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Using concept maps to understand mechanical physics concepts in high school students

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Using concept maps to understand mechanical physics concepts in high school students

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Abstract. The work presents a didactic proposal on the use of concept maps, for the understanding of mechanical physics. A didactic intervention based on Ausubel's theory was applied with the following activities: design, implementation and application of workshops based on real physical situations, where the elaboration of concept maps is the central axis, under the quantitative paradigm of interpretative level and action research method. The informants were 43 tenth grade students from a public educational institution located in the Department of Norte de Santander, Colombia. The results obtained showed that the use of concept maps as a didactic intervention favoured the significant learning of classical mechanics concepts. It was evident that the participating students achieved reflective analysis about the resolution of problems about the concepts of mechanics.

1. Introduction

the curricular guidelines [1] and the standards of competence [2] in natural sciences of the “Ministerio Nacional de Educación”, Colombia indicate that it is important to teach the theoretical and practical foundations of physics, starting from the movement of bodies and their interactions, from the concept of force, work and energy, all of this hand in hand with mathematical modelling, to explain problem situations immersed in nature. Therefore, there are reasons to think that students should have a very clear conceptual understanding of the laws and explanation of phenomena before entering algorithmic and algebraic procedures.

It is also known that students present difficulties when they must interpret from a physical model, transformations that are associated with everyday beliefs. It has been proven that it is very common for them to establish relationships between variables used in movement that have their origin in Aristotelian ideas. These ideas offer obstacles for the student during the construction of concepts associated with physics [3]. In addition, it is very common for students at different levels of training to face the solution of mechanics problems in an algebraic manner and out of context from the conceptual arguments of physics. It is not clear how the interactions between the bodies involved influence their rest or accelerated movement, this is an enormous obstacle to learning physics. Some background to be mentioned is related to the concepts of system and balance [4]. In the same sense, there are studies that describe a new pedagogical approach in mechanics [5], especially for free body diagrams [6].

On the other hand, concept mapping was chosen as a strategy to improve knowledge. For this choice, besides the characteristics of such strategy, it was taken into account that it is a resource that does not need special equipment or facilities, making it possible to use it in any type of school or classroom. An extensive and rigorous empirical validation confirms their effectiveness as instruments for improving the teaching/learning processes in the natural sciences [7-10], and especially in physics [11-14].

The previous background evidences research developed in the field of higher education but not in the pre-university levels such as basic and secondary education, which are the target population of this study. All this has motivated this paper, which consists of teaching concepts of classical mechanics under a constructivist approach and having as a core of concept map analysis. The achievements obtained benefit basic and secondary educational institutions insofar as it will allow the improvement of the teaching of physics in the different grades and additionally it can serve as a model to be applied in the other subjects Natural Sciences.

2. Theoretical framework

2.1. Conceptual foundations
Mechanics is the discipline of physics that describes and studies the positions of bodies and their variations in time according to their reciprocal interactions. Typical mechanical variables are positions and velocities, but also shapes and deformations of bodies, which are relative positions and position changes between points of a body. Mechanical actions are those that affect these types of variables, and they take place when one body, by means of the application of forces, pushes, moves or deforms another [15].

The theory that deals with forces and movements in the scale concerning daily life is the classical dynamics, whose three fundamental principles were enunciated by Newton, which are: (i) inertia. Everybody on which no forces act remains in its state of rest or uniform movement in a straight line. (ii) mass (Law of Impulse). If a force acts on the mass of a body, this receives an acceleration proportional to the direction of the force and of equal sense. (iii) action and reaction. Whenever one body exerts a force on another (action), the second body will exert a force of equal magnitude on the first one, intensity and direction, but in the opposite direction (reaction) [15].

2.2. Didactic foundations: concept maps and significant learning
A concept map is a technique that simultaneously represents a learning strategy, a method to capture the most significant aspects of a topic and a schematic resource to represent a set of conceptual meanings, included in a structure of propositions [16].

The advantages of using and applying concept maps have intrinsic characteristics, for knowledge representation: connectivity, relation types, categorization, concept hierarchization and the structural way of relating concepts to each other. In the same way, the ability to build or analyse a concept map on an argument or topic is closely related to abstract thinking skills. A weak capacity in the construction of maps often reflects the inability to express and understand at a logical-conceptual level [17]. In this order of ideas, the rational use of concept maps has its roots in the theories of information processing in learning and that refer to the principles of cognitive psychology. According to these theories [18]:

- Knowledge is organized in a propositional network.
- Connections are created between the propositions to form a network.
- The conceptual, propositional network of everyone is unique, because it is the result of the experiences of this person.
- The propositional network is not stable; as new information is learned; the network changes and new connections are formed between concepts and data.
- Propositions are typically described (in a simplified way) as connections with name or verbal phrase structures.
- Knowledge is retrieved or remembered because of an activation in the propositional network.

The background idea of concept maps derives from the theory of significant learning, since they can be very useful in facilitating learning in a formal teaching situation, in learning assessment and/or in the conceptual analysis of teaching matter [19]. Concept maps have their background in Ausubel's theory

[20,21], which occurs when the student intentionally tries to integrate new knowledge into existing knowledge. A student that manages to integrate new knowledge will have in his or her mind a more extensive cognitive network and therefore will have more information and knowledge retrieval paths. Therefore, concept maps are a way to stimulate and measure meaningful learning in the classroom. They are used as didactic and evaluation techniques of the student's learning. From a didactic point of view, concept maps stimulate significant learning by showing the relationships between concepts, their examples, interactions and necessary data associated to the knowledge or the subjects immersed as object of study. Furthermore, concept maps are a tool to generate the own relations between concepts and their analysis as such, turning concept maps into an assessment tool in the teaching-learning process.

3. Method

3.1. Approach and design
As the concept map is a metacognitive and qualitative instrument, the research was planned from the qualitative methodology to the interpretative level. Categories of analysis were not established a priori, but rather were defined as the intervention progressed. Therefore, the design method was action-research, as it was proposed to act in response to a problem. The teacher in charge of the group was involved in the research as he or she participated in all stages such as establishing categories and making decisions about curricular variables through an intervention based on meaningful learning with the following activities: Design, implementation and application of workshops based on real physical situations, where the elaboration of concept maps was the central axis.

3.2. Target population and key informants
The selection of informants was intentional because the target group was formed through mechanisms outside of teacher control. The intervention was developed with the participation of 43 students of both genders enrolled in tenth grade in 2019, belonging to a public educational institution located in the Department of Norte de Santander, Colombia. The students' ages are between 14 and 16 years old. It should be noted that this is the first introductory physics course in their academic training. The students who voluntarily participated in the intervention were informed about the nature and purposes of the process to be carried out.

3.3. Instruments
Bearing in mind the importance of the conceptual part in physics, the concept maps give a better structure because they interrelate different concepts and topics that allow clearly, to establish with arguments the lucidity or confusion that students present. To verify that the concept maps made by students are well elaborated, the criteria registered in Table 1 were considered. The original version of Novak and Gowin's instrument was applied [16]. At the same time, a categorization of the maps has been established, according to the total score obtained. It was also decided to establish a categorization based on the total points obtained by each concept map. The final values selected were as follows:

- Very low level: 0 to 9 points.
- Low level: 10 to 19 points.
- Intermediate level: 20 to 29 points.
- High level: 30 to 39 points.
- Very high level: 40 points or more.

3.4. Didactic intervention
The didactic intervention supported by significant learning was based on theoretical and experimental classes where inclined planes, wooden blocks, laboratory pulleys, dynamometer, chronometers, pita ropes and force table were used. It lasted 20 hours of class attendance. Additionally, it included the visualization and analysis of videos referring to problem situations where the concepts of physics are

evident, the analysis of images of physical situations and the systematization of force diagrams with a matrix of interaction of systems present in a physical situation.

For the elaboration of the concept maps in class, it was established that they would be groups of three students and that each student would present separately the concept map, the reading and the note taken from the discussion, before making the group map. For the concept maps, their use made it possible to determine misconceptions and to recognize the state of learning. For the didactic strategy related to the kinematics topic (5 exercises) we analysed whether students have clear concepts of position, speed, and acceleration; as well as, if they recognize these physical magnitudes as vectorial magnitudes.

For the subject of fundamental principles of dynamics (10 exercises), it was identified whether the students understand the approach of the principle of inertia. They also analysed their ideas about the cause of motion and its implications for speed and acceleration. Finally, the students' understanding of the interaction between two bodies was investigated, since it is common to consider a principle of dominance where "the stronger exerts more force"; "the stronger is usually the object of greater dimension, more activity and/or greater amount of mass". This conflict leads to erroneous interpretations of this law. For the theme of forces (20 exercises), we explored their conception of this concept; if they recognize the different types of force: Contact (friction and normal), those present by the action of the strings and those of gravity.

Table 1. Criteria for assessing a concept map [16].

Criteria	Being Evaluated	Valuation
Propositions	Observe whether the relationships between the various concepts are appropriate and necessary.	1 point for each valid and significant proposition that appears.
Hierarchy	Analyse the hierarchy levels of the correct concepts, considering that the more general concepts include the more specific ones.	5 points for each valid hierarchy level.
Cross connections	If the connections were well established, the relationships between concepts belonging to different parts of the conceptual map are analysed.	10 points for each valid and significant cross-connection. 2 points for each cross-connection that is valid but does not illustrate any synthesis between related groups of propositions or concepts.
Examples	Establish whether they were adequate, relevant, sufficient, and necessary.	1 point.

4. Results and discussion

The concept maps are examined, applying the instrument's assessment criteria manually to each one. This process is repeated twice, to avoid errors. The instrument's function is to analyse the topological structure of a concept map (see Table 2). From the analysis of the data, it can be deduced that half of the concept maps (50%) are part of the intermediate level, followed by the high level (29%). The results can be seen in Figure 1.

According to Figure 1 and Table 2, the results of the concept map review show in general terms an assessment of 30 points, which means that they served as didactic tools that allowed the teaching-learning process to be developed satisfactorily [7]. It is more difficult to establish relationships between concepts located in different map segments (13 points in crossed connections) among the 4 assessment criteria, as it is also evidenced in the results of [8], especially in relation to the dynamics principles, due to the lack of clarity of concepts and creativity needed, which prevent knowledge from lasting in the student's cognitive structure [9]. The above results show that the didactic intervention made it possible to observe the following strengths acquired by the students:

- Better construction of concept maps with a high degree of hierarchization and relationship of concepts, which allowed achieving a significant learning, developing skills and abilities in the understanding of mechanical physics concepts (construction of concepts, making them explicit and relating them to previous concepts).

- Development of creativity in the students at the time of performing the practices and relating them to the everyday world, additionally improved the use of formal and scientific language.
- They correctly related theory to practice, through experimentation, which also stimulated collaborative work among students.
- Their capacity for wonder was stimulated by increasing the desire to experiment with other movements to see what results would be obtained and how they could be explained.
- Strengths that have already been highlighted by previous studies [10-12].

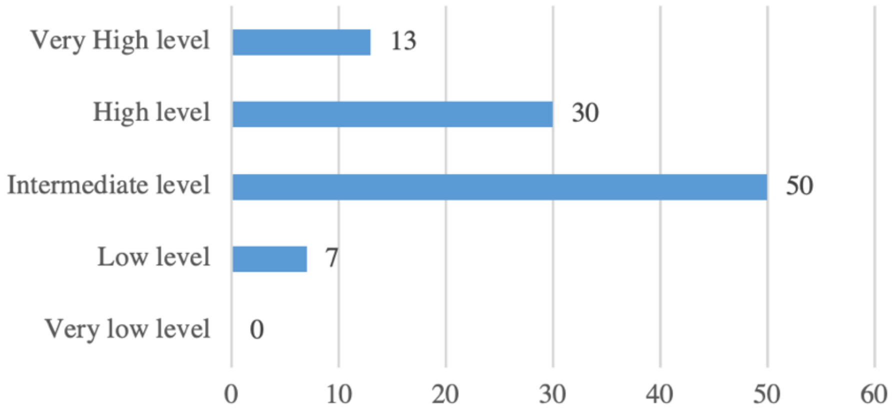

Figure 1. Results obtained with the instrument by Novak and Gowin.

Table 2. Relationship of percentages between physical concepts and valuation criteria.

Concepts	Valuation criteria					
	Propositions	Hierarchy	Cross connections	Examples	Average	Rating
Force	35.0	42.0	15.0	25.0	29.3	High level
Types of force	34.0	37.0	15.0	30.0	29.0	Intermediate level
Principle of dynamics	39.0	44.0	9.0	34.0	31.5	High level
Average	36.0	41.3	13.0	29.7	29.9	High level

The use of concept maps guides the teacher to a conceptually clearer design of curricular material. It facilitates group work while respecting individual characteristics [13]. Finally, the use of tools such as concept maps facilitates the construction of knowledge from the conceptual and experimental point of view. They make it easier for the student to identify the laws related to the experimental situation posed, generating themselves the paths or steps to follow in the search for the answers to the corresponding questions of the experimental situation posed. In addition, they provide a positive climate for student participation during their learning process [14].

5. Conclusions

Although the work was carried out as a pilot test, the results suggest that with the application of the intervention using concept maps, significant learning can be expected in the students, due to the identification of prior knowledge. It should also be mentioned that the success of the intervention corresponds to the dedication of the teacher, the students and the learning environment created. If significant constructivist learning is sought in students, it is necessary to rethink current physics courses (at least in high school), so the use of concept maps can be replicated towards other physics and science topics in general.

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