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Scientific skills in the physics learning process. A pilot study in secondary education

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Abstract. The objective of this article is to identify the competencies of students studying the subject of natural sciences - physics at the high school level, in accordance with the curricular guidelines of the Ministerio de Educación Nacional de Colombia. Methodologically, it was based on a quantitative design, using a student perception survey. The results show, from the students' point of view, that the teachers have knowledge of their discipline, but the follow-up and improvement of their pedagogical practice at the curricular, didactic and evaluation levels is questioned. It is questioned that the processes related to research and the scientific method are not linked to their classes, so that the students' level of competences is not the ideal one according to what is established from the curricular orientations at a national level.

1. Introduction

Today, science education is intended to be a means of acquiring knowledge and developing skills and attitudes that enable students to function in an increasingly scientific and technological social group. Increasingly, scientific, and technological and scientific skills enable them to generate and acquire knowledge, which improves and qualifies them within society.

In the international context, the Programme for International Student Assessment (PISA) test is an internationally developed standard assessment promoted by the Organization for Economic Co-operation and Development (OECD) and applied to 15-year-old students in OECD member countries. The objective of this project is to measure and compare students' competencies not only in terms of mastery of the educational curriculum, but also in terms of relevant knowledge and skills necessary for adult life in three areas: reading, mathematics and science [1]. Research shows that there is a disparity between what is proposed by the ministry and what is achieved in terms of competencies (including scientific ones) based on teachers' curricular designs, which affects the formation of these competencies in students [2,3].

In the Colombian context, the Ministerio de Educación Nacional (Mineducación) [4], presented a guide on basic standards of competencies in the natural sciences, which sought to redesign the curricula in educational institutions to make it possible to improve student achievement tests. However, there is still a low level of academic performance on the SABER tests, Instituto Colombiano para el Fomento de la Educación Superior (ICFES), specifically in the area of natural sciences, since the implementation of curricular orientations at the national level and the achievement of this goal are not met, hence the need to identify the scientific competencies that secondary education students possess in the context under study. As it corresponds to a pilot study, the purpose of this one has not been to generalize the relation between scientific competences with the physics learning process, but to have an approximation (partial results) to determine with more precision the relation between these variables in a later study



that includes a greater number of students of all the careers of the different educational institutions, in order to establish a triangulation between the antecedents and the theoretical positions that sustain it, to give account of the logics that explain how the scientific competences of the students affect the physics learning process.

1.1. Scientific skills and the teaching and learning process

The teaching of science has been characterized by being very rigid, which generates fear and failures in the learning of science in students, however, science and technology have contributed to improve the understanding of natural phenomena that occur, as well as the quality of life of people, thanks to their discoveries, contributions and applications. That is why today's society needs a scientific education that forms committed professionals to act and make decisions on the demands and problems that human communities go through [5].

The PISA programme, defines scientific competencies as the ability to use scientific knowledge to identify problems, acquire new knowledge, explain scientific phenomena and draw evidence-based conclusions on science-related issues [1]; on the other hand on the other hand, they are considered to be enriching since students manage to demonstrate in a non-reproductive way that they have learned science and that they are becoming aware of its value [6]. The scientific dimensions in the framework for the assessment of science proposed by the PISA 2006 project characterize scientific competence from four interrelated aspects: contexts; knowledge, skills, and attitudes [7]:

- Knowledge: Refers to knowledge of the natural world and science that refers to scientific research and explanations.
- Skills: understood as the identification of scientific issues, the explanation of scientific phenomena and the interpretation and use of scientific evidence.
- Attitudes: are focused on valuing interest in science, a favourable attitude towards scientific research and responsibility towards sustainable development.
- Context: areas in which the scientific knowledge, skills and attitudes developed are used.

1.2. Scientific skills and the teaching and learning process

For the Mineducación, Science standards seek to ensure that students develop the scientific skills and attitudes required to explore phenomena and to solve problems. This is achieved through the grades and educational levels. For the area of natural sciences and environmental education, it is done from the first to the ninth grade. In Middle Education, which includes the tenth and eleventh grades, the formation of scientific competencies is done from the subjects of physics and chemistry [4]. For its part, the ICFES the scientific competencies that students must develop in the classroom are [8]:

- Identify. Ability to recognize and differentiate relevant phenomena, representations, and questions about these phenomena.
- Investigate. Ability to pose appropriate questions and procedures and to seek, select, organize, and interpret relevant information to answer those questions.
- Explain. Ability to construct and understand arguments, representations or models that give reason for phenomena.
- Communicate. Ability to listen, put forward points of view and share knowledge.
- Teamwork. Ability to interact productively by assuming commitments.
- Willingness to accept the open, partial, and changing nature of knowledge and willingness to recognize the social dimension of knowledge and to assume it responsibly.

The first three competencies (identify, investigate and explain) are the basis or foundation of the evaluations applied in the SABER 5, 9, and 11 Tests carried out by ICFES. For the SABER 11 tests, until 2014, in the Physics test the competencies related to the attributes, interactions and dynamics of the physical systems were evaluated [9]. Today, in the physics test, the understanding of concepts, principles, and theories to describe the physical world with which the human being interacts is evaluated [10]. However, the ICFES establishes that interpreting, arguing and proposing are basic general

competencies that can be evaluated in consonance and complementarity with what is stipulated in the basic standards of competence [10]; interpretation makes it possible to appropriate representations of the world and, in general, of cultural heritage; arguing makes it possible to build explanations and establish agreements and, finally, proposing makes it possible to build new meanings and suggest actions assumed with responsibility, which implies foreseeing their possible consequences.

2. Method

2.1. Approach and design

Mixed approach, at the qualitative level, we sought to describe and interpret some elements related to scientific competencies in students. At a quantitative level, a questionnaire was developed to know and try to understand the development of scientific competences. We used the phenomenological type of study, which allows us to analyse the development of scientific skills in students. The elements used in the analysis correspond to the scientific competences, whose dimensions are knowledge, skills, attitudes, and context (transversal to the previous 3).

2.2. Population and sample

The educational institution where the research was conducted is a public, daytime institution, and belongs to the department of Norte de Santander, Colombia. The name is not disclosed due to ethical principles. The 10th grade group with 21 students, and the 11th grade group with 19 students, both with average ages in the range of 15 to 18 years. The selection was intentional, not random, since we sought to have students outside of secondary education, since they have had a more profound teaching-learning process in the sciences, and therefore have developed greater scientific skills in comparison with basic education.

2.3. Instruments

Survey through a questionnaire constituted in 2 parts, the first one of general data and the second one with 11 closed questions (see Table 1), with answer options, that evaluate the knowledge, procedures and attitudes of Physics, focused in determining the scientific competences that the students had. Some of the questions that were selected and restructured were taken from the PISA [1], SABER [10] tests and Alvarado & others [11]. The questionnaire was validated by 3 professional experts in Physics. This questionnaire was applied as a pilot test to a group of 11th grade students from another educational institution as part of its validation, from which the necessary adjustments were made before its application to the population under study.

3. Results and discussion

Based on the results obtained, the data have been separated according to the three dimensions that make up scientific competencies (knowledge, skills, and attitudes), to facilitate their study. It should be noted that the questionnaires were applied to 2 groups; however, the results are reported and combined in the same table.

3.1. Knowledge of scientific skills in physics

This dimension was evaluated through questions related to conceptual (from science) and procedural (about science) knowledge. The former refers to the basic concepts, principles and laws of physics, the latter are related to the processes that allow the description and understanding of natural phenomena through scientific research and explanation. The Table 1 to Table 3 present the frequency of student responses, which have been categorized as follows: correct response, incorrect response, and no response. Conceptual and procedural knowledge in physics. For scientific competence in physics, Table 1 presents the responses given by students regarding the knowledge of different electromagnetic phenomena and of wave nature (optics and waves) according to the competency standards for secondary education.

Table 1 shows that most of the students manage to answer correctly the questions that evaluate the conceptual knowledge, however, in the procedural knowledge, they did not have a good performance in the subjects of electromagnetism and optics and waves. Most of the students presented a good development of conceptual knowledge related to electromagnetic and optical phenomena, however, the same does not happen for the procedural knowledge, evidencing a deficiency in this type of knowledge.

Table 1. Distribution of students' frequencies in terms of knowledge of physics.

	Question	Frequency		
		Correct	Incorrect	No response
Conceptual	2	18	21	1
	3	32	7	1
	4	33	5	2
	5	35	4	1
	7	17	22	1
	8	18	20	2
	11	25	12	3
Procedural	1	12	25	3
	6	2	36	2
	9	27	12	1
	10	3	33	4

About 63.8% of the students present a good development of conceptual knowledge related to electromagnetic and optical phenomena, however, the same does not happen for the procedural knowledge, since 65.0% evidence a deficiency in this type of knowledge, there is a difficulty for the description and interpretation of them in aspects related to scientific research; which can be a product of the traditional pedagogical mediation used by the teacher, whose goal in physics is the memoristic reproduction of concepts [12,13]. Therefore, this causes that, in some situations, the student is unable to understand, explain and interpret scientific situations.

According to the Mineducación, in certain educational models, the conceptual, procedural and attitudinal contents are sequenced in accordance with the basic standards of competence of each of the disciplinary areas and with the explicit concepts in the curriculum [14], instead of merely repeating or reproducing systems of concepts already developed. In accordance with this, the curricular guidelines in natural sciences and environmental education provide students with basic scientific training to acquire and generate scientific knowledge. This implies developing the capacity to investigate to construct knowledge (conceptual and procedural) on scientific themes and problems. The development of thinking of this nature allows access to science, technology, and research [15], which makes it possible to systematically address problems or problematic situations of daily life using various methods and sources of scientific knowledge.

But the fact that there are curricular orientations to support the curricula does not guarantee that this is being done in the classrooms, as is evident from the results obtained. In addition, students tend to repeat the content, without understanding or establishing links between scientific knowledge and the needs of the everyday world. This leads to a stimulation of rote and mechanical learning that hinders the development of procedural knowledge related to scientific research [12].

3.2. Capacities of scientific competences in physics

This dimension is assessed through questions related to the ability to identify scientific issues, explain phenomena scientifically and use scientific evidence. Table 2 shows that the ability to identify scientific questions, the highest percentages tend towards incorrect answers, so it could be said that these skills are not developed in the population under study. In addition to procedural knowledge, it is necessary for the development of this ability that students recognize situations that can be investigated scientifically, as well as the characteristic features of an investigation such as: the selection of experimental designs and contrasting conjectures, the identification of characteristics and data analysis.

Table 2. Frequency table for scientific skills in physics.

Capacity	Answer	#	%
Identify scientific issues	Correct	8	20.0
	Incorrect	30	75.0
	No response	2	5.0
Explain phenomena scientifically	Correct	24	60.0
	Incorrect	15	37.5
	No response	1	2.5
Use scientific proof	Correct	28	70.0
	Incorrect	11	27.5
	No response	0	2.5

Similarly, the 60% of students show a better level of achievement in developing the ability to explain phenomena scientifically, since most were able to correctly answer the questions that evaluate this ability. This means that the students are able to interpret the phenomena in a scientific way, as well as recognize the descriptions and explanations that allow them to understand the situation presented in each case, so that they should resort to their knowledge in physics. Finally, it can be observed that the ability to use scientific tests obtained a higher percentage of correct answers (70%). It can be inferred that differences in students' development of skills are influenced by their understanding of knowledge of science and about science relevant to the unit assessed in each scientific competence. This could be conditioned by the inclusion of these in the curriculum planning of teachers. If we assume that the pedagogical mediation of teachers is traditional, we could say that this is one of the reasons why certain skills are not developed [12].

3.3. Attitudes of scientific skills in physics

This dimension is evaluated through questions linked to students' interest in scientific issues in Physics. Different questions were asked to evaluate the students' interest in expanding their knowledge in the subjects of electromagnetism and wave-like nature, both related to everyday life. The results are shown in Table 3.

Table 3 shows that most students are interested in knowing and understanding the different physical phenomena, presenting an average percentage of 65.0 especially for those topics related to current technologies such as cell phone operation. However, the theme related to the use of energy forms for sustainable development is the lowest with 45%.

Table 3. Percentage of students in relation to attitude and interest in science.

Items	Interested		Little interested		Not interested	
	f	%	f	%	f	%
Learn about the use of energy forms for sustainable development.	16	40.0	18	45.0	6	15.0
Learn about the origin of the rainbow, the colour of the sky and ultrasound.	26	65.0	9	22.5	5	12.5
Learn about the formation of rays and how the electric guitar works.	28	70.0	8	20.0	4	10.0
Learn about the Northern lights, the Earth's magnetic field and the functioning of cell phones.	28	70.0	9	22.5	3	7.5
Understand the physical principles of today's technologies.	32	80.0	5	12.5	3	7.5
Average		65.0		24.5		10.5%

Therefore, it is observed that in general the students do show interest in scientific matters, and it can even be inferred that this situation is influenced by the classroom environment presented by the teacher, since in his or her classes the teacher has an appropriation of the contents and a high motivation to teach them, which is fundamental for the development of attitudes on the part of the students in science

education [16]. Even though all students are immersed in the same classroom, some are not very interested or not interested at all in scientific issues, this could be due to the difficulty to understand scientific knowledge. It should be noted that the development of attitudes there are factors more specific to the nature of scientific knowledge that can account for the difficulty of their learning, such as: scientific thinking (they do not learn because they do not have the capacity for reflection and abstract reasoning) and conceptual change (they do not learn because they interpret the world from models other than those of science) [17].

Another factor that may be intervening in the development of attitudes is the traditional teaching model used by the teacher, which is limited to the reading, repetition and memorization of concepts [18], leaving aside the promotion of attitudes towards science, a situation that leads students to perceive science as difficult, irrelevant, unattractive and not connected to their interests and experiences [19,20].

4. Conclusion

In each dimension of the scientific competence, it could be inferred that for physics, most of the students presented a regular development of the studied scientific competence, which allows them in a basic way to identify, explain and use elements of scientific nature to give theoretical-practical solutions to problems faced in daily life related to electromagnetic and wave phenomena.

On the other hand, Physics teachers must incorporate and develop in their classes the different dimensions of scientific competences, seeking to use non-traditional pedagogical models that allow students to reach the appropriate level in these competences, although it is clear that the development of scientific competences cannot always be successfully promoted in all students, since there are personal, cognitive or contextual factors that have a predominant role in their development.

Finally, although the study carried out corresponds to a pilot test, it is clear that its purpose was not to generalize the relationship between scientific competences and the physics learning process, but to have partial results to determine more precisely the relationship between these variables in a later study that includes a greater number of students from different educational institutions at different educational levels, so that with these broader results a triangulation can be established between the background and the theoretical positions that support it, to account for the logics that explain how students' scientific competences affect the physics learning process.

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