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Scientific competencies around the study of physics in secondary school students. A review of knowledge

C A Hernández-Suárez[1], R Prada-Núñez[1], and W R Avendaño-Castro[1]
[1] Universidad Francisco de Paula Santander, San José de Cúcuta, Colombia

E-mail: cesaraugusto@ufps.edu.co

Abstract. This research seeks to analyze the degree of promotion and development of scientific competences based on the document Basic Standards of Competences in Natural Sciences proposed by the Ministerio de Educación Nacional, Colombia, specifically the competences associated with Physics. To this end, a twenty-item questionnaire is designed with a dichotomous response scale. The reliability analysis showed that the proposed scale had a good internal consistency regarding the measurement of scientific competences. The research adopts a quantitative descriptive approach based on the processing of data provided by 87 students from a private educational institution with emphasis on natural sciences in the city of San José de Cúcuta and enrolled between the ninth and eleventh grades. The results identify as a weakness in the teaching process, that teachers do not promote the use and articulation of diverse registers of semiotic representation of a set of data, a situation that limits the process of reasoning and resolution of problematic situations in everyday scenarios where the concepts of physics are present. Likewise, it was observed as a strength that teachers promote attitudinal skills in their students based on mutual respect, cooperative work and good communication. This type of research expands the knowledge that is available on the process of developing scientific competencies in the courses prior to entering higher education, so it is suggested to replicate this research process in students from different social contexts in order to improve the robustness of the questionnaire and provide valuable information to educational institutions on the design of improvement plans.

1. Introduction

In the mid-1990s, our country began to talk about competencies and how they should be linked to the school curriculum. After nine years of conversations on the subject, the Ministerio de Educación Nacional, Colombia, issued a guide document on basic standards of competencies in the natural sciences with the purpose of revising and redesigning curricula within educational institutions so that, accompanied by appropriate teaching strategies, teachers could develop and evaluate the performance of their students' competencies from the perspective of their teaching practice [1].

Several investigations have been developed in the national and international field, among which the works of [2-5] stand out, where it is evident that this teaching proposal was not being taken to the classroom, since teachers continued to privilege in the teaching of sciences the disciplinary contents in a clearly memoristic way and not what it should be, which is the development of competencies around the analysis of natural phenomena or daily situations that lead the student to generate possible explanations of what is happening. [3] states that this could be happening due to the lack of previous reflection on the nature of scientific knowledge, which becomes an obstacle for teachers to promote the development of these competencies.

The above, coupled with the fact that today's society is constantly changing at a very fast pace, requires the education system to respond to training expectations in order to make its graduates competent. Scientific competencies are of interest because students must develop certain basic skills in their school life such as the exploration and analysis of phenomena through observation which, added to the implementation of adequate resources for data collection, will allow them to explore the student's capacity to conjecture in search of possible alternative solutions, which will be validated only through action and interpretation of results.

These basic scientific skills, when accompanied by the knowledge of physics, will allow the future graduate to be competent in our society dominated by globalization. It is therefore expected that this research will make a diagnosis of the type of scientific competencies that teachers are promoting in the development of the chair, while proposing and validating a measurement instrument for this purpose.

2. Methodology

This research adopts a quantitative approach at the descriptive level, as the data were treated statistically to improve the process of characterizing the situation under study [6]. The research takes place at a specific time of the year and is carried out in the fourth period of 2019. The population was composed of all the students of the educational institution, totaling 188 students between the sixth and eleventh grades. For the selection of the sample members, a two-stage sampling was applied, in the first stage a non-probability sampling was applied with the convenience sampling technique (students from the ninth to the eleventh grade), and then a census was applied in the second stage.

The census is used as a data collection tool because it reaches many people and facilitates data processing [7]; based on the curriculum guidelines for the natural sciences, 20 items are written associated with the competencies that should be promoted in the development of the physics curriculum to obtain the Bachelor's degree. A dichotomous rating scale is used to evaluate each item formulated. The instrument is given to the students and they have approximately 20 minutes to fill it in, after being informed by the researchers; the data collected were digitized and processed with SPSS v23.

3. Results and discussion

The results obtained have been grouped into four topics: report of the demographic profile of the informants, weaknesses and strengths of the competences in physics promoted by the teachers, report of internal consistency of the instrument designed and factor analysis to identify the constructs identified in the opinion of the students.

3.1. Demographic profile

In the initial part of the instrument, some basic aspects of the informants are captured in order to provide the profile of the group: 37% are in ninth grade, 33% in tenth grade, and the remaining percentage are enrolled in eleventh grade; the age of students ranges from 14 to 17 years, with a predominance of 15 years in 56% of cases; women represent 65% of the sample; with respect to the socioeconomic stratum, 61% of the informants are concentrated in strata three and four, almost equally; and 58% say that if they like the subject of physics.

3.2. Analysis of scientific competences in physics

Table 1 shows in percentages the relationship of each of the scientific competences that were consulted with the students. It should be noted that, on average, 60% of the students say that these competences have been promoted and developed in the classroom by the teacher in charge of guiding the subject of physics. The informants highlight three competencies as the most strongly developed in their academic process:

- Relationship of mass, distance and gravitational attraction force between objects: This competence, typical of the comprehensive use of scientific knowledge, is directly related to the law of universal gravitation corresponding to classical physics and formulated by Isaac Newton,

where the gravitational interaction between bodies with mass is described. Newton deduced this law as the force of attraction between two bodies which is proportional to the product of their masses, but inversely proportional to the distance between them. It has been proven that many of them establish relationships between the variables involved in the movement that has its origin in Aristotelian ideas [8].

- I provide answers to my questions and compare them with those of other colleagues: This competence is associated with the attitudinal dimension of the student specifically with the dimensions of communication and teamwork, which are necessary in the process of forming future citizens who are respectful of differences and recognition of the social dimension of knowledge. This is consistent with the statement of [9] where we are invited to make our practice a conscious action and a transformative reflection.

- I identify constants and variables when performing an experiment: This competence is directly related to the aspects of the nature of physics, since the student must analyze the context where the event occurs in order to have the ability to differentiate information according to the nature of the event (constants or variables). In a complementary way, this competence is strongly associated with the methodological aspect, very close to the different steps of the scientific method, which in turn are directly related to the scientific competences of the investigation and explanation of phenomena [10].

Table 1. Percentage report of the competences against each answer option.

Ítems	Options	
	Yes	No
Comp_1. I ask specific questions based on observation of everyday events.	74%	26%
Comp_2. Formulates hypotheses, based on everyday knowledge or on topics seen in physics class.	66%	34%
Comp_3. I identify constants and variables when performing an experiment.	79%	21%
Comp_4. I propose a model to predict the results of my experiments.	64%	36%
Comp_5. I express measures of the characteristics of an object in the corresponding units.	66%	34%
Comp_6. I record my observations using diagrams, tables or graphs.	56%	44%
Comp_7. I use mathematics as a tool to model, analyze and present data.	66%	34%
Comp_8. I draw conclusions from the experiments I carry out, even if I do not obtain the expected results.	69%	31%
Comp_9. I propose answers to my questions and compare them with those of other colleagues.	82%	18%
Comp_10. I communicate the results using graphs, tables or algebraic equations.	35%	65%
Comp_11. I establish relationships between the different forces that act on bodies at rest or in uniform rectilinear movement.	69%	31%
Comp_12. I mathematically model the movement of everyday objects from the forces acting on them.	61%	39%
Comp_13. I explain the transformation of mechanical energy into thermal energy.	52%	48%
Comp_14. I establish relationships between stability and the center of mass of an object.	38%	62%
Comp_15. I establish relationships between conservation of linear momentum and momentum in systems of objects.	53%	47%
Comp_16. I explain the behavior of fluids in motion and at rest.	54%	46%
Comp_17. I relate mass, distance and gravitational attraction force between objects.	83%	17%
Comp_18. I establish relationships between the model of the gravitational field and the law of universal gravitation.	43%	57%
Comp_19. I establish relationships between the gravitational and electrostatic fields and between the electric and magnetic fields.	43%	57%
Comp_20. I relate voltage and current to the different elements of an electric circuit.	46%	54%
Average percentage	60%	40%

Likewise, as the three most positively developed competencies were identified, the students also recognize that in their academic formation process weaknesses have been evidenced that can be considered as opportunities for improvement.

- I communicate the results using graphs, tables or algebraic equations: This competence is associated with the capacity that the student must have in terms of communication of the knowledge generated, highlighting the strong link between mathematics and physics, since it is from the field of research of mathematical education where the works of [11-14] and that have been studied in the local context in the works of [15-19]. In this theory we begin to talk about the use and coherent articulation of diverse registers of semiotic representation given the abstract nature of many mathematical concepts.
- I establish relationships between stability and the center of mass of an object: This competence is associated with the disciplinary aspects of Physics, specifically with the use and understanding of scientific knowledge to give explanations to phenomena. This subject is a combination of basic topics in physics (force, mass, inertia) with mathematical concepts, specifically spatial thinking.
- I establish relationships between the gravitational field model and between the electric and magnetic fields: directly related to the disciplinary aspects of physics, as the previous competence, it is associated with the use and understanding of phenomena to understand scientific knowledge. From the disciplinary point of view, it is expected that the student will be able to establish differences and similarities between these three types of fields, such as whether they are conservative fields or not, whether their lines of force are open or closed, of attraction or repulsion, among many other characteristics.

3.3. Reliability report
To evaluate the reliability of the designed questionnaire and the internal consistency of the designed scale, Cronbach's Alpha statistician is used, which can be used both in questionnaires with Likert scale answer options and with dichotomous answer options, as in this case in which the SPSS internally makes use of the method known as KR-20 (Equation (1)) being a special case of Cronbach's Alfa [20].

$$r = \frac{k}{k-1}\left[1 - \frac{\sum_{i=1}^{k} p_i q_i}{\sigma_X^2}\right].$$ (1)

This statistic reports a value ranging from 0 to 1, assuming as an evaluation criterion that the closer it is to one, the better and more reliable it is. It can be verified that the value obtained for the Cronbach's Alpha statistic was 0.763, offering a good internal consistency [21], for the proposed scale with the 20 items considered. In addition, Table 2 allows us to verify that if any item is eliminated from the questionnaire, there is no improvement in the Cronbach's Alpha value, so the internal consistency of the proposed questionnaire is ratified.

Table 2. Cronbach's Alpha value if the element has been deleted.

Item	Statistical	Item	Statistical
Comp_1	0.644	Comp_11	0.644
Comp_2	0.636	Comp_12	0.630
Comp_3	0.622	Comp_13	0.646
Comp_4	0.659	Comp_14	0.677
Comp_5	0.719	Comp_15	0.647
Comp_6	0.642	Comp_16	0.709
Comp_7	0.706	Comp_17	0.654
Comp_8	0.651	Comp_18	0.643
Comp_9	0.664	Comp_19	0.669
Comp_10	0.671	Comp_20	0.666

3.4. Analysis factorial of the scientific competences on physics

Finally, the analysis of this set of data is closed with the Factorial Analysis understood as a statistical tool that allows to reduce the dimensionality of the variables from the analysis of the relations between them. It is stated that these relationships can be explained from a series of unobservable (latent) variables called factors, the number of factors being substantially lower than the number of items in the questionnaire, so it is expected to determine the latent variables that group scientific competences in Physics according to the students' opinions.

When the KMO test is performed, a value of 0.714 is obtained which is higher than 0.700 and is therefore a good measure as mentioned in [22]. With respect to the Bartlett Sphericity Test, a significance level of 0.000 is obtained, so it is concluded that with the data obtained there is goodness of fit [23]. This viability is corroborated by the values of the communality of each of the items, which present values between 0.500 and 0.920, with the exception of item 4, which states that I propose models to predict the results of my experiments, whose communality value is 0.482. When the factorial analysis is carried out, five factors or latent variables with a self-value greater than 1.5 are obtained and all together explain 66.43% of the total common variance. Table 3 shows a summary of the item grouping process and the latent variables obtained.

The factors obtained could be interpreted as the degree of familiarity or knowledge that students have about the various physics subjects that should be developed in the secondary school curriculum. From this point of view, the subjects associated with Mechanics are highlighted as strengths, in contrast to the subjects associated with fluid mechanics as those that are less worked on or those that present greater academic difficulties, as highlighted in [24] who highlight conceptual confusion between density and weight, associate pressure with the mass or force that a body has or attribute greater density to a fluid just because it has greater viscosity.

Table 3. Principal component analysis summary.

Factors	Variance explained	Grouped items	Loading
Laws of movement	22.3%	3,2,11,17	0.845, 0.768, 0.715, 0.651
Energy and amount of movement	15.6%	13,14,7,15,18	0.793, 0.720, -0.676, 0.567, 0.495
Mathematical modeling and magnetism	10.9%	19,4,5,12,1	0.769, 0.664, -0.613, 0.604, 0.545
Electrical energy and physical phenomena	9.8%	9,10,20,8	-0.677, 0.662, -0.638, 0.606
Semiotic and fluid representation records	7.9%	6,16	0.868, 0.568

4. Conclusions

At a cognitive level, the research allowed the identification of conceptual strengths of the surveyed students on basic issues such as the identification of constants or variables and their relationships in the environment of an experiment or a proposed problem. Favorable results are also reported around the themes corresponding to the part of Physics that analyses and studies bodies at rest or in movement.

The main weakness in the pedagogical practice of physics teachers in the analyzed institution is concentrated in the scarce connection that teachers establish between the different mathematical concepts and the solution of all kinds of physics problems, such as situations of movement in one or two dimensions, the laws of motion, energy, rotational movement and the law of gravity, electricity and magnetism, among many other concepts. At the attitudinal level, students recognize as a strength the promotion of cooperative work while generating spaces for both individual and group reasoning, leading students to present their arguments, to listen to those of their peers and to respect their differences.

As regards the proposed scale, it was found that it had good reliability indicators. Then, in order to continue evaluating it, we suggested its application in other educational contexts with different demographic and academic characteristics, given that the educational institution where it was applied has historically been characterized by good results in the Saber 11 tests in the area of natural sciences, given that this is its academic emphasis.

Finally, from the factorial analysis it was possible to obtain a possible hierarchy of the physical concepts promoted in the classroom, ratifying in the factors obtained what has already been mentioned:

possible disconnection of mathematical skills such as modelling, in the solution of physics problems; at the same time the themes of kinematics and dynamics are shown as strengths and those associated with fluids at rest or in movement remain as aspects to be strengthened.

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