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To cite this article: C A Hernández *et al* 2021 *J. Phys.: Conf. Ser.* **2073** 012003

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Gains in active learning of physics: a measurement applying the test of understanding graphs of kinematics

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Abstract. To teach the subject of physics in the classroom it is required that the teacher has and plans to carry a didactic strategy with him. Within this context is the methodology called Active physics learning, which is a strategy within the classroom and in the laboratory, as it allows the student to learn physics without depending on a textbook or the teacher who guides the course. The test of understanding graphs of kinematics assesses students' comprehension of kinematics. We report the application of an active learning experience for the conceptual learning of kinematics of students taking the subject of physics in an elementary and middle school. The study is quasi-experimental with a single group of 29 students using a pretest-intervention-posttest design. With the results of the pretest and posttest the Hake learning gain index was estimated and showed evidence of the implementation of active learning in the conceptual evolution of students in kinematic concepts and their representation by means of graphs. This becomes a precedent for the improvement of pedagogical practice in favor of quality education.

1. Introduction

The conceptual mastery of sciences such as physics is necessary for the advancement of technological development and is therefore important in the educational process; but for some students, they relate it to problems that involve a few formulas, but which only a small group of people can solve. This has created various difficulties that afflict the educational environment, in which mental schemes and incorrect preconceptions predominate, leading to reasoning that does not allow problem solving [1-3].

With the curricular guidelines, standards, and competencies in natural sciences of the Colombian Ministry of National Education, the aim is for students to approach the learning of physics [4,5], especially kinematics, which is fundamental for understanding concepts such as forces, energy and the various interactions between systems and their consequences on the movement of bodies, which explain various situations in nature [6]. Consequently, students, before entering mathematical procedures, must be very clear about the conceptual part to understand the laws and explanations of phenomena. Therefore, helping a conceptual change requires teaching activities that start from what the student knows, in a social teaching context [7,8], that favor the clear, stable, and organized reconstruction of knowledge with which they can face and solve diverse situations and, at the same time, acquire knowledge that demands a higher level of abstraction within the same field.

The intervention developed in this study is based on the strategy followed for the conceptual learning of kinematics through active learning, which presupposes that knowledge is constructed based on the students' preconceptions and those proposed by the teaching. As far as possible, we worked with movements from everyday life, exemplifying abstract concepts as much as possible. In the intervention, work in small groups, where they experiment with kinematic concepts such as changes in position,

speed, and acceleration with body movements, which is based on the perspective of collaborative work based on sociocultural theory [7] and cognitive development [9]. The activities within active learning are based on representation through graphs, where the student can solve kinematic problems in one-dimensional movement without applying formulas and is based on the concept that learning physics is based on the conceptual part, the rest arises from the relationship of variables that are found in everyday life [1].

On the other hand, Beichner [10] presented the test of understanding of graphs in kinematics (hereinafter TUG-K), to assess university students' understanding of kinematic graphs. This test has been widely used in physics education [1-11]. Zavala, Barniol & Tejeda [11] improve the TUG-K in Spanish version, to evaluate in a more complete way the understanding of students in the different related objectives (dimensions) of the test. It diagnoses the knowledge and learning of students from secondary education to the beginning of a physics course in university programmers. It is also used as a pretest-posttest to determine the validity of some teaching strategies used during students' conceptual learning or learning gains [12] and new didactic materials such as video analysis [13], tutorial-type activity [14], and an e-learning module [15]. It also evaluates the ability to interpret kinematic graphics with other variables [16], and to investigate the pedagogical content knowledge of the teachers on kinematic graphics [17].

In accordance with the above, from the framework of the implementation of a different strategy to the traditional one in the subject of physics, the hypothesis proposed is whether the teaching of kinematics from the perspective of active learning allows for a conceptual evolution of the students' learning. For this purpose, the TUG-K was applied, and Hake's factor was calculated to find out the conceptual level of the students in relation to the concepts of kinematics.

2. Method

The research was conducted under the quantitative paradigm, with purposive sampling, because the target groups are formed through input mechanisms outside the teachers' control. The design was quasi-experimental, in which the TUG-K [11] was applied as a pre-test to explore students' preconceptions of Newtonian mechanics, followed by a teaching intervention based on active strategies [7-9] that included activities such as design, implementation and application of workshops based on real physical situations in the context of kinematics. At the end of the intervention, the TUG-K was applied again as a post-test allowing to estimate the so-called Hake learning gain [12].

The implementation of the proposal was developed with 29 11th grade students from an educational institution located in Norte de Santander, Colombia. The ages of the students are between 15 years old and 17 years old. It should be noted that this is the second physics course in their academic training, since in previous grades the physics component was seen within the area of natural sciences. All the young people who participated in the experience were informed orally about the nature and purpose of the experience; their response was unanimous acceptance of wanting to participate actively in the process. In addition, they were informed of the commitment made to the institutional directives to provide a copy of the project and its results, which will be available for any type of consultation.

2.1. Instruments

The original version of the test TUG-K assesses the understanding of the concept of slope and the concept of area under the curve in kinematic graphs. The test assesses 7 objectives. Objective 1 and objective 2 are directly related as they assess the concept of slope. On the other hand, objective 3 and objective 4 are also directly related as they assess the concept of area under the curve. Objective 5, objective 6, and objective 7 assess in different ways the understanding of the concept of slope and/or the concept of area under the curve [11]. In the Spanish-translated version, which is the one used in this study, for example, students should be able to determine the velocity at a point from the position graph using the concept of slope, and they should be able to determine the change of position in an interval from the velocity graph using the concept of area under the curve. Table 1 presents a complete description of the TUG-K where the 21 items are grouped into the 7 test objectives.

Table 1. Description of the TUG-K items grouped in each of the objectives.

Objectives	Items	Concept
(1) Determine the velocity at a point from the graph of the position interval	5, 13, 17	Slope concept at a point
(2) Determine the acceleration at a point from the velocity graph	2, 6, 7	
(3) Determine the change in position in an interval from the velocity graph	4, 18, 20	Concept of area under the curve in an interval
(4) Determine the change in velocity over an interval from the acceleration graph	1, 10, 16	
(5) Select a corresponding graph from a given one	11, 14, 15	Slope concept and/or area under the curve
(6) Select textual description from a given graph	3, 8, 21	
(7) Select a graph from a given textual description	9, 12, 19	

2.2. Data collection procedure

To analyze the initial state (preconceptions and diagnosis) that the students had of kinematics, the TUG-K was applied as a pretest. Based on the results of the pretest, an intervention based on active learning was implemented. The classes were of a theoretical-practical type with a laboratory with the following learning objectives: (1) to obtain the kinematic equations of uniform and uniformly accelerated motions and from them determine the mean and instantaneous position, velocity, and acceleration between and at given values of time; (2) relate graphs of motion, their slopes, and bounded areas, to the parameters of motion.

The educational intervention supported by active learning assumes that knowledge is constructed based on the students' preconceptions and those proposed by the educational process. As far as possible, we worked with movements from everyday life, exemplifying the abstract concepts as much as possible, working in small groups to experience the concepts of position, change of position and above more abstract concepts of velocity, change of velocity and acceleration. It was analyzed whether the students are clear about the concepts of position, velocity, and acceleration, as vector magnitudes. The discussion of results is group-based, supervised by the teacher, who also confronts different groups if they have different results. Finally, the TUG-K was applied again, and the so-called learning gain was estimated using the Hake's factor of each of the five aspects into which the study was divided.

The Hake's factor, also called relative gain of conceptual learning, indicates the average real gain of standardized conceptual learning [12]. It is used to determine the level of conceptual learning achievements in the implementation of a didactic strategy, that is, with the results of an evaluation (pre-test and post-test) the impact on the assimilation of type knowledge is determined conceptual. In the case of this proposal, the g factor allows to establish the changes achieved in the different dimensions of the TUG-K when implementing a didactic strategy, since the low, medium, and high levels of achievement in the g factor are related to the level of conceptual mastery of the phases of the TUG-K. For the calculation of the Hake's factor g the Equation (1) is used [12].

This factor can take values between 0 and 1, where 0 represents no learning, while 1 corresponds to the maximum possible learning. [12] further proposes to categorize the results of training into low ($g < 0.3$), medium ($0.3 < g < 0.7$) and high ($g > 0.7$) normalized gain zones.

$$g = \frac{\text{TUG-K}_{post}(\%) - \text{TUG-K}_{pre}(\%)}{100 - \text{TUG-K}_{pre}(\%)}. \tag{1}$$

3. Results and discussion

The results of the descriptive and inferential statistics for the pre-test and post-test are presented below. Figure 1 shows that the items of the posttest objectives achieved a higher percentage of correct answers, especially in the objectives associated with determining the change in velocity in an interval from the acceleration graph (81.1%), determining the velocity at a point from the graph of or position interval (78.2%), and selecting a graph from a given textual description (77%), which they are related to the

concepts of slope and/or area under the curve. Table 2 presents the results of the descriptive statistics of the pretest and posttest. The table shows a much higher mean percentage in the post-test.
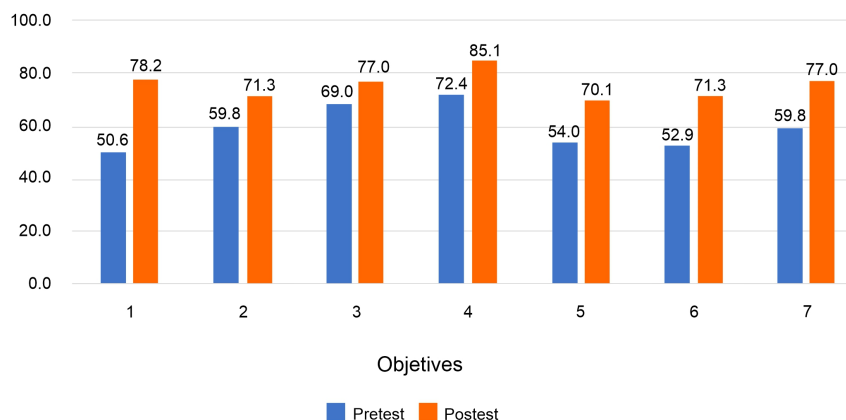

Figure 1. Comparison of the average of correct answers per objective between the pretest and posttest.

Table 2. Results between pretest and posttest.

	Average	N	DE	DE average
Pretest average	59.76	29	14.04	2.61
Posttest average	75.70	29	14.30	2.66

Figure 2 presents the comparison in box-and-whisker plots of the averages of the TUG-K instrument applied as pretest and posttest to the 29 students. The figure also shows that the mean and median of the pre-test are lower than those achieved in the post-test.
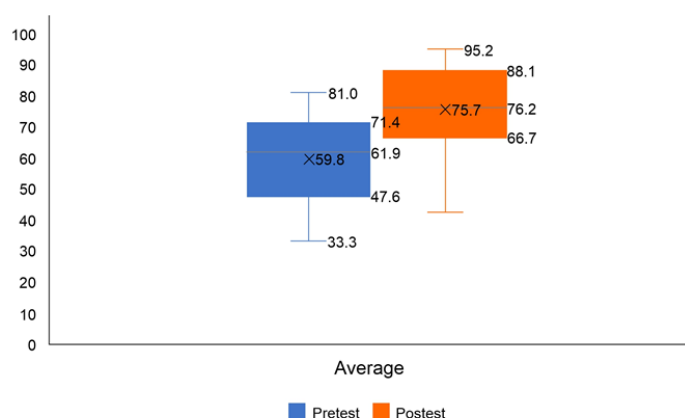

Figure 2. Box and whisker plot for both measurements.

Table 3 shows the results of the t-Student's hypothesis test for paired (dependent) samples, which makes it possible to compare the effectiveness of a didactic strategy [18], in this case active learning. These results show an increase in the conceptual level of the students at the end of the post-test (mean = 75.70; sd = 14.30) compared to the data obtained in the pre-test (mean = 59.80; sd = 14.03), the results are statistically significant ($p < 0.05$; t = -5.61; df = 28). A large effect size is obtained (d = 1.06) with a test power of 99.99%, exceeding the 80.00% considered large by [19].

By calculating the Hake factor (g), the students demonstrate a better understanding of the concepts of kinematics. The didactic intervention facilitated teamwork with favorable results, presenting a conceptual increase of the group after the development of the didactic intervention supported by active learning (see Table 4).

There was an increase in the percentage of students who answered the items in the posttest compared to the pretest, in agreement with [1] who showed improvements in the results of the posttest after the application of video analysis as a prelude to the kinematics laboratories. A mean Hake gain was achieved with a value of g = 0.40, presenting a conceptual increase of the group after the analysis of the video in the development of the activities, obtaining similar results to [1-6], who also in their study obtained a mean Hake gain.

The incorporation and application of new didactic and methodological strategies that are entertaining for students indicates conceptual improvements in them coinciding with [20], who suggest that, in the trends of educational public policies implemented in Colombia, new strategies that lead to teamwork and pedagogical innovation should be taught. Finally, active learning of physics has demonstrated its potential for improvement with respect to traditional teaching, even though the problems of teaching physics in the study context are characterized by the scarcity of economic resources and technology, coinciding with what [6,21,22] show in their research.

Table 3. Paired sampling tests.

	Differences							
	Average	DE	DE Average	95% confidence interval of the difference		t	df	Significance (tailed)
				Lower	Upper			
Pretest average – posttest average	-15.9	15.3	2.8	-21.7	-10.1	-5.6	28	0.000

Table 4. Hake factor.

Student groups	Average pretest TUG-K	Average posttest TUG-K	g
11th grade students	59.8	75.7	0.40

4. Conclusions

This report has presented the preliminary results of a proposal inscribed in active learning and is based on the students, through their experience, developing the kinematic concepts. The use of the test of understanding of graphs in kinematics has made it possible to identify both the importance of the specific difficulties of the students and the degree of achievement of the applied methodology. The results show that it is possible, with limitations at the infrastructure and technology level given in the study context, to obtain very satisfactory results. In a first analysis, most of the learning difficulties characteristic of kinematics and its representation through graphs seem to have been reduced. However, a small percentage of all students have difficulties in the use and interpretation of kinematic graphs.

After the analysis of the pre-test/post-test of the test of understanding of graphs in kinematics, it is shown that the didactic intervention supported by active strategies, especially group work, favored participation in all phases of the project and allowed significant learning in the students under study. The learning gain gives a mean value of 0.40, indicating a mean increase in the conceptual gain of the students through the implementation of the intervention supported by active learning, especially in the objectives associated with determining the change in velocity in an interval from the acceleration graph, determining the velocity at a point from the graph of or position interval, and selecting a graph from a given textual description, which they are related to the concepts of slope and/or area under the curve.

Likewise, the use of the pre-test results allowed us to identify both the importance of the students' difficulties and the level of achievement of the intervention methodology. Its use, both in the programming of activities and in the evaluation of learning, is important for the curricular planning process, which allows for the improvement of learning. In addition, the results obtained make us reflect on the usefulness of active learning in a context that has much less resources and economic and technological support in its physics laboratories, compared to laboratories in first world countries.

Finally, the experience carried out is, however, a first step in a more in-depth study. The test of understanding of graphs in kinematics is a multiple-choice test designed to assess students' understanding of kinematics graphs. The test could be used by researchers and teachers, to investigate the level of understanding of physics concepts of students in different grades and/or institutions, and to test the effectiveness of new materials for didactic use, among others.

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