A tutorial-type activity to overcome learning difficulties in understanding graphics in kinematics

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Abstract

Understanding graphics in kinematics is one of the basic skills expected from engineering and science students. However, after administering the Test of Understanding Graphs in Kinematics (TUG-K), it has been found that students have many misconceptions and learning difficulties [1]. To overcome some of these difficulties, we created a tutorial-type activity that was designed with the inspiration of the Tutorials in Introductory Physics [2]. In this work, we show the results obtained after the implementation of our activity with students in Introduction to Physics, a remedial-type physics course for freshmen engineering students. Using the TUG-K as a pre and post-test, the implementation of this first version of the activity proves to have helped students. However, it also shows that the activity could be improved, hence ideas for the second version of the activity will be discussed.

Keywords: Understanding kinematics graphs, tutorial-type activity, remedial physics.

Resumen

Entender los gráficos de la cinemática es una de las habilidades básicas esperadas de estudiantes de Ingeniería y Ciencia. Sin embargo, después de administrar la Prueba de Comprensión de Gráficos en Cinemática (TUG-K), se ha encontrado que los estudiantes tienen muchas ideas erróneas y dificultades de aprendizaje [1]. Para superar algunas de estas dificultades, hemos creado una actividad de tipo tutorial que fue diseñada con la inspiración de los tutoriales de introducción a la Física [2]. En este trabajo se muestran los resultados obtenidos tras la ejecución de nuestra actividad con los alumnos de Introducción a la Física, un curso de Física correctiva para los estudiantes de primer año de Ingeniería. Utilizando el TUG-K como un pre y post-test, la ejecución de esta primera versión de la actividad demuestra haber ayudado a los estudiantes. Sin embargo, también muestra que la actividad podría ser mejorada, por lo tanto, se discutirán ideas para la segunda versión de la actividad.

Palabras clave: Comprensión de gráficas de cinemática, actividad tipo-tutorial, Física remedial.

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I. INTRODUCTION

The ability of understanding graphics in kinematics is a competence needed in the learning of universitary physics [1, 2, 3, 4]. These years has been observed that only 20% of students who are admitted in engineering careers are capable of taking their first university physics course [4]. Difficulties in understanding graphics are been mainly analyzed in kinematics, a mechanics area that requires the comprehension of concepts like position, displacement, velocity, acceleration and the relationships in themselves. The lack of mastery of interpretation of graphs has provoked that some physics educators [1, 2] have had develop research interests in this topic. [1] built a taxonomy of misconceptions in understanding graphics in kinematics and [2, 3, 4, 5] made research to deepen in this line.

Physics teachers utilize graphs in the teaching of kinematics, having the idea that students will easily understand them. [5] Considers that if we want capable students of using graphs as a learning tool either in laboratory or classroom, we have to be aware of the difficulties that students have when handling graphics.

In this study we were devoted to analyze the comprehension of graphic relationships between position, displacement, velocity and acceleration, based on some research about obstacles to interpret these concepts [1, 2]. Two mathematic concepts strongly related with our research were: 1) The concept of derivative and 2) The concept of integral. The first concept was associated with the study of understanding of velocity and acceleration. The second concept was associated with the study of understanding of change of velocity and displacement. This scenario obeyed to an intention of knowing the ability of founding a mathematical relationship between a graphic representation and a physical concept [1]. Furthermore, we wanted to know if students had the skill of reading some description and match the corresponding representation. The test of understanding graphics in kinematics (TUG-K) [2] explores the students' conceptual basis in this topic. TUG-K has 21 items, which evaluate fundamental kinematics concepts in their graphic representations, having as options the most popular misconceptions of the students.

Also, we implemented a tutorial-type activity, inspired by University of Washington tutorials [6], an active learning methodology that confronts the students with their conceptual difficulties.

Our research objective was to improve the understanding of graphs in kinematics with a type-tutorial activity.

In this work, we explain our design of research in section II, the test that we use as research instrument and the student populations involved in the investigation. We show results in section III, followed by discussion in section IV. Conclusions and comments for future research are located in section V.

II. METHODOLOGY

A. Design of research

We divide our work in three phases: 1) the implementation of a diagnostic tool (TUG-K), 2) to discover our test objectives to improve in students and 3) to design of a tutorial-type activity.

In phase 1), we test the initial state of students in understanding graphs in kinematics and design or redesign items by applying of TUG-K. This test was applied pre and post instruction.

In phase 2), we administrate TUG-K to novice and expert students, after that we grade test and define priorities in type-tutorial design.

In phase 3), we randomly select experimental and control groups and applied our tutorial-type activity.

In phase 4) experimental groups took TUG-K again.

B. Instrument

Beichner [2] designed a test what enabling us to have a detailed view of student´s mastery on kinematics graphs. Part of his work was to review previous studies, noting that some students' difficulties are: 1) to think that a graph is a picture of the situation, 2) to confuse the height of a graph with its slope value and 3) indistinct use of the equation $v = d/t$.

TUG-K [2] examines the graph-understanding skill, presenting as options the most common misconceptions. A modified diagnostic tool was generated [8], which assesses the understanding of displacement, velocity and acceleration, and the relationships among them.

The content of the test TUG-K was divided in 7 objectives, which are classified in Table I.

TABLE I. Objectives of the TUG-K.

Given	*The student will*
1.Position-time graph	Determine velocity
2.Velocity-time graph	Determine acceleration
3.Velocity-time graph	Determine displacement
4.Acceleration-time graph	Determine change in velocity
5.A kinematics graph	Select another corresponding graph
6.A kinematics graph	Select textual description
7.Textual motion description	Select corresponding graph

We worked with a modified TUG-K [8], which was prepared according to the needs of this study. It has the same objectives but different kind of items. TUG-K [2] has 21 items and our modified version [8] has 26 items.

In Table I there are seven objectives which evaluate physical concepts. These objectives have two mathematical concepts associated. Objectives 1 and 2 are associated with the concept of derivative, objectives 3 and 4 are associated with the concept of integral. Objectives 5, 6 and 7 assess how the student take a description and relate it with a graph and viceversa.

Modified TUG-K [8] was taken by all the students who participated in our study. We used the diagnostic tool before instruction to know the initial conceptual state and after instruction to know the final conceptual state. The test had a duration of 25 minutes.

C. Participants

We had three kinds of student populations in our study. The first population was the non-experts, 18 year-old, who were students taking Remedial Physics. They took the TUG-K [8] after having been studying graphs in kinematics. We were interested in their TUG-K [8] results because they would give us the real final conceptual state. With their results we could know initial difficulties in learning to cover in our tutorial-type activity.

The second population was experts, who were junior Physics engineering students, 20-year-old. With their TUG-K [8] results we could obtain our educative goal, because they gave us the ideal knowledge state for students who had taken kinematics lessons.

A third population was the Remedial Physics students who would answer the tutorial-type activity. This population had two statuses: Novices and Remedial Physics students (RPS). They were known as novices before taking the tutorial-type activity and were named Remedial Physics students (RPS) after taking the tutorial-type activity.

D. The tutorial-type activity

Tutorials in Introductory Physics [7] are an academic basis to design an educational activity. Each tutorial is result of some research years, and has a structure that puts the student in the center of his own learning process.

The tutorial-type activity showed an area-under-the curve problem in a velocity graph without clarifying the required operation. Also, it asked student to identify the physical variable that appears in the horizontal axis and to calculate geometrically and physically the same operation. Later, the student would compare results of both methods and write a kinematics concept related to obtain velocity.

This process was performed for constant and variable velocities with the intention of the student to demystify the idea of a non-increasing constant velocity. It was also expected from the student to generalize the operation for both cases. The same idea was applied to acceleration, targeting the difficulty of the student to recognize the change of velocity as the physical quantity associated to the area under the curve in an acceleration graph, both in the constant and variable cases. The tutorial-type activity was applied in Spanish to Mexican students.

III. RESULTS

In the first phase, we applied TUG-K [8] to non-experts. These students took kinematics lessons with methodologies less active.

TABLE II. Results in a post-instruction test to Physics Remedial students.

Objective	Score
1	0,43
2	0,48
3	0,41
4	0,26
5	0,46
6	0,57
7	0,57

Results in Table II suggested that objectives 3 and 4 could be our research difficulties. These results graded understanding of velocity and acceleration, associated with the integral significance. With these objectives in mind we designed a tutorial-type activity, which had to be covered in a 50-minute lesson. It was answered in 4-student teams.

TUG-K [8] was applied to 63 expert students, who obtained higher results that non-experts. These expert students have been utilizing kinematics concepts along two university years.

TABLE III. Results in TUG-K [8] to Junior Physics Engineering students.

Objective	Score
1	0,76
2	0,81
3	0,68
4	0,65
5	0,77
6	0,79
7	0,75

This population was supposed to dominate kinematics concepts. They were taking advanced physics topics when answered the TUG-K [8]. It can be observed in Table III that despite their score was higher than non-experts, they had lower scores in objectives 3 and 4 than the rest of objectives. This global result told us what could be our educative goal and possibly will limit our tutorial-type activity.

In the experimental semester, 196 novices answered the TUG-K [8] before taking the tutorial-type activity. After that, we implement the tutorial-type activity and evaluated their final conceptual state by applying TUG-K [8] again.

RPS obtained different scores.

TABLE IV. Results obtained by Remedial Physics students.

Objective	Score Pre	Score Post	ΔS (RP)
1	0,29	0,46	0,17
2	0,26	0,58	0,32
3	0,26	0,58	0,32
4	0,23	0,46	0,2
5	0,23	0,47	0,24
6	0,34	0,53	0,19
7	0,27	0,5	0,23

We were interested in improving the score in objectives 3 and 4. We can observe that students who realized the tutorial-type activity had a better score than students who didn´t have one active learning educational activity (see Table II).

We analyzed the problem with another parameter, the gamma factor Γ, which is a wrong models concentration [9]. In order to calculate the gamma factor, we have to follow an equation.

$$\Gamma = \frac{\sqrt{m-1}}{\sqrt{m-1}-1} \times \left(\frac{\sqrt{\sum_{i=1}^{m} n_i^2 - S^2}}{N-S} - \frac{1}{\sqrt{m-1}} \right). \quad (1)$$

Where:
m: Number of test options.
n_i: Number of students who selected the i-th option.
n: Total number of students.
S: Students fraction who rightly answer each item.

The Γ factor indicates only an incorrect model if its value hangs around 0.7-0.9 and S values of 0-0.2. If Γ has same previously mentioned values but S values of 0.2-0.7, we would be talking about 2 incorrect models in a determined population. An ideal educational situation could be to take students from the many incorrect model zone to one incorrect model.

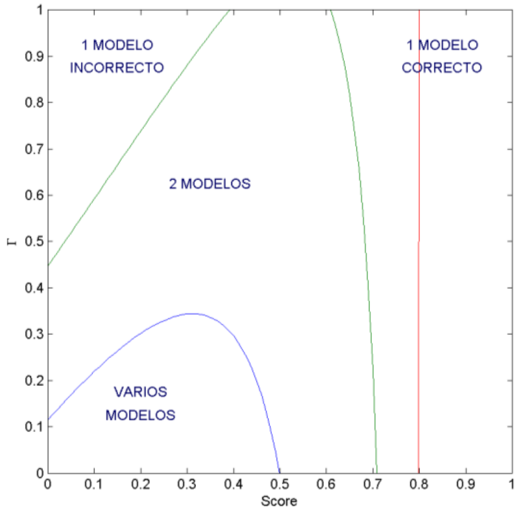

FIGURE 1. ***S-*** *Γ* graphs divided by zones.

In this work TUG-K [8] objectives were represented like dots in this kind of graph. A ***S-*** *Γ* graph was generated for each Remedial Physics population to know how were scattered incorrect models. Fig. 1 was included with illustrative intentions. The best zone in Fig. 1 is the last fringe, because it represents an easily detectable incorrect model.

Students' results under the light of score and gamma factors are summarized in table below.

TABLE V. TUG-K [8] results for different populations involved in this study.

Population	Novices		Remedial Physics students		Experts	
Objective	*S*	*Γ*	*S*	*Γ*	*S*	*Γ*
1	0,29	0,56	0,46	0,64	0,76	0,57
2	0,26	0,53	0,58	0,67	0,81	0,68
3	0,26	0,46	0,46	0,63	0,68	0,40
4	0,23	0,61	0,47	0,64	0,65	0,57
5	0,23	0,44	0,49	0,61	0,77	0,58
6	0,34	0,53	0,53	0,72	0,79	0,62
7	0,27	0,44	0,50	0,62	0,75	0,63

The values obtained for *S*- *Γ* concentration analysis have two approaches. The first approach, based on *S* results, indicates that the more score, the more students who grade better in TUG-K [8]. The second approach, based on *Γ* suggests that under determined values of *S*, some values of *Γ* reflect that participants in this study are nearer to decrease their incorrect models to one incorrect model.

IV. DISCUSSION

The common misconceptions showed to students in TUG-K [8] in objective 3 were:

1) displacement Δx = time t/distance d.
2) Δx = straight lecture of velocity.
3) $\Delta x = t*d$.
4) Δx = slope of a velocity-graph.
5) Δx = slope of random data.

The common misconceptions showed to students in TUG-K [8] in objective 3 were:

1) Identification of change of velocity in an increasing acceleration graph.
2) Identification of change of velocity in a constant acceleration graph.
3) Identification of change of velocity in a decreasing acceleration graph.
4) Identification of change of velocity in an increasing acceleration graph.
5) Identification of change of velocity in a decreasing acceleration graph.

These misconceptions were cognitively included in the tutorial-type activity, which apparently decreased the distance between experts and novices in the understanding of graphs on kinematics.

Even though, the challenge of moving novices to experts still exists. The search of reduction of *Γ* factor also could help to improve TUG-K [8] score. In Table V we have smaller *Γ* values for experts than for novices. This situation represents a little probability of Γ living in a random zone, which would improve the clarity to distinct misconceptions.

We show results of novices before educational intervention, each dot represents one TUG-K [8] objective.

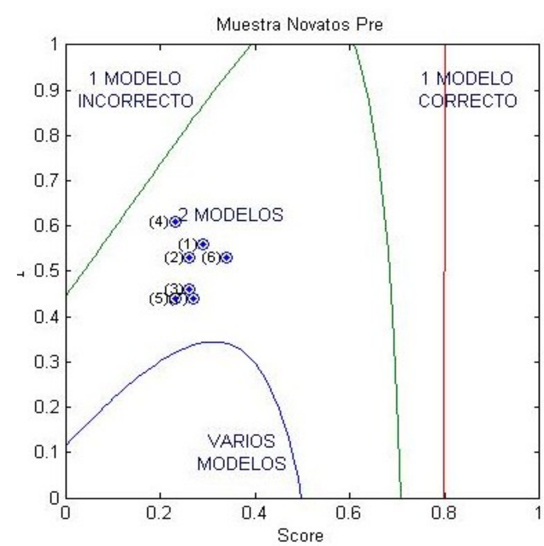

FIGURE 2. Novices initial conceptual state.

The objectives 3 and 4 had the lowest values, next to objective 5. After the intervention, students obtained different grades.

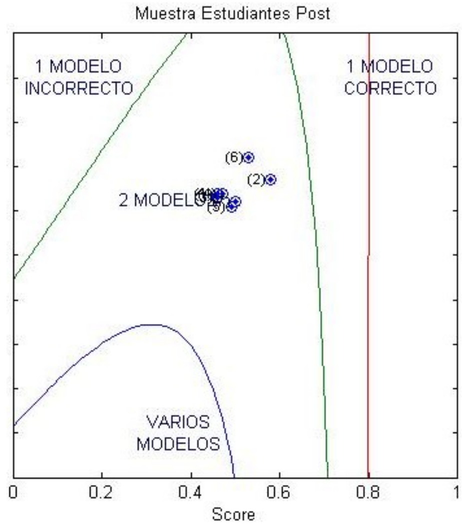

FIGURE 3. Remedial Physics students final conceptual state.

The movement of dots suggests that some misconceptions changed in students' preferences. The right movement indicates us that our students approached a little to a state with one correct model.

V. CONCLUSIONS AND FUTURE RESEARCH

In this work we show results of a tutorial-type activity implementation to improve the understanding of kinematics graphs. In order to have a structure, we follow next phases: a) To modify a diagnosis tool to evaluate kinematics graphs [8], b) to obtain basic information to elaborate a taxonomy of difficulties, c) to obtain conceptual states from experts, non-experts and novices, d) to design a tutorial-type activity to confront learning difficulties, e) to implement this activity, f) to evaluate students before and after instruction.

We identified abilities that students need to improve. We worked with objectives 3 and 4 during our research and obtained some good results, but, it would be desirable to reach experts knowledge's in application of area under the curve. We observed that determination of position given a velocity graph and change of velocity graph given an acceleration graph could be taken as research topics.

A tutorial-type activity helps students to think by themselves and to build their knowledge.

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