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SCIENTIFIC REASONING LEVELS IN PHYSICS EDUCATION: CHALLENGES AND OPPORTUNITIES

Abstract

Scientific reasoning plays a fundamental role in high school science education, as it enables students to develop the cognitive skills necessary for understanding and analyzing scientific phenomena. In disciplines such as Physics, fostering this type of reasoning is essential for effective teaching and learning processes. This study aimed to assess the scientific reasoning levels of high school students in the central zone of Zapopan at the University of Guadalajara. To achieve this, the Scientific Reasoning Test in the Classroom was administered to a sample of 351 second-semester students from the afternoon shift across six high schools affiliated with the institution. The findings revealed no significant differences (p = 0.667, $p < 0.05$) in scientific reasoning levels among 336 students, indicating a predominant reliance on empirical-inductive reasoning. These results underscore the need to integrate classroom strategies and activities that cultivate combinatorial and correlational thinking, as well as the ability to control variables, to promote higher levels of scientific reasoning.

Keywords: Scientific reasoning, high school students, empirical-inductive reasoning, teaching-learning, cognitive skills, control of variables, combinatorial thinking

Introduction

The interest in studying scientific reasoning in high school students arises from the concerning results observed in standardized tests such as PISA or PLANEA, which reveal insufficient development levels in this cognitive process [1]. Given that the high school stage encompasses key adolescent ages (14-18 years), scientific reasoning becomes crucial for maturational development. This type of reasoning involves an abstract thinking activity [2]. This essential skill allows students to conceptualize or understand intangible ideas and situations [3], such as the physical phenomena addressed in the Physics Learning Unit (PLU) curriculum.

Furthermore, the interest in diagnosing scientific reasoning is justified because this process is fundamental to the development of intelligence [3-46]. During adolescence, scientific reasoning is crucial for achieving equilibrium in the formal thought stage, where young people must be able to make deductions, draw conclusions, and formulate hypotheses without relying on direct observation [4]. This implies that, in formal thought, students can work with concepts they have not directly experienced [5].

The above suggests that in physics education, fostering meaningful learning among students would be more effective if the development of formal thinking characteristics were promoted beforehand. In this way, students could understand complex phenomena, such as electromagnetic interactions, without direct experimentation, as formal thinking, nurtured by the metacognitive system [6], enables reflection on one’s thoughts and behaviors. To achieve this level of understanding, it is essential to engage students from the outset in activities that stimulate their formal and metacognitive thinking.

It is also essential to consider the context in learning development and scientific reasoning. Environmental factors can either facilitate or hinder the learning process. For example, some studies have shown that individuals from disadvantaged backgrounds tend to achieve lower results on intelligence and academic performance tests compared to their peers without these disadvantages [7]. Differences in cognitive development between these social groups are often more pronounced than differences in physical health [8].

However, given the diversity of schools included in this study's sample, only a general overview of the students and schools within the High School Education System (SEMS) is considered. For instance, it was observed that classes are taught in both morning and afternoon shifts and that a significant portion of the student population comes from households earning between two and five minimum wages.

Additionally, the graduate profile of SEMS high schools emphasizes the importance of fostering essential skills and competencies for students' holistic growth [9]. Among these, logical-mathematical reasoning and scientific thinking stand out, as they not only contribute to problem-solving but also to a deeper understanding of the world [10]. These competencies enable high school graduates to tackle challenges systematically and structuredly, identifying patterns, formulating hypotheses, and rigorously evaluating evidence [11].

Nevertheless, while the influence of context on the study's results is acknowledged, the primary focus of this research is not on the contextual variable. This is due to the inherent limitations of the quantitative methodology employed, which does not allow for an in-depth exploration of environmental particularities. Thus, although context may influence reasoning processes, this study focuses on analyzing these processes from a broader perspective, without considering the specific contextual details of each student.

Therefore, this research aims to identify differences in scientific reasoning among high schools within SEMS in the central zone of Zapopan, specifically in the following schools: 7, 8, 10, 15, 19, and 21. To achieve this, a diagnostic assessment was conducted using a scientific reasoning test in the classroom. This instrument classifies reasoning into three main types: empirical-inductive, transitional from empirical-inductive to hypothetical-deductive, and hypothetical-deductive [12]. Based on this diagnosis, it was possible to evaluate and analyze differences in students' scientific reasoning across the selected high schools.

The research was conducted in two stages: the application of the scientific reasoning instrument to students and the diagnostic evaluation of the results obtained. Subsequently, a statistical analysis was performed to identify significant variations between the different schools. The purpose of this analysis is to determine students' levels of scientific reasoning and consider these findings when designing teaching and learning strategies. In this way, the goal is to prioritize the development of cognitive processes, such as scientific reasoning, rather than focusing solely on the thematic content of the Physics Learning Unit.

This study provides insights into one of the potential causes of unsatisfactory performance in standardized tests, such as PISA or PLANEA, by offering a diagnosis of students' scientific reasoning levels. This diagnosis enables teachers to adapt classroom activities, facilitating an approach that progresses from reasoning based on concrete objects to the understanding of abstract (verbal) representations of phenomena [13]. In other words, the aim is to guide students from a reasoning stage that requires the physical visualization of phenomena to generate hypotheses or conclusions, toward the development of more advanced formal thinking.

Physics, as part of a curricular axis that integrates different areas of knowledge, has a greater impact on learning when it is based on an initial cognitive diagnosis of students. This allows for an assessment of how the high school students' context influences the design of teaching-learning strategies that not only align with curricular plans and programs but also respond to the specific needs of their environment.

In summary, a cognitive diagnosis of scientific reasoning helps identify the extent to which these skills can be developed, thereby contributing to better learning acquisition. In this way, cognition becomes the starting point and is complemented by thematic content to improve educational quality.

General Objective:

1. To assess and compare the levels of scientific reasoning among high school students from different schools within the High School Education System (SEMS) in the central zone of

Zapopan, to identify patterns and differences that may inform the design of more effective teaching-learning strategies in physics education

Specific Objectives:

1. To diagnose students' scientific reasoning levels using a standardized assessment tool that classifies reasoning into empirical-inductive, transitional, and hypothetical-deductive types.
2. To analyze statistical differences in scientific reasoning levels among students from High Schools 7, 8, 10, 15, 19, and 21.
3. To provide insights that can support the design of pedagogical strategies aimed at enhancing scientific reasoning skills, thereby improving students' understanding of abstract scientific concepts in physics.

Research questions

1. What are the predominant levels of scientific reasoning (empirical-inductive, transitional, or hypothetical-deductive) among high school students in SEMS schools in Zapopan?
2. Are there statistically significant differences in scientific reasoning levels among students from different schools within SEMS?

Materials and research methods

This study employs a quantitative methodology, in which data were collected using a scientific reasoning assessment instrument administered to high school students (*n* = 351). The primary initial assumption is that there are no significant variations in scientific reasoning among students from the participating schools.

To conduct the research, permission was requested through the Coordination of High School No. 7, which contacted the administrators of each involved school. These administrators, in turn, directed us to their respective school coordinators to organize in-person visits for the instrument's application.

Assessment Instrument

The instrument used in this study is the Lawson Classroom Test of Scientific Reasoning, which has been validated and translated into Spanish in Mexico by Dr. Genaro Zavala and the Innovation and Research Group in Physics Education at the Technological Institute of Monterrey, Campus Monterrey. This test has high reliability (Cronbach's alpha of 0.78) and is designed for use with high school and middle school students. It allows for the analysis of the following categories:

1. Physical concepts
2. Proportions
3. Understanding of variables
4. Probability
5. Observation and hypothetical-deductive skills

These categories indicate the level of reasoning based on the skills demonstrated, as shown in Table 1.

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

Thematic	Skills	Items
Conservation of physical quantities	The student applies the reasoning of conservation of perceptible objects and their properties	1, 2, 3, 4
Proportionality thinking	The student recognizes and interprets the relationships of figures by 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 in which they control for 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 that certain assumptions will remain true in the design of an experiment	15, 16, 17, 18
Combinatorial and Correlational Thinking	The student considers experimental combinations, although some are not realized 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 note that some items have a transitory character towards other levels of thinking, as in the case of items 11 to 14, where probabilistic thinking is included, and items 23 and 24, in which hypothetical-deductive reasoning is reached.		

Reasoning Levels Evaluated

This test aims to assess the following types of reasoning:

1. Empirical-inductive reasoning (0-4 pairs): Characterized by students' difficulty in testing hypotheses based on observable causal agents. While they may engage in mental experiments, their thinking remains concrete, meaning they relate to tangible objects but struggle with abstract or verbalized concepts.
2. Transitional reasoning between empirical-inductive and hypothetical-deductive (5-8 pairs): Concrete thinking is consolidated, but the validation of verbal hypotheses remains inconsistent.
3. Hypothetical-deductive reasoning (9-11 pairs + two independent responses): Students can test hypotheses based on both observed and unobserved phenomena. Their thinking is formal, meaning they can formulate and test hypotheses.

The test consists of 24 multiple-choice items, organized into 11 pairs, where each pair is designed to evaluate response consistency. A response is considered correct only if both items in the pair are correct. Items 23 and 24 are independently assessed and do not require a pair to be considered accurate.

Inclusion Criteria

To be eligible for participation, students had to meet the following criteria:

1. Be between 15 and 18 years old.
2. Be an active student at one of the SEMS high schools in central Zapopan (High Schools 7, 8, 10, 15, 19, 21).
3. Be enrolled in the second semester.
4. Be from the afternoon shift of the 2023B academic calendar.
5. Have previously taken a physics course.

Exclusion Criteria

Students were excluded if they:

1. Did not complete the entire questionnaire.
2. We are repeating the Physics Learning Subject.

Testing Conditions

The following conditions were observed during the instrument's application:

1. Electronic devices were not allowed during the test.
2. Students were only allowed to use a pencil to answer.
3. The maximum duration of the test was 30 minutes.

Table 2 presents the sample of students from each high school.

Table 2 - Obtaining the proportional samples for the application of the instrument

High school	Student population*	Number of students in the generation**	Proportional share***
7	5373	985	106
8	3,309	551	61
10	4,696	782	68
15	3,401	566	68
19	2,736	456	38
21	436	72	10

Note: The number of samples is proportional to the number of students.

*The total student population took the 2022 Rectory General Statistical Report as a reference, so the figures for 2023 may have changed.

**From the above, the number of students per generation was obtained by dividing the total number of students by 6 to obtain an approximate value. **

***Taking into account the above, the proportional part would result in 10% of the generation; however, some quantities could vary due to the actual sample obtained *in situ*.

Sample Considerations

The instrument evaluates three levels of reasoning:

1. Empirical-inductive reasoning
2. Transitional reasoning (empirical-inductive to hypothetical-deductive)
3. Hypothetical-deductive reasoning

Since the instrument was applied in six different schools, sample proportions varied, deviating from a 10% representativeness relative to the general student population (see Table 2). These variations resulted from fieldwork factors, such as fluctuations in student numbers, class size, and attendance rates. However, these differences do not affect the statistical analysis, as a non-parametric statistical test was used, which is appropriate for handling diverse sample sizes.

Results and its discussion

It is essential to note that the primary objective of this research was to assess the level of scientific reasoning among students from various high schools in the central zone of Zapopan within the SEMS. Specifically, this diagnosis focuses on students who have previously completed the Physics I course and are regular second-semester students continuing with the Physics II course.

In addition to identifying the students' overall level of scientific reasoning, this research also aims to pinpoint thematic areas within physics that could be emphasized in courses to promote cognitive development in scientific reasoning.

This section presents the results obtained through the application of the scientific reasoning test in the classroom. These results were analyzed using a statistical variance test to determine whether there is a significant difference supporting the stated hypothesis.

The diagnostic process began with the application of the Shapiro-Wilk normality test in SPSS, which is used to determine whether a parametric or non-parametric statistical test should be performed. In this case, the test statistic value W ($p = 0.000 < 0.05$) indicated that the data do not follow a normal distribution.

As a result, the Kruskal-Wallis test was chosen, as it does not require samples of the same size to determine whether there are significant differences in the medians of these six independent groups concerning the level of scientific reasoning achieved.

The assumptions considered for the diagnosis of scientific reasoning in the schools were as follows:

1. H_0 = There are no significant differences in the results of the scientific reasoning test in the classroom among student groups from different high schools.
2. H_1 = There are significant differences in the results of the scientific reasoning test in the classroom among student groups from different high schools.

After analyzing the results, the null hypothesis was accepted ($p = 0.667 > 0.05$), suggesting that there are no significant differences in scientific reasoning among student groups from different schools.

However, in addition to comparing results between different schools, possible significant differences within student groups in each school were also explored. To conduct this additional analysis, the following assumptions were considered:

1. H_0 = There are no significant differences in the results of the scientific reasoning test in the classroom among student groups from different high schools.
2. H_1 = There are significant differences in the results of the scientific reasoning test in the classroom among student groups from different high schools.

The statistical analysis revealed that the alternative hypothesis was accepted ($p = 0.020 < 0.05$), indicating that at least one group significantly differs from the others in terms of scientific reasoning level.

Since a significant difference among groups has been identified, it is essential to perform post hoc tests to determine which specific groups differ from each other. These tests help to understand better the nature of the observed differences and control Type I error, which can occur in the p-value when comparing multiple samples. For this reason, the Bonferroni test was selected, as it compares all samples and adjusts p-values according to the number of comparisons made, which in this case involves six high schools, as shown in Table 3.

Table 3 - Bonferroni test for P-value adjustment

			Level of reasoning		Total
			1	2	
High School	7	Recount	103_a	3_a	106
		Fixed residue	,87938	-,87938	
	8	Recount	$58,00000_a$	$3,00000_a$	61
		Fixed residue	-,27381	,27381	
	10	Recount	$62,00000_a$	$6,00000_b$	68
		Fixed residue	-2,06595	2,06595	
	15	Recount	$68,00000_a$	$,00000_a$	68
		Fixed residue	1,94040	-1,94040	
	19	Recount	$37,00000_a$	$1,00000_a$	38
		Fixed residue	,52993	-,52993	
	21	Recount	$8,00000_a$	$2,00000_b$	10
		Fixed residue	-2,49460	2,49460	
Total		Recount	336,00000	15,00000	351

Note: From the adjustment of the *p*-value, it is possible to identify that High Schools 10 and 21 have significant differences compared to the others.

According to the results of the Kruskal-Wallis test, no significant differences were found in the levels of scientific reasoning among the student groups from high schools 7, 8, 10, 15, 19, and 21. This suggests that, in general, students from these schools do not exhibit significant variations in their scientific reasoning abilities. However, a more detailed analysis of individual results within each school revealed significant differences between some student groups and those of other high schools. In particular, the post hoc test highlighted that High Schools 10 and 21 show significant differences when compared to the other schools included in the study.

After examining the results, the next step was to interpret them to address the research question. This analysis not only contributes to the field of physics but also offers relevant considerations for teaching this course. By reviewing the items on the test that received the highest and lowest number of correct answers, functional patterns were identified to adjust educational strategies based on the students' needs. Table 4 presents the total number of students who correctly answered each item.

Table 4 - Frequency of correct reagents per plant

Thematic	HS7	HS8	HS10	HS15	HS19	HS21
Conservation of physical quantities	48	45	52	40	29	4
	27	22	20	10	10	4
Proportionality thinking	7	4	4	4	3	1
	3	0	3	1	0	0
Identification and control of variables	7	6	5	3	5	0
	3	3	2	4	1	1
	7	5	1	2	1	1
Probabilistic thinking	8	10	10	8	2	0
	7	1	3	8	3	1
Combinatorial and Correlational Thinking	12	7	6	6	0	1
	5	3	3	8	0	2
	35	18	17	18	17	4
	39	24	25	28	17	2
Note: It is important to remember that the items are considered correct as long as they are even.						

For example, if items 1 and 2 are both correct, then they are considered so. This does not apply to the last two items, which are scored independently.

In Table 4, the frequency with which students from each school correctly answered the pairs of items in the instrument, based on the topics addressed, is presented. This analysis revealed that there is no normal distribution in the responses ($p = 0.000 < 0.05$), which led to the application of the non-parametric Kruskal-Wallis test. One of the findings is that, for the first pair of items related to the conservation of physical quantities, no significant differences were found between students from the different schools ($p = 0.000 < 0.05$), contrary to the other items.

This suggests that students have developed reasoning that allows them to correctly apply the concept of conservation to perceivable objects and their properties. For example, in the context of high school physics, particularly in the topic of free fall, most students demonstrated an understanding that when a ball is thrown from a certain height, it follows *uniformly accelerated linear motion* due to the acceleration of gravity.

However, dDespite this understanding, there are other, more complex variables that students did not adequately consider in their responses. For example, factors such as air resistance, the proportional relationship between position and time, and the ball's mass were not integrated into their reasoning for a more precise answer.

Finally, in Graphs 1 and 2, it is noticeable that the majority of students (336) from the evaluated high schools are at the empirical-inductive reasoning level (Level 1). This indicates that students are unable to formulate and test hypotheses based on observable causal agents, but they can perform mental experiments. This reflects concrete thinking, where students relate directly to specific objects and data but not to verbalized hypotheses or abstract concepts. An example of this type of reasoning can be seen in problems involving *uniform rectilinear motion*. Here, a Level 1 student might correctly handle the basic variables of the exercise, such as time, distance, and speed, because they are dealing with specific data and direct observations of a moving object. However, due to the nature of their thinking, it is common for these students to overlook or fail to consider more abstract or complex aspects, such as unit conversions or variations in speed.

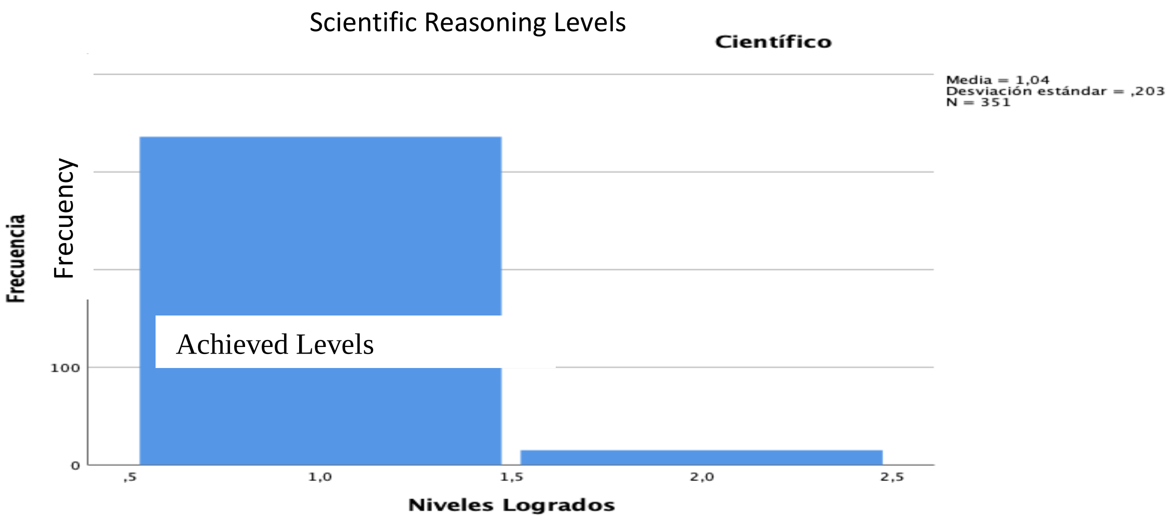

Figure 1 - Level of scientific reasoning achieved by the entire sample of students

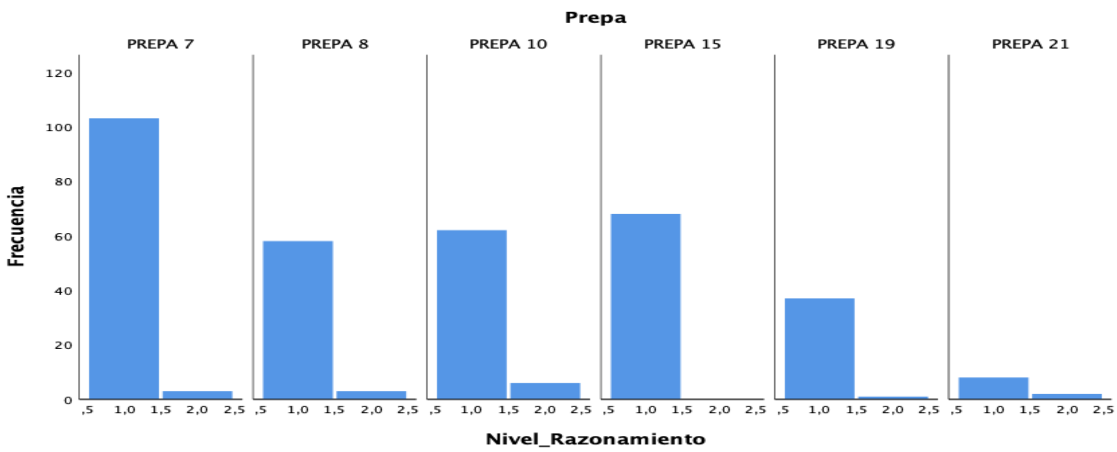

Figure 2 - The levels of scientific reasoning achieved by school

Conclusion

In this research, conducted in high schools of the University of Guadalajara's central zone in Zapopan, it was observed that most students evaluated through the classroom scientific reasoning test are at the empirical-inductive reasoning level, characterized by concrete thinking. This means that students can perform mental experiments and work with specific objects. However, they face difficulties when testing their hypotheses, as these are often based solely on observable causal factors.

For example, in solving *uniform rectilinear motion* problems, students can demonstrate strong skills when working with concrete and essential data, such as the variables of speed, time, and distance. Since these variables are observable in this type of motion, students can measure them without needing to infer other factors involved.

Nevertheless, to improve and elevate the reasoning level of high school students in the field of physics towards a hypothetical-deductive reasoning level [14], which is the expected level in this disciplinary field, it is necessary to propose and integrate activities holistically that align with the context and the students' familiarity with their environment to develop skills [15]. As mentioned, certain contextual elements, such as marginalization, can negatively affect the cognitive processes of students [7-77].

In this sense, although the focus of this research did not center on contextual considerations, it is necessary to recognize that these are fundamental in promoting more advanced scientific reasoning. This is particularly relevant for those students who obtained low scores after the application of the instrument, in areas such as proportional thinking, identification and control of variables, probabilistic thinking, and combinatorial and correlational thinking.

For example, practical experimental exercises focused on kinematics could be designed, allowing students to explore and demonstrate the proportional relationships between physical variables tangibly. In the case of free fall, students could be allowed to control variables such as the height from which an object is dropped and measure the time it takes to reach the ground. By making these measurements and comparing the results, students can understand how altitude affects the fall time, thus promoting the development of variable control-oriented thinking, as well as combinatorial and correlational thinking.

Furthermore, in the context of *uniform rectilinear motion*, students can advance their ability to identify and control variables in more complex situations, such as adjusting the speed of an object to ensure its final position matches a specific location. This approach not only reinforces the understanding that manipulating one variable affects the others but also teaches that these variables are interrelated through a mathematical formula.

By carrying out these exercises, the student recognizes the direct influence of speed on the final position and also understands how this relationship is structured mathematically. This type of practice strengthens the student's ability to solve more challenging physics problems, as it forces them to consider how variables interact within a system.

Additionally, technological tools, such as specialized physics teaching software (like PhET Interactive Simulations), create a favorable environment for examining proportional relationships and transformations of variables involved in various physics topics within virtual environments.

In this way, the student acquires more skills that transcend concrete thinking, as they consider and manipulate additional variables and constantly review their effects and implications in their everyday life through formulas, fostering more hypothetical-deductive reasoning. This type of reasoning enables the student not only to contrast prior knowledge with new learning but also to formulate and verify new assumptions.

Finally, although currently, young students in the high schools of the central zone of Zapopan at the University of Guadalajara are at the empirical-inductive reasoning level, the incorporation of these practices in the Physics course would not only improve the understanding of more complex concepts but also prepare students to apply thinking skills in a variety of contexts and subjects. This would promote an integral education in physics, positively impacting the student's cognitive development by encouraging the strengthening of critical reasoning skills, rather than being limited to memorization.

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ФИЗИКАҒА ОҚЫТУДАҒЫ ҒЫЛЫМИ ОЙЛАУ ДЕҢГЕЙЛЕРІ: ҚИЫНДЫҚТАР МЕН МҮМКІНДІКТЕР

Аңдатпа

Ғылыми ойлау орта мектептегі жаратылыстану пәндерін оқытуда маңызды рөл атқарады, өйткені ол оқушыларға ғылыми құбылыстарды түсіну және талдау үшін қажетті танымдық дағдыларды дамытуға мүмкіндік береді. Физика сияқты пәндерде бұл түрдегі пайымдауды қалыптастыру оқыту үдерісінде маңызды болып табылады. Бұл зерттеу Гвадалахара университетінің Запопан орталық аймағындағы орта мектеп оқушыларының ғылыми пайымдау деңгейлерін бағалауға бағытталған. Осы мақсатта осы оқу орнына қарасты алты орта мектептің күндізгі бөлімінің екінші семестрінде оқитын $n = 351$ оқушысына Сыныптағы ғылыми пайымдау тесті жүргізілді. Нәтижелер 336 оқушының ғылыми пайымдау деңгейлерінде айтарлықтай айырмашылық жоқ екенін көрсетті ($p = 0{,}667 > 0{,}05$), бұл оқушылардың эмпирикалық-индуктивті пайымдауға негізделетінін айқындады. Бұл нәтижелер сыныптағы стратегиялар мен іс-әрекеттерді енгізу қажеттілігін көрсетеді, олар комбинаторлық және корреляциялық ойлауды, сондай-ақ айнымалыларды бақылау қабілетін дамытып, ғылыми ойлаудың жоғары деңгейлеріне қол жеткізуге ықпал етеді.

Негізгі сөздер: Ғылыми ойлау, жоғары сынып оқушылары, эмпирико-индуктивті ойлау, оқыту мен оқу үдерісі, танымдық дағдылар, айнымалыларды бақылау, комбинаторлық ойлау

УРОВНИ НАУЧНОГО МЫШЛЕНИЯ В ОБУЧЕНИИ ФИЗИКЕ: ТРУДНОСТИ И ВОЗМОЖНОСТИ

Аннотация

Научное мышление играет фундаментальную роль в обучении естественным наукам в старшей школе, поскольку оно позволяет учащимся развивать когнитивные навыки, необходимые для понимания и анализа научных явлений. В таких дисциплинах, как физика, развитие этого типа мышления имеет важное значение для учебного процесса. Цель данного исследования заключалась в оценке уровней научного мышления у учащихся старших классов центральной зоны Сапопана в Университете Гвадалахары. Для этого был проведен Тест на научное мышление в классе среди выборки из $n = 351$ учащегося второго семестра дневного отделения, обучающихся в шести старших школах, относящихся к данному учреждению. Результаты не выявили значимых различий ($p = 0{,}667 > 0{,}05$) в уровнях научного мышления среди 336 учащихся, что указывает на преобладание эмпирико-индуктивного мышления. Эти результаты подчеркивают необходимость интеграции в учебный процесс стратегий и видов деятельности, способствующих развитию

комбинаторного и корреляционного мышления, а также способности контролировать переменные, что способствует достижению более высокого уровня научного мышления.

Ключевые слова: Научное мышление, ученики старших классов, эмпирико-индуктивное мышление, процесс преподавания и обучения, когнитивные навыки, контроль переменных, комбинаторное мышление

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