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Difficulties in the interpretation of kinematics graphs in secondary basic education students

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Abstract. This research reports the findings derived from the identification of the difficulties exhibited by a group of 76 students from different grades of basic secondary education in a private educational institution with an emphasis on science education. The students were given a questionnaire presenting five situations based on the Position-Time graph associated with uniform rectilinear motion of particles. The research approach is of a quantitative nature at a descriptive level with a field design, since it was the students who filled in the instrument. It is highlighted as a finding in the opinion of the students that the subject has been seen in class, but due to the teacher's methodology it is not fully understood by them. The results show that the students have a long list of difficulties mainly due to the lack of articulation of mathematical concepts in physical contexts, a situation that prevents them from analyzing the proposed statements, reasoning about the approaches, and improving in the process of searching for alternative solutions with clear arguments.

1. Introduction

Communication has always been considered a natural action between two or more individuals in nature, regardless of the type of medium or language used. In the context of humanity, communication is shown to be a powerful resource that facilitates the exchange of ideas or messages in order to ensure understanding between the actors involved.

From this induction the question arises, where would we be as a human race if we could not count on communication? As mentioned in [1] when defining communication as "the action of approaching and exchanging messages, is what makes people know each other, dialogue, interpret the needs of others, what they have and what they require" [1], then this process is necessary in the interaction of people and becomes more important when talking about the educational process. Given that education has historically been a preponderant factor in the development of society since it gives rise to ideas and possible alternative solutions to the difficulties that arise in daily life.

Educational communication demands the commitment of all those involved (students, teachers, administrators, parents, and the community in general), but in terms of what directly affects the quality of education, it should be emphasized that there must be good communication between the teacher and the students in order to guarantee that the students understand the messages that the teacher wishes to share. Without forgetting the importance of the non-verbal communication expressed by the teacher towards the students, towards their needs and towards the study of the subject he/she is guiding [2].

But in order to guarantee the quality of educational communication, the teacher is required to assume a leading role, since before addressing the concepts of the discipline, he/she must first structure his/her class didactically, with the aim of awakening the interest and motivation of his/her students for the

subject to be developed, leading them to feel confident and secure in class and then, to provide spaces for reflection where critical thinking, reasoning, argumentation, among others, take precedence. As stated in the research by [3] when referring to the results of the McKinsey report on the factors that influence good results in education, which highlights that "the key factor in education is the teachers. It is not so much the investment in buildings that matters..., but in the intelligence and preparation of the teacher" [3].

The current context in which students live is characterized by the strong trend towards globalization with the dominant use of technological resources, which has affected the educational process in the generation and demand for new scientific competences in order to be an active part of society. As stated, "the development of competences associated with the educational potential of science cannot be neglected: critical, reflective and analytical capacity, technical knowledge and skills, appreciation of work and the ability to create and research" [4].

Article 5, article 7, article 9, and article 13 of [5] establish basic science education as one of the aims of education in Colombia. Later, through the "Lineamientos Curriculares de Estándares de Competencias" [6] are issued with the aim of promoting the development of scientific culture. Paraphrasing what is stated in the "Estándares Básicos de Competencias en Ciencias Naturales" [7], this document clearly defines what students should learn by defining a reference on what they should know and know how to do. It recognizes the importance of developing the competences necessary for training in natural sciences "from observation and interaction with the environment; the collection of information...to conceptualization, abstraction and the use of explanatory models...of observable phenomena...of the universe" [7].

Reviewing the competences of natural sciences from the different grades of primary basic education, we find that students should begin to compare movements and displacements of living beings and objects, and then in sixth grade record observations and results using diagrams, graphs, and tables, so that they use mathematics as a tool for organizing, analyzing, and presenting data. As can be seen, the concepts of kinematics appear in the school curriculum from fourth grade onwards and are then complemented by mathematics in the representation or interpretation of data using various registers such as tables, graphs, formulas, among others.

It is in this context in which this research was developed, where the aim was to adopt a route, little used by teachers in classroom work, which consisted of providing the student with a graphical representation and from it, generate a series of questions that demanded understanding of it in order to interpret it and thus analyze what happened with the speed of the bodies in position-time graphs.

It is made clear that in this type of graphs the speed ends up being the slope of the straight line associated with the uniform rectilinear movement that the body follows. It was then hoped to generate a space for the articulation of knowledge that would be coherent with the type of situations presented in nationally standardized tests and break with the traditional teaching scheme, which ends up being a reductionist and operative practice of scientific competences [8].

2. Method

This research process takes as its population all students enrolled for the year 2021 in grades six to eleven in a private educational institution located in the metropolitan area of the San José de Cúcuta, Colombia. In total there are 195 (N = 195) students and by calculating the sample size (n_1) through Equation (1), and by means of Equation (2) a total of 76 students ($n_0 = 76$) are determined as the optimal sample size assuming a probability of success of 70% (P = 0.7), an error of 5% (e = 0.05) and a confidence level of 95% (equivalent to Z = 1.96) with a significance level of 5% ($\alpha = 0.05$). Additionally, it was considered as an inclusion criterion that the students were attending the institution in person, so the sampling process used was probabilistic as stated in [9].

$$n_1 = \frac{N * Z^2 * \frac{\alpha}{2} * P * (1-P)}{e^2 * (N-1) + Z^2 * \frac{\alpha}{2} * P * (1-P)},$$

(1)

$$n_0 = \frac{n_1}{1 + \frac{n_1}{N}}. \tag{2}$$

Regarding the instrument, it is composed of two sections, starting with the profile of the students, and then proposing five situations derived from the research work of [10], but the questions have been adjusted to the characteristics of the informants and the social context in which they live. The instrument has been validated by the method of expert judgement, which was formed by the group of researchers accompanied by the teacher in charge of the subject at the institution, who contributed his knowledge of the work carried out and the language of the statements in order to ensure understanding by the students.

In each proposed situation, students began by selecting the correct answer to be chosen from a group of options (closed answers) but were then asked to justify the reasoning behind their choice. The students had a continuous block of 90 minutes, in which they were first sensitized before completing the questionnaire. Once the data were collected, the data were digitized, with each row representing the responses of one student. The data were then processed by organizing the information in tables (simple or cross tabular) or graphs in order to characterize the level exhibited by the students.

For all the above mentioned, it is concluded that this research fits the characteristics of the quantitative approach at a descriptive level, since the researchers access the data directly from the primary source, without manipulating any of them, but they are statistically processed in order to highlight the most relevant [11].

3. Results and discussions
The results derived from the application of the instrument used in this research are presented below, starting with the demographic profile of the informants, and then analyzing the results obtained in each of the situations raised.

3.1. Demographic and academic profile
Regarding the characteristics of the informants in this research, it was determined that there is a predominance of the male gender with 64.5% of the cases, in contrast with 35.5% corresponding to females. Age ranged from 11 years old to 17 years old, with an average of 14.1 years old and a standard deviation of 2.2 years old, which allows us to calculate the coefficient of variation, whose value is 15.6%, which according to [12] offers admissible variation.

The skewness coefficient is -0.119, so the histogram of the data has a slight tail to the left with frequencies distributed throughout the range, generating a platykurtic distribution effect that is consistent with the kurtosis value (-1.457). These two statistics characterize the diversity of ages observed in the informants according to the grades analyzed; with respect to the grade of the informants, it was identified that they participated from sixth to eleventh grade with percentages ranging between 10.5% and 22.4%, with a lower percentage in eighth grade and a higher presence in sixth grade.

When disaggregating the concentration of gender by grade, the use of cross tables was used, which made it possible to determine that females were concentrated in grades eleven, nine and seven, while males dominated in grades six and ten. In eighth grade, there is an almost equal distribution by gender.

When asked whether they had seen physics subjects at the institution, all the students answered yes, which is consistent with the emphasis of the educational institution, which corresponds to training in natural sciences. To conclude this approach to knowledge of the academic process, students were asked whether they liked the physics classes and the way in which the teacher guides the subject, and it was determined that 38.2% were not satisfied with this aspect, while the remaining percentage (equivalent to 61.8%) said that the classes were good and that they had a positive attitude towards the subject.

This aspect coincides with that stated by [13], who assert that traditional teaching practices centered on repetition, memory and the teacher should be replaced by teaching processes focused on the student, giving them the opportunity to take on an active and committed role in their actual learning.

3.2. Situations associated with kinematics

The results derived from each of the proposed situations regarding the interpretation of position-time graphs are presented below; as highlighted in [14], it is necessary to articulate diverse registers of semiotic representation to solve the conceptual weaknesses that the students have in relation to the topics.

3.2.1. Situation 1. A position-time graph is presented in which there are two objects A and B, where object A starts from the reference position (zero) and in 5 seconds reaches 50 meters, while object B starts from a position 20 meters further away from the reference point and during the same 5 seconds moves to a position of 35 meters. The graph shows that the straight lines intersect 3 seconds after the start of the simultaneous travel of both objects, which is why two key sections are identified in the graph, before and after the first 3 seconds; when students were asked if they could infer from the graph whether at some point in time objects A and B would have the same speed, 61.8% (equivalent to 47 informants) said yes while the remaining 38.2% (equivalent to 29 informants) said no.

The arguments given are shown in Table 1, where various criteria can be observed to support the argumentation, for example, 83.0% of those who said that at some point the objects had the same speed based their argument on the cut-off point of both lines where the equality of values is assumed there, coinciding with the conclusions of the research by [15], but of these only 23.4% recognize that the slope of the line corresponds to the speed, while the others associate the crossing of lines as a function of one of the variables associated with each axis; it should be noted that there is a common argument between those students who accepted and those who rejected the equality of speed, based on the angle of inclination of the straight line with respect to the abscissa axis.

On the other hand, 26.7% of those who answered no, secure their argument in the light of the initial position of both bodies. Finally, it should be noted that approximately 8% of the total number of informants (equivalent to 20.7% of those who said no) stated that they did not understand the proposed situation.

Table 1. Comparative of the arguments given according to the answer option.

Arguments	Accept	Reject
They reach the same speed (the slope) when the two straight lines cross	23.4%	
Because they cross each other when they reached 30 cm	25.5%	
Because in time 3 seconds both objects have the same speed	34.1%	
Because line A is steeper than line B, it goes faster	17.0%	51.7%
The initial position of the lines is different, so they are not equal		27.6%
I do not understand the situation		20.7%
Total	100.0%	100.0%

3.2.2. Situation 2. Again a position-time graph is shown that corresponds to the route followed by a car in a straight line assuming a petrol station as a reference point, where three sections with different characteristics are identified: (a) the car is 10 meters before the petrol station (negative value) and in one second it reaches the position 10 meters after the petrol station; (b) then it stops in this place for two seconds; (c) subsequently it advances 10 meters further for three seconds.

From the description, it is identified that there is a different value of speed in each path, with the first path (from zero to one second) having the highest speed. From this reasoning, the students had to select the time interval in which the highest speed was observed. From Table 2, 30.3% argue that the maximum speed is reached in the first run because it takes less time or because it is seen to go up faster on the straight line. 47.4% of the informants chose path 3 because it is the path in which the maximum position is reached, not knowing the time it takes to arrive, *i.e.*, they validate their argument only by observing the values of the ordinate axis.

In a complementary way, the students are asked, if you want the speed of the car to be 10 meters per second in trip three, which of the following options would be the correct one? The correct answer stating that a final position of 40 meters is reached in the same three seconds was provided by 18.4% of the

informants, while the remaining percentage opted for incomplete or misleading options such as increasing 10 meters more from the initial position of this run or increasing to 30 meters in the three seconds. This last answer shows that they have the concept of velocity as the quotient between position and time, but they are unaware of the initial position of the object.

Table 2. Frequencies for the routes followed.

Response options	Frequency	Percentage
Path 1: between zero and one second	23	30.3
Path 2: between one and three seconds	13	17.1
Trip 3: between three and six seconds	36	47.4
The speed is the same throughout the journey	4	5.3
Total	76	100.0

3.2.3. Situation 3. In this situation, the students are given two graphs, a position-time graph showing an increase in position of 10 meters per second from the origin, while the second velocity-time graph shows a constant function with a value of 10 meters per second during the observation time; the students had to answer whether the graphs corresponded to the motion of the same object.

From the first graph, it is possible to determine the velocity and verify that it is always the same, which is why it is correct to state that the velocity is constant, so it is concluded that the two graphs are associated and that it corresponds to the behavior of the position and velocity over time. Therefore, it is determined that 28.9% say that the two graphs correspond to the movement of the same object, arguing that the greater the position, the longer the time increases, which shows that they are not clear about the concepts of independent and dependent variables. Likewise, a small group of students mentioned that the graphs always go forward in time and therefore correspond to the same movement, so that time is evident in them as an independent variable, but with total ignorance of the concept of velocity as the slope of the straight line in the position-time graph.

Approximately 71.1% of the informants' state that the graphs do not correspond to the same movement, supported by two arguments: (a) 37.0% state that "the statement says that it is a function of time, despite being the same time the graphs are different, so they are not the same", which shows that they are unaware of the relationship between time and the other variables; (b) the remaining 34.0% state that "one function is increasing and the other is a constant, so they are not the same". Regarding the above, it is shown that some of them are recognized real functions from a mathematical point of view, but they are completely unaware of the physical context of the variables in question.

3.2.4. Situation 4. It is mentioned in the statement that a body is dropped freely from a certain height and is therefore subject only to the action of the acceleration of gravity. Students were asked to select from four different position-time graphs the one that corresponded to the motion of the body.

Table 3 shows that only 13.2% of the informants selected the correct answer (option 1) which represents the effect of the acceleration in the exponential way in which its increasing rate increases; of the remaining percentage, 35.8% (option 4) have conceptual difficulties at the mathematical level given that the graph does not represent a function, while 31.6% (option 3) associate the graph with the possible trajectory that a body follows when it follows a parabolic shot, possibly associating it with the fall of the body. Finally, 18.4% who selected option 2, assume a uniform motion that goes against the presence of the acceleration of gravity, thus evidencing weaknesses in the concepts of kinematics.

3.2.5. Situation 5. The test ends with a graphical representation in which there are two parallel straight lines that represent the position of two bodies moving at a constant speed of 10 Km per hour for six hours each, with the difference that body A leaves three hours before body (B); students were asked to infer from the graph the speed of the two bodies. Approximately 63.2% of the informants affirm that one of the bodies has a higher speed, for example, 39.5% say that the speed of body A is higher because it travelled the distance in less time while 23.7% affirm that body B is the fastest despite having arrived

last; these answers show the analysis of the variables separately and not as a function in which a correspondence relationship is established between the values of two variables.

Approximately 13.2% of the respondents affirm that the velocity increases as time passes independently of the observed body, but they do not dare to affirm that the velocity is the same, demonstrating that they do not know that if two straight lines are parallel (Y_1 parallel with Y_2), this implies the equality of their slopes ($m_1 = m_2$) as stated in the system of canonical linear Equation (3), so that when this condition is fulfilled, the increase is the same in both cases. The values B_{10} and B_{20} are the intercepts with the ordinate axis and x the independent variable.

$$\begin{cases} Y_1 = m_1 x + B_{10} \\ Y_2 = m_2 x + B_{20} \end{cases}. \qquad (3)$$

Greater difficulties are evidenced when extracting the data from the graph to be able to determine the velocities. Finally, 23.7% say that the two bodies have the same velocity even though they travel with different time differences. 4.9% of them say that they have the same velocity, only that they have different positions, a response that shows confusion between the variables associated with each coordinate axis.

As a synthesis of the process advanced, it can be said that it is necessary for teachers in the development of classes to promote the coherent articulation of different registers of representation, as outlined in the findings of the work of [16], in which it is stated that part of the difficulties are due to confinement to one register of representation, that is to say, that the teacher in his teaching process always orients his work to go from the algebraic expression to the representation in the cartesian plane, passing through the tabular register, but when the inverse process is attempted, a series of obstacles automatically arise in the students.

Table 3. Description of the type of position-time graph that follows the motion of the body as it falls.

Response options	Frequency	Percentage
Option 1. Increasing quadratic function starting from the origin and reaching a position of 40 cm in two seconds	10	13.2
Option 2. Linear function growing steadily at a rate of 10 meters per second starting from the origin	14	18.4
Option 3. Decreasing quadratic function with vertex at the point (0;40) and reaching the ground in two seconds	24	31.6
Option 4. A straight vertical line parallel to the y-axis which, with a constant time of two seconds, descends from 40 cm to 0 cm	28	36.8
Total	76	100.0

4. Conclusions

After carrying out this research, it was determined that despite being an educational institution whose emphasis is on training in natural sciences, where students begin to work with basic concepts of physics, such as distance, speed, force, rest, movement, among others, from the grades of primary basic education.

In the particular case of students in any of the grades of secondary basic or technical high school, they begin intuitively to analyze the movement of bodies, as a relationship between the distance travelled by a body as time passes, and then go on to interpret and describe what happens in position-time graphs.

From the above, it can be concluded that with respect to the curricular proposal of the institution, students would be expected to be able to resolve the proposed situations, which generates a point of reflection on how the physics teacher is developing the contents and competences that he/she is promoting in classroom work.

Furthermore, it was determined that at most one out of four informants was efficient in the articulation of mathematical concepts applied to situations or approaches specific to physics. This aspect reduces the probability of success in tests such as the Saber 11 test, given that many of the approaches are based on graphical recording and require the ability to abstract data to solve problematic situations.

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