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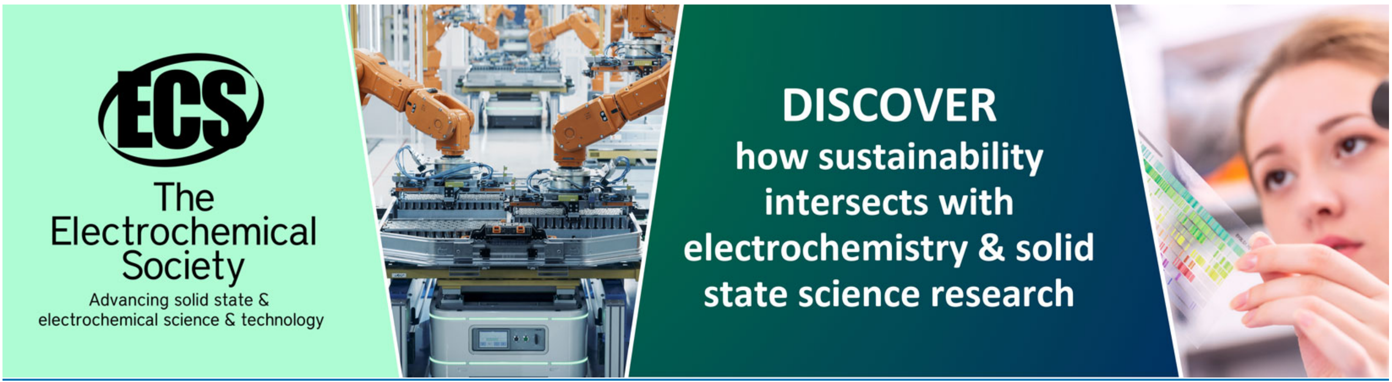

Didactic Engineering as a research method in physics teaching

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Abstract. Several mathematical concepts have application in physics; this paper reports the results of a pedagogical investigation based on the methodology known as didactic engineering, which has been proposed with the aim of improving the skills exhibited by a group of eleventh grade students from a private institution in the interpretation of kinematic graphs. The concept of the slope of the straight line and how this mathematical concept can represent velocity or acceleration according to the variables considered in the kinematics graph provided was enhanced in the pedagogical intervention. This methodology offers a process of internal validation, after comparing the results obtained in a knowledge test at two different points in time (pre-test and post-test). The results allowed us to identify improvements in all students in terms of basic kinematics graph interpretation skills, and a group of students stood out by advancing in more complex reasoning and interpretation processes. These results contribute to the improvement of the pedagogical practices of Physics teachers at secondary and middle school levels, making them more competent when they enter higher education.

1. Introduction

Didactic engineering arose around the 1980s as a simile of the work carried out by an engineer in which, to carry out a project, he or she starts from scientific disciplinary knowledge and then undergoes scientific supervision processes [1]. This current of research has its origins in the didactics of mathematics in France and arises "as a methodology for the technological realizations of the findings of the theory of didactic situations and didactic transposition" [2]. The term didactic engineering is used with a double function in the didactics of mathematics: it is used as a research methodology, and to produce teaching and learning situations; in the latter sense, and quoting [3], it is used: the term didactic engineering designates a set of class sequences conceived, organized, and articulated over time in a coherent manner by a teacher-engineer in order to carry out a learning project of a given mathematical content for a group of pupils; throughout the exchanges between the teacher and the pupils.

The project evolves according to the pupils' reactions to the teacher's decisions and choices; thus, didactic engineering is at the same time a product resulting from an a priori analysis, and a process, resulting from an adaptation of the implementation of a product according to the dynamic conditions of a class. As already mentioned, didactic engineering is based on the theory of didactic situations [4] and the theory of didactic transposition [5], in which from their vision they consider the didactics of mathematics as the analysis of the interactions between disciplinary knowledge, the educational system in which it is developed and the students with whom they work, following as the only objective the understanding and the correct appropriation of the concepts by the student.

Didactic engineering as a research method is characterized by following an experimental scheme based on classroom didactic realizations, which involves the conception, realization, observation and analysis of sequences designed to support the teaching process; in it, two levels are distinguished: (a) microengineering level characterized by focusing on the study of a specific topic, it is developed at the local level and focuses on specific classroom phenomena; while (b) the macro-engineering level addresses the same characteristics of the previous level with the complexity of adding the analysis of the teaching and learning processes.

Didactic engineering, as a research methodology based on classroom experimentation, differs from other methodologies in that it requires external validation, *i.e.*, it requires a control group and an experimental group to establish differences in the performance of the two groups by means of statistical comparisons. This is not the case of didactic engineering, which is located "in the register of case studies and whose validation is essentially internal, based on the confrontation between a priori and a posteriori analysis" [6].

In the following sections of this report, the characteristics of didactic engineering as a research method are presented, which not only contributes to the field of mathematics, but can also be extrapolated to other areas of knowledge, as in this case, which corresponds to the study of a subject in physics, essential in the process of developing scientific competences associated with classical mechanics, specifically with kinematics. Nowadays, both in the field of mathematics education and in the study of physics, the reading and interpretation of graphs is required, since they stimulate the cognitive processes necessary for the processing of information while contributing to the understanding of the phenomena associated with the concepts of variation and/or change. since everyone should have the ability to analyze information in a simple way, communicate it or use it to promote the learning of science as outlined in the work of [7].

Despite its importance, the interpretation of graphs is a challenging and complex process as outlined in the works of [8,9], who highlight that a good number of students are familiar with the elaboration of graphs, since they elaborate or manipulate them with ease. The difficulties become evident when they must perform the reverse process, i.e., when they must extract the characteristics of the information contained in them. One study highlights that physics teachers should promote the development of the ability to read and interpret graphs associated with the representation of the movement of bodies, in order to subsequently move on to the process of interpreting more complex graphs [10].

In this context, we report below the global results of an investigation that adopts the three levels defined by [11] in order to measure the effect of the didactic sequence designed and applied to the students who took part in this investigation. The levels of interpretation are as follows: (a) level elementary, involving the extraction of data or the isolated reading of points; (b) level intermediate, requiring the identification of trends in the relationship of variables; (c) level high, requiring a deep understanding of the behavior of the data.

2. Method

As mentioned in the previous section, the methodology called didactic engineering is used, in which four phases are developed in strict order: preliminary analysis, conception and a priori analysis, experimentation and a posteriori analysis. This methodology proposes the cyclical development of the stages in order to produce an improvement both in the educational system and in the teaching and learning processes, since through it, the quality of learning can be observed and evaluated according to the interventions made by the teacher in his or her pedagogical practice [12].

2.1. Preliminary analysis

In this phase of the research, an epistemological, cognitive, and didactic analysis is carried out on the content under study and its effect on the teaching and learning processes, from which the importance of understanding the concept of variation or change associated with Physics situations is derived. It is common to use graphical representations that, when interpreted, are not as simple as they seem, since, as [13] points out, students, regardless of their academic level, have difficulty identifying differences between the position, speed, or acceleration of a vehicle. object when in motion. In this sense, the difficulties that students have when interpreting graphs that represent various parameters associated with the passage of time are highlighted [10]. At this stage of the process, a knowledge test is applied that functions as a diagnostic test or pre-test, which is designed by the researchers in conjunction with the teacher in charge of the subject and a second physics teacher with more than twenty years of experience.

The test consists of three graphs, one corresponds to a position-time description, another is a position-time plot for uniform rectilinear motion (URM) and the last graph is speed-time for accelerated rectilinear motion (ARM) and from them, three questions are proposed in order to analyze the reasoning given by the students associated with the levels of understanding defined by Wainer H [11].

2.2. A priori conception and analysis

In this second phase, the researchers select relevant variables on which they will act in order to generate an effect on the problem under study. In this case, action was taken on didactic variables at micro or local level directly related to the organization of the didactic sequence that was applied [6-14].

The main variable considered was the type of semiotic register to be worked on in the situations proposed in the didactic sequence. As an initial activity, the description of the position of an object during a certain interval of time was presented in natural language, then the students were asked to identify how many stretches are described in the path followed by the object, then using a table they had to identify the characteristics of each stretch, highlighting the moment and position, both initial and final, to finish with the graphic representation of the situation in a position-time plot.

Subsequently, a series of variations are presented to the situation in order to induce the concept of speed from the definition of the slope of the straight line, *i.e.*, the quotient between the differential of the position and the differential of the time; then the group is asked to represent in a speed-time graph what happened in each section. Similarly, with this second graph, it is proposed to analyze what the slope represents, with the aim of inducing the concept of acceleration. This situation ends with the construction of the acceleration-time plot and is accompanied by a series of reasoning in which students are expected to identify that a situation of body movement can be associated with different graphical representations depending on the variable being analyzed as a function of time.

Once the students have reasoned about this situation, they are invited to carry out the reverse process, *i.e.*, they are given a position-time plot with which they must carry out certain activities: (a) identify the different moments of the body's movement; (b) describe what happens in each section of the trajectory described in terms of the variables at the beginning and end of the trajectory; (c) determine the velocity in each section; (d) construct the velocity-time plot; (e) determine the acceleration in each section; (f) elaborate the acceleration-time plot.

This process is repeated with some variations; six more situations are used in which the graphical representations are always provided, in two cases of position-time, then two graphs of velocity-time and two graphs of acceleration-time. In the cases of the velocity and acceleration plots, the order of the questions varies with the intention that the students carry out the inverse process that by resorting to the algebraic expressions that associate the variables, positions, distances and other necessary variables are calculated. In all cases, it is always proposed to start from the interpretation of the graph, to rely on the reasoning guided by the researcher in order to be able to describe and construct the remaining graphs (there should always be three graphs for each situation posed).

2.3. Experimentation

In this phase of the pedagogical process, the researchers carried out the fieldwork or application of the proposed didactic sequence, with the participation of 14 eleventh grade students from a group of 35 people enrolled during the year 2021, who are attending their educational institution, which is private in nature with an emphasis on training in Natural Sciences, *i.e.*, the students have been working on concepts in this area since the sixth grade of basic secondary education; the execution of the sequence was developed during two consecutive sessions of 120 minutes each.

The students, the teacher of the subject and the researchers participated in it, so that while the teacher developed the didactic sequence, one of the researchers supported the students by clarifying doubts and the other two researchers recorded all kinds of questions, actions and other answers given or expressed by the students in the execution of the activity to be subsequently analyzed and described in the following phase. Therefore, it is affirmed that this research adopts a field design where the data collection resorts to non-probabilistic sampling under the voluntary sampling technique.

2.4. Ex-post analysis and evaluation

In this last phase of the research, the data collected throughout the experimentation are analyzed, considering the observations recorded during the execution of the didactic sequence and in the process of comparing the results obtained from the diagnostic test (pretest) with those obtained when the knowledge test is applied again at the end of the pedagogical intervention (posttest). The data collected are processed in a descriptive way using resources such as frequencies, percentages and/or graphs, so it is concluded that a quantitative approach is adopted in the research.

3. Results

Regarding the profile of the students, it was determined that they are students of both genders, with an average age of 16.5 years. All of them have been at the school since sixth grade, which is equivalent to saying that they have been in contact with this subject for several years, but seven out of ten of them highlight as a negative aspect that they find some classes boring or demotivating. The following is a comparison of the answers given by the students in the two moments in which the evaluation was applied (pre-test and post-test) for each of the situations posed and for each of the proposed questions.

Situation 1, description of the trajectory of an object; Figure 1 represents the trajectory of an object for nine seconds from an initial reference position. Table 1 shows the items associated with each situation together with the results derived from the processing of the responses at both points of the assessment in order to compare the results.

Table 1. Comparative results in situation 1.

Item	Pretest	Posttest
What is the position of the body after the first five seconds have elapsed?	42.8% define body position in terms of elapsed time, while the remaining percentage have difficulties in establishing this link between body position and elapsed time.	85.7% identify the correspondence relationship between the initial and final values of time and position for each section of the path taken by the body. The remaining percentage explain what happens on each axis, but not jointly.
At what time interval does the body stop?	42.8% state that two seconds after having started the body movement, the body stops for another two seconds at 20 seconds from the starting point. The remaining percentage state that the body stops, confirming the question, but do not describe this situation in terms of either time or position.	85.7% say that the body stops when between two and four seconds have elapsed, but 64.3% of them justify this based on the horizontal behavior of this section of the trajectory by calculating the difference in the position at the two points along the section and determining that its value is zero. 14.3% associate stopping with the horizontal position of the straight line, but do not justify any process.
What happens to the movement of the body in the 6 to 9 second interval?	42.8% say that the body returns 45 units of distance to the starting point in those three seconds, while the remaining percentage say that the body is still moving, but do not elaborate on the description of the movement.	78.6% conclude that the body returns to the starting position because that section of the trajectory has a negative slope and is therefore decreasing. The remaining percentage mentions that the body returns but does not describe either values on the axes or relationships between the variables.
Wainer level of interpretation	42.8% are at the high level, while 57.2% are at the elementary level.	78.6% are at the high level, 7.1% at the intermediate level, and the remaining percentage at the elementary level.

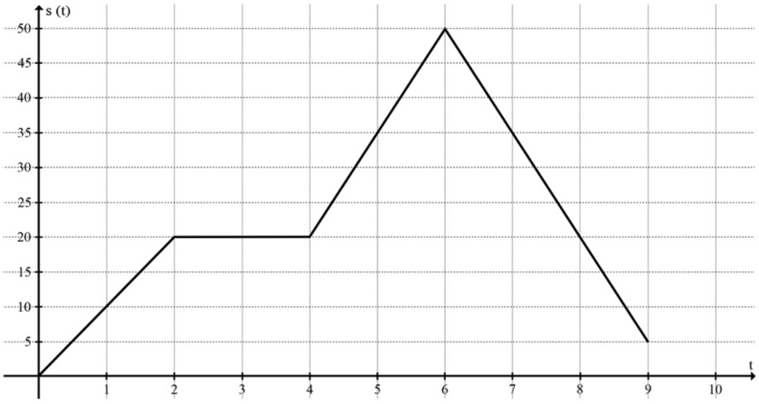

Figure 1. Trajectory followed by an object.

Situation 2, URM; an object in its motion travels a distance measured in meters with respect to time (t), s(t), measured in seconds, following the trajectory described in Figure 2. Table 2 shows the items associated with each situation together with the results derived from the processing of the responses at both points of the assessment in order to compare the results.

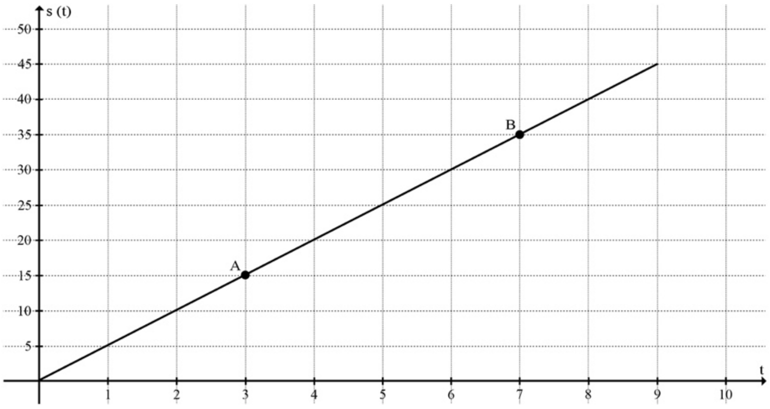

Figure 2. Trajectory followed by an object.

Table 2. Comparative results in situation 2.

Item	Pretest	Posttest
What is the velocity of the particle at point A and B?	35.7% say that the speed has the same value at both points, determining that its value is 5 meters for every second that elapses since the start of the movement. 35.7% describe the movement, but do not determine the speed, while 28.6% say that the line corresponds to an increasing function but do not interpret it in terms of the physical variables analyzed.	All the students conclude that the velocity at points A and B is the same, after using the expression of velocity. Of these, 85.7% state that the velocity increases steadily at a rate of 5 meters per second, since this corresponds to the value of the slope of the straight line drawn by the particle's trajectory.
Can the motion be said to be uniform rectilinear?	35.7% affirm that the movement is rectilinear due to the trajectory described by the particle, but do not conclude whether it is uniform or not. The remaining percentage provide descriptions of the movement in different moments in time, without directly answering the question.	All the students conclude that the motion described by the particle is rectilinear, but 71.4% of them argue that it is uniform because the position increases by 5 meters for every second that elapses, so this value is constant; while the remaining 28.6% do not provide any argument regarding the uniformity criterion.
Wainer level of interpretation	35.7% are at the high level, while 64.3% are at the elementary level.	71.4% are at the high level, while 28.6% are at the intermediate level.

Situation 3, ARM; Figure 3 describes the velocity of an object as time goes by. Table 3 shows the items associated with each situation together with the results derived from the processing of the responses at both points of the assessment in order to compare the results.

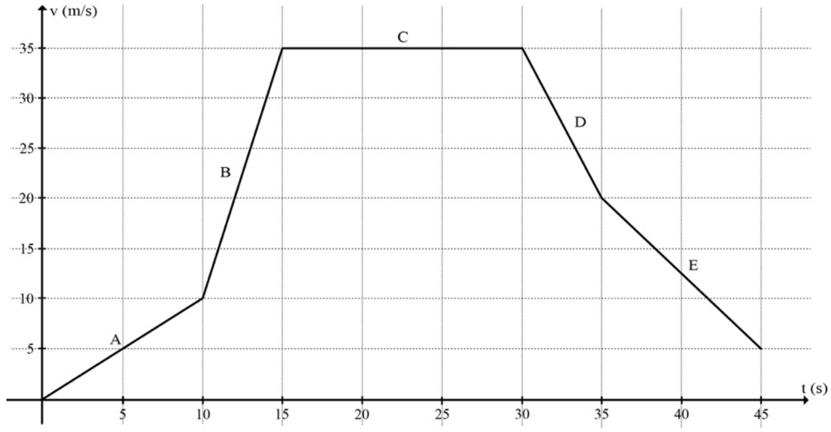

Figure 3. Trajectory followed by an object.

Table 3. Comparative results in situation 3.

Item	Pretest	Posttest
How long has the car been in motion?	71.4% state that the car moved for 45 seconds, but do not expand on their argument. The remaining percentage claim that in section C, the body stopped because the straight line is horizontal and deduct this time from the total time spent.	All students conclude that the body moves during the 45 seconds, and 85.7% of them complement their answer with a detailed description of the characteristics of each section of the route according to the variables involved.
In which section of the trajectory does the car driver apply the brakes?	All of them conclude that in sections D and E of the trajectory the application of brakes is evident, but 64.3% rely on the trajectory, while the others compare the initial and final value of the ordinate.	All of them conclude that brakes are applied in sections D and E of the trajectory, but 85.7% are based on the negative value of the slope, so that the variables are inversely related. The rest do not give any arguments for their answer.
In which section does the body experience the greatest acceleration?	78.6% relied on the inclination or elevation of the straight line in the analyzed section, which led them to conclude that section B was the steepest, while the others conclude that there is positive and negative acceleration in the described situation, but without supports.	92.8% resort to determining the slope of the straight line in each section and associate this value with the acceleration, so they conclude that the maximum acceleration is experienced in section B. The remaining 7.2% rely only on the elevation of the straight line to select this section, but do not argue any process. The remaining 7.2% rely only on the elevation of the straight line to select this section, but do not argue any process.
Wainer level of interpretation	35.7% are at the high level, while 64.3% are at the elementary level.	85.7% are at the high level, while 14.3% are at the intermediate level.

4. Conclusion

After the application of didactic engineering as a research method, it was possible to identify that the pedagogical process used by the Physics teacher at this educational institution is based on a traditional teaching approach that always follows the same solution algorithm, so that when situations outside this scheme are proposed to the students, they immediately cause difficulties that prevent them from obtaining better academic performance.

Therefore, it is concluded that part of the difficulties exhibited by students have been caused by the limitations arising from the teaching process, then in that sense, the implementation of the didactic sequence in the teaching process showed that if students are offered a variety of resources that enhance processes such as reasoning, problem solving along with the use and articulation of various semiotic registers of representation, their academic performance improves as occurred in this research; despite the limitations derived from the sampling and the fact that it is a micro-research exercise, it also provides a research background that invites Physics teachers to rethink their pedagogical processes and the competences they hope to develop in their students.

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