the Lawson Classroom Test of Scientific Reasoning (CTSR) 3ro. A (azul) vs 3ro. C (gris)

Note. The results are presented based on pairs of questions within each group, with up to pair 4 indicating empirical-inductive reasoning. Own elaboration.

Now, it's important to note that the following analyses were considered in this study:

1. Pre vs post of the lawson classroom test of scientific reasoning for the 3rd-A group: a. H0 = There are no significant variations in the results between both tests b. H1 = There are significant variations in the results between both tests
2. Pre vs Post of the lawson classroom test of scientific reasoning for the 3rd-C group: a. H0 = There are no significant variations in the results between both tests b. H1 = There are significant variations in the results between both tests
3. Pre-test of the lawson classroom test of scientific reasoning between the 3rd-A and 3rd-C groups: a. H0 = There are no significant variations in the results of the pre-test between the groups b. H1 = There are significant variations in the results of the pre-test between the groups
4. Post-test of the lawson classroom test of scientific reasoning between the 3rd-A and 3rd-C groups: a. H0 = There are no significant variations in the results of the post-test between the groups b. H1 = There are significant variations in the results of the post-test between the groups

With the assumptions above, the results obtained after both the pre-test and post-test applications in both groups are listed below:

1. Based on the normality test, H1 is accepted ($0.009 < 0.05$). This indicates that there is no normal distribution of data in the Lawson Classroom Test of Scientific Reasoning for the experimental 3rd-A group, necessitating a non-parametric test. Using the Wilcoxon Signed-Rank Test, no statistically significant variations were found ($z = -0.130$; p value $= 0.897 > 0.05$; $g = 0.000$) in the scores between

the pre-test (Mdn = 2; range = 7) and post-test (Mdn = 2; range = 8) of the Lawson Classroom Test of Scientific Reasoning for the experimental 3rd-A group.

2. Based on the normality test, H0 is accepted (0.078 > 0.05). This indicates a normal distribution of data in the Lawson Classroom Test of Scientific Reasoning for the control 3rd-C group, enabling a parametric test. Using the Student's t-test, no statistically significant variations were found (t(29) = -0.629; p value = 0.536 > 0.05; d = 0.08) in the scores between the pre-test (M = 2.47; SD = 1.737) and post-test (M = 2.62; SD = 1.668) of the Lawson Classroom Test of Scientific Reasoning for the control 3rd-C group.

3. Based on the normality test, H1 is accepted (0.000 < 0.05). This indicates that there is no normal distribution of pre-test results of the Lawson Classroom Test of Scientific Reasoning between the 3rd-A and 3rd-C groups, requiring a non-parametric test. Using the Mann-Whitney U test, no statistically significant variations were found (z = -0.340; p value = 0.734 > 0.05; g = 0.053) in the pre-test scores between the 3rd-A group (Mdn = 2; range = 8) and the 3rd-C group (Mdn = 3; range = 8) in the Lawson Classroom Test of Scientific Reasoning.

4. Based on the normality test, H1 is accepted (0.000 < 0.05). This indicates that there is no normal distribution of post-test results of the Lawson Classroom Test of Scientific Reasoning between the 3rd-A and 3rd-C groups, necessitating a non-parametric test. Using the Mann-Whitney U test, no statistically significant variations were found (z = -0.343; p value = 0.732 > 0.05; g = 0.053) in the post-test scores between the 3rd-A group (Mdn = 2; range = 8) and the 3rd-C group (Mdn = 3; range = 8) in the Lawson Classroom Test of Scientific Reasoning.

Now, in Figures 2 and 3, it can be observed that despite there being no statistically significant variations between the results of the pre-test and post-test of the Lawson Classroom Test of Scientific Reasoning (CTSR) in both groups, it's important to note that in the post-test (Figure 3), even though the test indicates that pairs 0 to 4 represent empirical-inductive reasoning, most students scored higher than just one correct pair of questions compared to the pre-test. For instance, in the intervention group (3rd-A), the number of students with only one correct pair of questions reduced from 11 to 2, with most falling between 3 and 4 correct pairs of answers. A similar case occurred in the 3rd-C group. Thus, the percentage of students who scored only one correct pair of questions in the CTSR test decreased from 34.8% (23 students) to 6.1% (4 students).

These variations are important to highlight as they can be further analyzed to better understand their influence on both groups. The two groups followed different teaching strategies, except for the problem-solving aspect where the same strategy was used. This may have had an impact, as this test evaluates scientific reasoning.

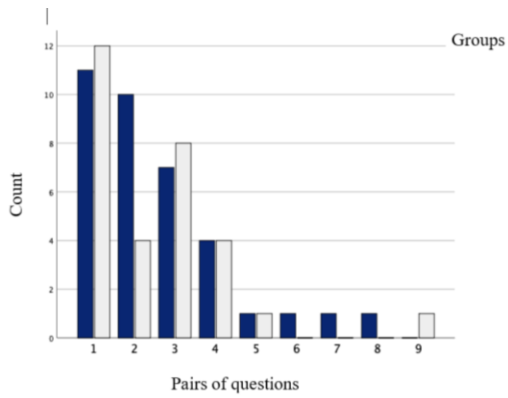

Figura 2 - Resultados Pretest CTSR ambos grupos

Note. Own elaboration.

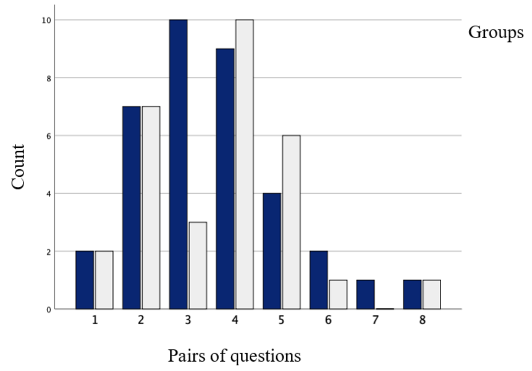

Figura 3 - Resultados Post test CTSR ambos grupos

Note. Own elaboration.

If we analyze the graphs of the pre-test and post-test CTSR (Figures 2 and 3), it's noticeable that for the experimental group, there is a reduction in the number of students who answered only one pair of questions correctly, decreasing from 11 to only one student. The remaining students (35) answered more than one pair correctly. Thus, looking at the results this way, following Lawson (1977), above the third pair (6 questions), proportional thinking is utilized, where students are capable of recognizing and interpreting relationships between numbers and variables.

Conclusion.

The development of scientific reasoning is of utmost importance within school contexts, particularly among adolescent populations, as they are in a stage of formal thinking. Throughout their academic journeys, this skill is promoted across various subjects, including Physics. However, certain contextual factors can play a significant role as either hindrances or facilitators of scientific reasoning. In this case, it has been evident that an environment characterized by high levels of marginalization impacts teaching and learning processes, even when didactic strategies aimed at fostering reasoning development are implemented.

Thus, while the study's intention was to establish variations in scientific reasoning, it was observed that students facing conditions of high marginalization mostly initiate and persist in empirical-deductive reasoning throughout their school years. Therefore, there were no significant variations even with the implementation of didactic interventions.

In this context, it can be inferred that despite students' ability to engage in mental experiments, they struggle to prove hypotheses based on observable phenomena. Put differently, students can only recognize natural phenomena through variables that have a higher likelihood of occurring.

Furthermore, although the potential for formal thinking exists at this age, its access encounters obstacles, resulting in concrete thinking being the prevalent form of reasoning. In other words, students can only relate to concrete objects rather than verbalized hypotheses.

Ultimately, understanding the level of scientific reasoning among most students, particularly those in highly marginalized contexts, shifts the focus toward considering not only the students' environment but also the teaching-learning strategies. Especially in the field of Physics, emphasis should be placed on activities that specifically target hypothetical-deductive reasoning. This way, teaching thematic content would contribute to the development of scientific reasoning rather than merely covering a subject matter [11], [12].

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ШЕКТЕУЛІ КОНТЕКСТТЕГІ ОРТА МЕКТЕП ОҚУШЫЛАРЫНЫҢ ФИЗИКА САБАҚТАРЫНДА ҒЫЛЫМИ ОЙЛАУЫН ДАМЫТУ

Аңдатпа.

Ғылыми пайымдауды зерттеудің көптеген маңызды себептері бар: Ұлттық (planea) және халықаралық (Pisa) деңгейлеріндегі стандартталған тесттері оқушылардың қаншалықты жақсы оқып жатқанын нақты көрсетпейтіндігін, оқушылардың сыни тұрғыдан ойлауға ынталандырудан гөрі мұғалімдердің көбінесе тақырыпты оқытуға назар аударуына қарайды. Осыған байланысты, бұл зерттеудің мақсаты физиканы «Жоғары маргинализация» деп аталатын орта мектеп деңгейінде оқытқанда ғылыми пайымдауда қандай өзгерістер болатынын анықтау. Мұны істеу үшін Лоусонның «Сыныптағы ғылыми негіздеме» тесті пайдаланылды. Екі топқа тест берілді, бірінші топқа бақылау тесті және екінші топқа эксперименттік. Эксперименттік топта шама, бірлік және айнымалы сияқты ұғымдарды қолдануға бағытталған оқыту әрекеті жүргізілді. Мұғалімдер студенттердің бұл ұғымдарды байланыстыруда қиындықтарға тап болғанын олардың жаттығу орындауы қиынға соққанын хабарлады. Бақылау тобы, керісінше, сыныпты әдеттегідей алды. Дегенмен, екі топ үшін де тесттен кейінгі нәтижелер эксперименталды топ пен бақылау тобы арасында статистикалық маңызды айырмашылықтар болмағанын көрсетті. Осы нәтижелерге қарамастан, студенттер физика курсының бірінші бөлімінде эмпирикалық-индуктивті пайымдауда қалатыны анықталды. Сондықтан, ұқсас жағдайларда студенттерді оқытудағы міндет гипотетикалық-дедуктивті пайымдауға көшуге ықпал ететін әрекеттерді жобалауы болады.

Негізгі сөздер: ғылыми ойлау, жоғары сынып оқушылары, физика, жоғары маргинализация, оқыту-оқыту стратегиясы.

РАЗВИТИЕ НАУЧНОГО МЫШЛЕНИЯ НА УРОКАХ ФИЗИКИ У СТАРШЕКЛАССНИКОВ ИЗ МАРГИНАЛИЗИРОВАННЫХ КОНТЕКСТОВ

Аннотация.

Важность изучения научных рассуждений имеет решающее значение по разным причинам: от неудовлетворительных результатов стандартизированных тестов как на национальном (planea), так и на международном (Pisa) уровнях, которые определяют качество обучения, до уровня классной комнаты, где часто отдается предпочтение освещению программы тематического контента, а не поощрение рассуждений как таковых. В свете этого настоящая статья направлена на определение различий в научных рассуждениях, которые происходят во время преподавания физики в средней школе с высоким уровнем маргинализации. Для этого использовался тест Лоусона «Научное рассуждение в классе», а в экспериментальной и контрольной группах были проведены предварительные и последующие тесты соответственно. В экспериментальной группе было реализовано дидактическое вмешательство, направленное на применение таких понятий, как величина, единица измерения и переменная, поскольку преподаватели сообщили, что учащимся было трудно соотносить эти понятия, что приводило к путанице при выполнении упражнений. Напротив, занятие проводилось как обычно для контрольной группы. Однако результаты после тестирования обеих групп показывают, что между экспериментальной и контрольной группами не было статистически значимых различий. Несмотря на эти результаты, было обнаружено, что в течение первой части курса физики студенты продолжают использовать эмпирико-индуктивные рассуждения. Поэтому разработка мероприятий, которые облегчат переход от гипотетического рассуждения к дедуктивному, может стать проблемой при обучении студентов в аналогичных обстоятельствах.

Ключевые слова: научное мышление, старшеклассники, физика, высокая маргинализация, стратегии преподавания-обучения.

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