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PROBLEMS IN THE COMPREHENSION OF KINEMATIC GRAPHS IN ELEMENTARY SCHOOL

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Abstract

This document shows the difficulties identified in a group of 76 students from sixth to ninth grade of a private educational institution whose training emphasis is the teaching of Natural Sciences. A questionnaire was applied to them in which there were five proposed situations which were based on the position-time graph associated with uniform rectilinear motion. A quantitative approach was adopted at a descriptive level with a field design, since the questionnaire was filled out by the primary informants. The main evidence was identified as the presence of conceptions around the subject, since there is not a total understanding of the subject due to the teaching methodology promoted by the teacher. The results show that 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 finding alternative solutions with clear arguments.

Keywords: semiotic registers of representation, conceptions, space-time graphs.

RESUMEN

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Este documento muestra las dificultades que se identificaron en un grupo de 76 estudiantes de sexto a noveno grado de una institución educativa de naturaleza privada cuyo énfasis de formación es la enseñanza de las Ciencias Naturales. Se les aplicó un cuestionario en el que había cinco situaciones propuestas las cuales se fundamentaban en el gráfico posición-tiempo asociado al movimiento rectilíneo uniforme. Se adopta un enfoque cuantitativo a nivel descriptivo con un diseño de campo, puesto que el cuestionario fue diligenciado por los informantes primarios. Se identificó como principal evidencia la presencia de concepciones alrededor del tema para no existe comprensión total del asunto a causa de la metodología de enseñanza promocionada por el docente. Los resultados muestran que los estudiantes tienen una larga lista de dificultades principalmente por la falta de articulación de los conceptos matemáticos en contextos físicos, situación que les impide analizar los enunciados propuestos, razonar sobre los planteamientos y mejorar en el proceso de búsqueda de alternativas de solución con argumentos claros.

Palabras clave: Registros semióticos de representación, concepciones, gráficas de espacio-tiempo.

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 (Vanegas et al., 2022). In the context of humanity, communication is shown as a powerful resource that facilitates the exchange of ideas or messages to ensure understanding between the actors involved (Vanegas & Gamboa, 2022a; Vanegas & Gamboa, 2022b; Prada, Gamboa & Avendaño, 2021a; Aréniz-Arévalo, 2017; Espinel-Rubio et al., 2020). This exchange ensures that the individual has the ability to establish a greater number of relationships with others, which is of great benefit when carrying out different activities of daily life (Román, 2021).

From this induction, the question arises, where would humans be if we could not count on communication? As mentioned in Vélez and Solórzano (2016), 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” (p. 253). 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 everyday life.

Educational communication requires the commitment of all those involved (students, teachers, managers, parents and the community in general), but regarding the quality of education, it should be emphasized that there must be good communication between the teacher and the students to ensure that they understand the messages that the teacher wants to share, without neglecting the professional preparation of teachers, which also represents an essential element in the analysis of effectiveness in communication (Pflücker, 2020). 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 (Domínguez, 2009).

But, ensuring the quality of educational communication (Gamboa, 2016) requires that the teacher assumes a leading role, since before addressing the concepts of the discipline, he must first structure his class didactically, in order to arouse the interest and motivation of his students for the topic to be developed (Urbina, 2017), leading them to feel confident and secure in class and then, provide spaces for reflection where critical thinking, reasoning, argumentation, among others, prevail.

As stated in Enkvist's research (2010) 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. What is important is not so much the investment in the building..., but in the intelligence and preparation of the teacher” (p. 50).

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 competencies to be an active part of society (Prada et al., 2021b; Contreras-Colmenares & Jiménez-Villamarín, 2020). As stated by Castro & Ramírez (2013), “the development of competencies associated with the formative potential of the sciences must be critical, reflective and analytical capacity, technical knowledge and skills, valuing work and the ability to create and investigate” (p. 31).

In addition to the above, education is currently going through one of the most critical points worldwide, thanks to the new methodologies created to deal with the appearance in 2019 of the Covid-19 virus, which originated in China, but quickly spread to different countries in all continents, thus affecting multiple economic sectors, including education. In this context, governments around the world, decreed mandatory quarantine, thus avoiding the transmission of the virus through social distancing (Inter-American Development Bank, 2020) to which educational institutions were no strangers and were immediately forced to devise alternatives to comply with the academic calendar without exposing teachers and students to the contagion of the aforementioned virus.

The need arises then to implement technological resources as a bridge between teachers and students, who carry out their academic training in virtual environments, based on principles such as MOOC (Massive Open Online Course), proposed by Dave Cormirer and Bryan Alexander in Canada in 2008 (Lopez-Meneses & Vazques, 2020).

This undoubtedly constitutes a challenge for educational management, since it was not only the design of a strategy, but also what it implied to execute it. The use of digital platforms, training and constant motivation of teachers, have been a priority within the approach of objectives and goals (Artavia & Castro, 2019; Prada, Hernández & Gamboa, 2019; Hernández Suárez et al., 2018).

Articles 5, 7, 9 and 13 of Law 115 (1994) establish the teaching of Natural Sciences as one of the purposes of education in Colombia. Subsequently, through the Ministry of National Education

(Mineducación, 1998), the Curricular Guidelines and Competency Standards were issued in order to promote the development of scientific culture.

Paraphrasing what is stated in the Basic Competency Standards in Natural Sciences (Mineducación, 2004), 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 competencies necessary for training in Natural Sciences "from observation and interaction with the environment; the collection of information...to the conceptualization, abstraction and use of explanatory models...of observable phenomena...of the universe" (p. 9).

Reviewing the Natural Sciences competencies of the different grades of Primary Basic Education, students must begin to compare movements and displacements of living beings and objects, and then in sixth grade record observations and results through diagrams, graphs and tables, so that they use mathematics as a tool to organize, analyze and present the data. As can be seen, the concepts of kinematics appear in the school curriculum starting in fourth grade, and are then complemented by mathematics in the representation or interpretation of data through the use of various records such as tables, figure, formulas, among others.

It is in this context in which this research was developed, where it was intended to adopt a way, 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 required its understanding to interpret it and thus analyze what happened with the speed of the bodies in the Position-Time graphs.

It is clarified that in this type of graphs the speed ends up being the slope of the straight line associated to the uniform rectilinear motion followed by the body. It was expected then to generate a space for the articulation of knowledge that was coherent with the type of situations presented in the national standardized tests and to break with the traditional teaching scheme, which ends up being a reductionist and operative practice of scientific competences (Alvarado & García, 2008).

METHODOLOGY

This research process takes as its population all students enrolled for the year 2021 in the sixth to eleventh grades of a private educational institution located in the metropolitan area of the city of San José de Cúcuta. In total, there are 195 ($N = 195$) students and calculating the size of the sample (n_1) through Equation (1), and by means of Equation (2) a total of 76 ($n_0 = 76$) students as the optimal sample size assuming a probability of success of 70%, an error of 5%, and an error of 5%. ($P = 0.7$) a 5% error ($e = 0.05$) 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 attended the institution in person, so the sampling process used was probabilistic as pointed out by Martínez (2012).

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

$$n_0 = \frac{n_1}{1 + \frac{n_1}{N}} \quad (2)$$

As for 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 Tejeda and Domínguez (2015), but the questions have been adjusted to the characteristics of the informants and the social context in which they live. The instrument was validated by the expert judgment method, 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 done and the language of the statements to ensure understanding by the students. In each proposed situation, students began by selecting the correct answer to choose from a set of options (closed responses), but were then asked to justify the reasoning for their choice. Students had a continuous block of 90 minutes, in which they were first sensitized before completing the questionnaire. Once the data were collected, they were digitized, with each row representing the responses of one student. The data were then processed by organizing the information in tables (simple or crossed) or graphs to characterize the level exhibited by the students.

Based on the above, it is concluded that this research fits the characteristics of the quantitative approach at the descriptive level, since the researchers access the data directly from the primary source, without manipulating any of them, but they are statistically processed to highlight what is most relevant (Hernández-Sampieri & Mendoza, 2018).

RESULTS

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

Demographic and academic profile

Regarding the characteristics of the informants in this investigation, 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. The age ranges between 11 and 17 years, with a mean of 14.1 years and a standard deviation of 2.2 years, which allows to calculate the coefficient of variation, whose value is 15.6%, which according to Amon (2000) offers an 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 platicurtic distribution effect that is consistent with the kurtosis value (-1.457). These two statistics characterize the age diversity 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 from 10.5% to 22.4%, with a lower percentage in eighth grade and a higher presence in sixth grade. When disaggregating the gender concentration by grade, the use of cross tables was used, which made it possible to determine that females are concentrated in grades eleven, nine and seven, while males predominate in grades six and ten. In eighth grade, there is an almost equal distribution by gender.

When asked if they had seen physics subjects at the institution, all 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 the knowledge of the academic process, the students were asked if 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 pointed out by Fernández et al. (2009), who state that traditional teaching practices centered on repetition, memory and the teacher should be replaced by teaching processes centered on the student, giving him/her the opportunity to assume an active and committed role in his/her own learning.

Situations associated with kinematics

The results derived from each of the proposed situations in relation to the interpretation of the Position-Time graphs are presented below. As highlighted in Prada-Núñez et al. (2016), it is necessary to articulate diverse registers of semiotic representation to resolve the conceptual weaknesses that students have in relation to the topics.

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 the course of 5 seconds reaches 50 meters, while object B starts from a position 20 meters farther 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 cross 3 seconds after the start of the simultaneous displacement of both objects, so that two key sections are identified in the graph, before and after the first 3 seconds.

When the students were asked if they could infer from the graph whether at some point 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 several criteria to support the argument can be observed. The arguments given are shown in Table 1, where various criteria to support the argument can be observed. 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 equal values are assumed in the same, coinciding with the conclusions of the research by Martínez and Iturriza (2016), but of them, 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 is worth noting that there is a common argument between the students who accept and those who reject the equality of velocity, 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 based on the initial position of both bodies. Finally, it is worth noting that approximately 8% of the total number of informants (equivalent to 20.7% of those who said no) claim not to understand the proposed situation

Table 1. *Comparative table of the arguments given according to the response option.*

Arguments	Accept	Reject
They reach the same speed (the slope) when the two straight lines intersect.	23.4%	
Because they cross when they reach 30 centimeters.	25.5%	
Because in time 3 seconds both objects have the same velocity.	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%

Situation 2. Again, a Position-Time graph is shown corresponding to the path followed by a car in a straight line assuming a gas station as a reference point, where three sections with different characteristics are identified: a) the car is positioned 10 meters before the gas station (negative value) and in one second it reaches the position 10 meters after the gas station; b) then it stops at this place for two seconds; c) subsequently, it advances 10 meters more for three seconds. From the description, it is identified that there is a different value of velocity in each trajectory, with the first trajectory (from zero to one second) having the highest velocity. From this reasoning, students were to select the time interval in which the highest velocity was observed.

From Table 2, it can be noted that 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. 47.4% of the informants chose run 3 because it is the run in which the maximum position is reached, without knowing the time it takes to arrive, i.e., they validate their argument only by observing the values of the ordinate axis.

Table 2. *Table of frequencies of 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
Path 3: between three and six seconds	36	47.4
The speed is the same during the entire trip.	4	5.3
Total	76	100.0

Complementarily, students are asked, if one wants 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 indicating 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 trip or increasing to 30 meters in the three seconds. This last response shows that they have the concept of velocity as a quotient between position and time, but do not know the initial position of the object.

In this situation, students are given two graphs, a Position-Time graph showing a position increase 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 correspond to the motion of the same object. From the first graph, it is possible to determine the velocity and verify that it is the same at all times, so 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 position and velocity over time.

It was determined that 28.9% said that the two graphs correspond to the movement of the same object, arguing that the greater the position, the longer the time, which shows that they are not clear about the concepts of independent and dependent variable. Of this group, a small group of students mentioned that the graphs always advance 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, relying on 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 equal”, which shows that they do not know 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 equal”. This argument shows that they recognize some real functions from a mathematical point of view, but they are completely unaware of the physical context of the variables.

Situation 4. It is mentioned in the statement that a body is allowed to fall freely from a certain height and, therefore, is subject only to the action of the acceleration of gravity. Students were asked to select, among 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 acceleration in an exponential way in which its rate of increase rises. Of the remaining percentage, 35.8% (option 4) have conceptual difficulties at the mathematical level since 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.

Table 3. *Description of the type of Position-Time graph that follows the motion of the falling body.*

Response options	**Frequency**	**Percentage**
Option 1. Quadratic increasing function starting from the origin and reaching a position of 40 cm in two seconds.	10	13.2
Option 2. Linear function increasing 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. Vertical line parallel to the axis and which, with a constant time of two seconds, descends from 40 to 0 centimeters.	28	36.8
Total	76	100.0

Situation 5. The test ends with a graphical representation in which there are two parallel straight lines representing the position of two bodies moving at a constant speed of 10 kilometers per hour for six hours each, with the difference that body A departs three hours before body B. The students were asked to deduce from the graph the speed of the two bodies. Students were asked to deduce from the graph the velocity of the two bodies.

Approximately 63.2% of the informants affirm that one of the bodies has greater speed, for example, 39.5% say that the speed of body A is greater because it traveled the distance in less time while 23.7% affirm that body B is the fastest despite having arrived last. These responses 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 with the passage of time independently of the observed body, but they do not dare to affirm that the velocity is the same, showing that they do not know that if two straight lines are parallel (Y_1 parallel to Y_2), which implies the equality of their slopes ($m_1 = m_2$) as shown in the system of canonical linear equations (3), so that when this condition is fulfilled, the increase is the same in both cases. The values B_{10} y B_{20} are the intercepts with the ordinate axis and X the independent variable.

$$\{Y_1 = m_1 x + B_{10}\ Y_2 = m_2 x + B_{20} \quad (3)$$

There are greater difficulties in extracting the data from the graph in order to determine the velocities. Finally, 23.7% say that the two bodies have the same velocity even though they move with different time difference. 4.9% 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 advanced process, it can be said that it is necessary for the teacher in the development of the classes to promote the coherent articulation of the different registers of representation, as outlined in the findings of the work of Choco (2019), in which it is stated that part of the difficulties are due to the confinement to a single register of representation, that is, 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.

CONCLUSIONS

After conducting this research, it was determined that despite being an educational institution whose emphasis is on training in Natural Sciences, students begin to work with basic concepts of Physics, such as distance, speed, force, rest, motion, among others, from the grades of Primary Basic Education.

In the particular case of students in any of the Basic or Technical Secondary grades, they begin to intuitively analyze the movement of bodies, as a relationship between the distance traveled by a body as time passes, and then go on to interpret and describe what happens in the Position-Time graphs. From the above, it can be concluded that with respect to the curricular proposal of the institution, it would be expected that students are able to solve the proposed situations, which generates a point of reflection on how the Physics teacher is developing the contents and competencies that he is promoting in the classroom work.

In addition, it was determined that at most one out of every 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, given that many of the approaches are based on graphic recording and require the ability to abstract data to solve problematic situations.

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