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# TLS aimed to stimulate the attainment of a metacognitive strategy on kinematics models, within a cooperative learning approach

*(TLS para produzir estratégias metacognitivas sobre modelo cinemáticos num contexto de ensino cooperativo)*

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This manuscript proposes a teaching-learning sequence (or TLS) for undergraduate students with prior calculus background about kinematics models, based on metacognition and cooperative learning. It aims to help them to acquire a well-structured, simple and short strategy to check their graphs of position, velocity and acceleration, in which the method is based on derivatives. It may be used in courses addressed with traditional methods, but it is designed for active learning approaches. This TLS was twice piloted, mainly with sophomore engineering students, having positive results, and it is offered as a contribution for the growing international repository of physics TLSs.
**Keywords:** TLS, kinematics, cooperative-learning, metacognition.

Este manuscrito propõe uma sequência de ensino-aprendizagem (ou TLS) para alunos de graduação, com conhecimentos prévios de cálculo sobre modelos em cinemática, com base em metacognição e aprendizagem cooperativa. Destina-se a ajudá-los a adquirir uma estratégia bem estruturada e simples para conferir os seus gráficos de posição, velocidade e aceleração, que são a base do método. Esse esquema pode ser usado em cursos tradicionais, mas é projetado para abordagens de aprendizagem ativa. Este TLS foi aplicado duas vezes, principalmente para estudantes de engenharia do segundo ano, tendo resultados positivos, e é oferecido como uma contribuição para o crescente repositório internacional de TLSs na área de física.
**Palavras-chave:** TLS, cinemática, ensino cooperativo, metacognição.

## 1. Introduction

The result of a pre test for a lab session taken during the 2013 fall semester suggested that students were capable of *memorizing* the acceleration model for the free fall kinematic model, whilst not showing any evidence towards understanding its significance at any level. This conclusion was made under the light of the evidence analyzed in previous work [1].

The aforementioned work motivated the design and validation of a TLS on the matter, product that is addressed in the present manuscript.

The proposed TLS rests on two theoretical backgrounds: metacognitive skills and cooperative learning, and it is sequenced according to the Kolb cycle.

### 1.1. Metacognitive skills

Metacognitive skills refers to acquired abilities that *allows monitoring, guiding, steering, and controlling one's learning and problem-solving behavior*, as explained by Veenman [2] and, in few words, emerge on certain activities expressly done by the students. They can be divided by the moment they occur, as follows:

- Onset of task performance. Activities that allow the student to be prepared for following a task, by refreshing prior task and metacognitive knowledge.
- During task performance. Activities that guide and control the task itself, including: checking, correcting and note taking.
- At the End of task performance. Activities that allow the student to appraise, assess, interpret and learn from the task's results.

Evidence shows that metacognitive skills are part of an abilities repertoire that subjects use, more than being domain exclusive [2]. This is interesting, because this justifies the importance given to derivatives during

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the TLS process and the capability of an easy extension to other kinematics model cases.

The proposed TLS was designed following a top-down model, in which a guided program (the method) allows activating metacognitive skills in order to correct errors while performing a task.

### 1.2. Cooperative learning

The proposed TLS falls into the Informal category of cooperative learning strategies, according to David W. Johnson and Roger T. Johnson's work [3].

Accordingly to the Johnsons's description, the essential elements the TLS should have in order to succeed as a learning activity are: positive interdependence, individual and group accountability, promotive interaction, in-task work plus teamwork skills, and group processing. All this elements are taken into account in the TLS, in order to maximize it's effectiveness.

Also, small groups, pre-tests and post-tests are recommended by the aforenamed authors, characteristics also covered by the proposed TLS.

### 1.3. Kolb learning cycle of four stages

Experience reforms what we learn, and learning is an emergent process. The Kolb experiential learning cycle recognizes four different stages: *having* an experience, *reflecting* about it, *learning about* the experience and *applying* the acquired knowledge into new grounds This epistemological view is opposed to the traditional one, because the last perceives learning as a fixed outcome [4].

## 2. Methodology

Two pilot studies were done with the kind participation of sophomore and junior engineering students from the Pontificia Universidad Católica de Valparaíso. The first trial allowed the author to correct the material related to stages 2 and 3 of the Kolb cycle, while the second trial was used to quantify a gain factor and explore beyond stage 4.

All students were firstly assessed with a pre-test on derivatives and a classic kinematics question about free fall. Also, after the first pilot study, the material was peer reviewed, and thus, improved. Finally, the second pilot group was assessed with a post-test and a Likert scale test about their beliefs on their TLS experience.

The methodology follows a mixed (qualitative/quantitative) approach.

### 2.1. TLS full description

The TLS is designed for a full teaching period of 90 minutes. Students form groups of three members with heterogeneous skills, chosen by the professor. This can be done accordingly to the pre-test results if quickly observed, or by previous grades or other diagnostic test available to the professor.

It does not need active learning classrooms, and the carbon footprint is really low. One instructor for every 10 groups was enough during the trials, so it is recommended that bigger classes involves teaching assistants.

The TLS has 4 stages, following the Kolb experiential learning cycle, as explained below.

#### 2.1.1. Stage 1: Concrete experience

In order to stimulate the student's engagement with the TLS, they are confronted with their own need to assess their initial performance or initial task knowledge. Thus, a pre-test on derivatives and a pre-test on kinematics are individually done, as shown in Appendix A.

Then, the professor allows them to interact with each other, sitting in triads. It was observed that students were *extremely* eager to find out about their performance, suggesting the *need* explained above was effectively initialized. Clearly, their intrinsic motivation was awaken.

The given order of the pre-test was intentioned to avoid contamination on the kinematics assessment, because it is mainly a diagnostic evaluation.

These activities are consistent with the *onset of performance* metacognitive skills description, allowing the students to activate prior knowledge, at the same time generating doubts that will be matter of discussion during the rest of the TLS. It is important to help them activate their calculus background, since the goal of the activity is *physics* oriented.

#### 2.1.2. Stage 2: Reflective observation

With the triads formed, students receive 1 tutorial and 2 different color pens by group. The first page of the material (see Appendix B) belongs to this stage, and it address the *during performance* metacognitive skills, because they are asked to take notes.

This first page consists on the exact same kinematics question assessed on the pre-test. As we can expect from the literature, just the reflective, cooperative working approach will allow them to correct their previous answers, but it was observed that not all of them achieved perfection. It was effectively observed how the Johnsons's elements emerge, bringing out the teamwork skills, very much appreciated on the STEM careers.

#### 2.1.3. Stage 3: Abstract conceptualization

The third stage should help the students gaining both knowledge and skills about their experience. This stage is addressed on the second page of the material (see Appendix B), which also covers the *during task performance* metacognitive skills, because they are asked to check and correct their previous work according to a method, and taking notes.

This second page consists on explaining the characteristics of the free fall model, followed by the derivative definitions of acceleration and velocity (with the objective of refreshing and activating prior knowledge, in relation with the derivatives pre-test) intercalated by control-and-checking questions to show the students *how to* evaluate and correct their prior activity results (the method). The tutorial asks the students to write down how the process goes. As we can see, this follows the theoretical background on which the TLS stands.

The last task of the tutorial addresses specifically the *at the end of task performance* metacognitive skills, since they can interpret and summarize their work.

The professor can change the pre-test question and the abstract conceptualization accordingly (which is the first paragraph in page 2 of the tutorial, see Appendix B) i.e. a circular motion with tangential acceleration model, and the TLS's spirit remains the same because as stated before, metacognitive skills are not domain exclusive.

#### 2.1.4. Stage 4: Active experimentation

The students need to try out their skills into new situations. They are given a new sheet with similar kinematic questions about graphs on position, velocity and acceleration (see Appendix C). According to the chosen epistemological point of view, the cycle should repeat itself, if the students successfully integrated the strategy into their own metacognitive repertoire. We will se to that with a small post-test trial.

The following figure (Fig. 1) integrates the framework and shows how the different elements work with each other.

## 3. Results and discussion

### 3.1. First pilot group results

From 20 sophomore and junior students, none of them had a correct pre-test on the assessed free fall model, even though they had previous instruction on the matter.

The pre-test on kinematics and the first page of the tutorial were scored from 0 to 3, 1 point for each of the three graphs. The results are presented on Table 1. This allows identifying the moment in which the students corrected their models.

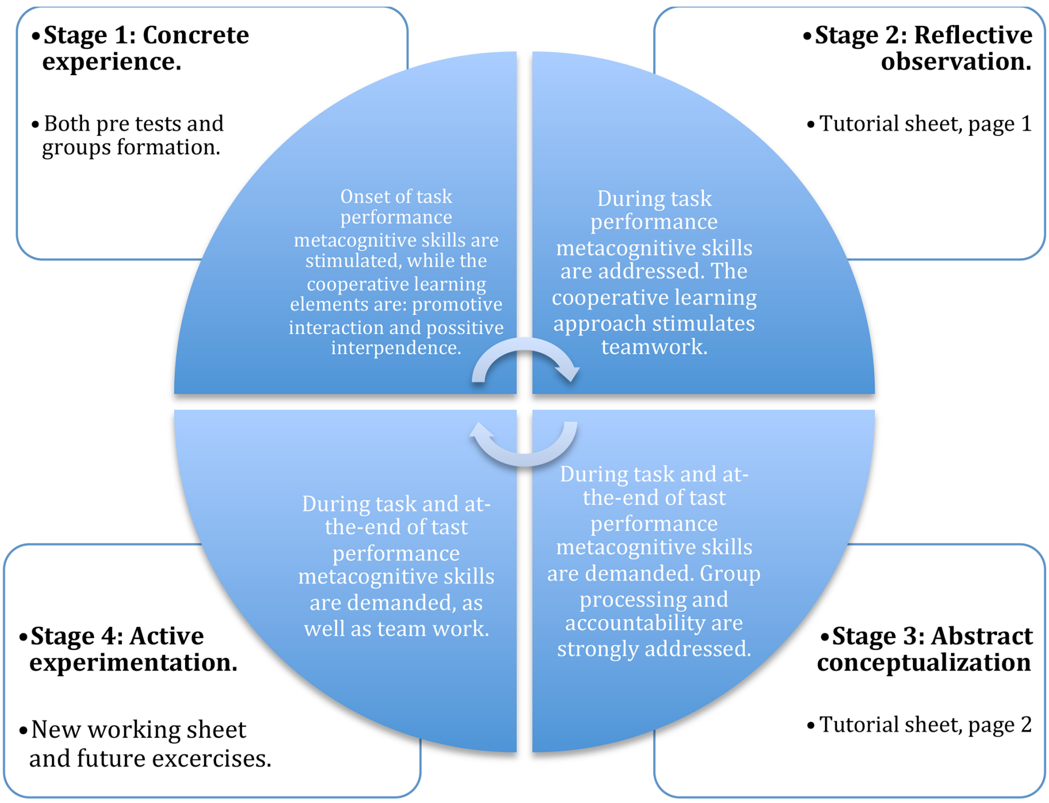



Figure 1 - Interaction flow between the theoretical background topics and the TLS, including the Kolb cycle, the metacognitive skills (accordingly to their emerging moment), and some cooperative learning elements.

Table 1 - Results for the first pilot group. Stages a, b and c refers to the Kolb learning cycle. The pre-test score is the average from the members of each group, while the tutorial's scores are the group's result. All scores range from 0 to 3. A distinction is made about the *moment* in which the students corrected their models, on the last column of the table.

| Group | Stage a: Pre-test score (average) | Stage b: First part of the tutorial score | Stage c: Second part of the tutorial score | Comments |
|---|---|---|---|---|
| 1 | 1 | 2 | 3 | The group successfully corrected the models in stage c |
| 2 | 1 | 3 | 3 | The group successfully corrected the models in stage b |
| 3 | 1 | 2 | 3 | The group successfully corrected the models in stage c |
| 4 | 0,67 | 1 | 2 | The group makes a partial correction, because their velocity graph ends at mid air, but it is still a linear model with a correct negative incline |
| 5 | 1 | 3 | 3 | The group successfully corrected the models in stage b |
| 6 | 1,67 | 2 | 3 | The group successfully corrected the models in stage c |
| 7 | 0,67 | 3 | 3 | The group successfully corrected the models in stage b |
| 8 | 1,33 | 2 | 3 | The group successfully corrected the models in stage c |

From Table 1, it is possible to say that 3 groups successfully corrected their prior models only by working in a cooperative way. On the other hand, 4 groups were able to make the final corrections to their models with the help of stage c (abstract conceptualization) of the TLS. Only one group failed in totally correcting their work, but they did achieve a partial correction, which must be taken into account as a positive effect since they started with a poor pre-test average score.

### 3.2. Second pilot group results

29 sophomore and junior students participated in the final validation of the TLS. 15 students agreed to participate on the TLS analysis, and all of them agreed to participate in the final anonymous questionnaire. The results were similar to the first trial, and are shown in Table 2.

Group 5 was very interesting to work, they could not agree on their own mistakes, mainly due to a fail in teamwork. With some extra guidance from the professor, this was overcome.

The following images (Figs. 2 to 4) are scans from the actual pre-test and TLS work.

### 3.3. Second pilot group opinions

An anonymous questionnaire of a Likert equal interval scale was made immediately after the last TLS stage, in order to assess the student's beliefs on the experience, using 1 for strongly disagree and 5 for strongly agree assuming that the values are equally spaced.

Affirmations used and their respective mode (m) are shown in Table 3.

The categories are the following: Affirmations 1, 2 and 10 belong to Category I about a superficial comprehension and appreciation of the TLS. Affirmations 3, 4, and 5 belong to Category II, assessing the theoretical background of the TLS. Affirmations 6, 7, 8 and 9 represent Category III, about how they perceived the strategy itself, and how they stand about it.

Null hypothesis H: Uniform values ranging from 1 to 5 are given to the affirmations.

An analysis about the above, is offered in Table 4.

Table 2 - Results for 15 students from the second pilot group. In this case, three groups achieved their corrections during the stage b of the TLS, while the other three groups successfully corrected the models during stage c.

| Group | Stage a: Pre-test score (average) | Stage b: First part of the tutorial score | Stage c: Second part of the tutorial score | Comments |
|---|---|---|---|---|
| 1 | 0,67 | 3 | 3 | The group successfully corrected the models in stage b |
| 2 | 1,67 | 3 | 3 | The group successfully corrected the models in stage b |
| 3 | 1 | 2 | 3 | The group successfully corrected the models in stage c |
| 4 | 1,33 | 3 | 3 | The group successfully corrected the models in stage b |
| 5 | 0 | 0 | 3 | The group successfully corrected the models in stage b This group needed more guidance from the professor than the rest of the course, mostly because of their poor prior knowledge |
| 6 | 0,33 | 0 | 3 | The group successfully corrected the models in stage c |

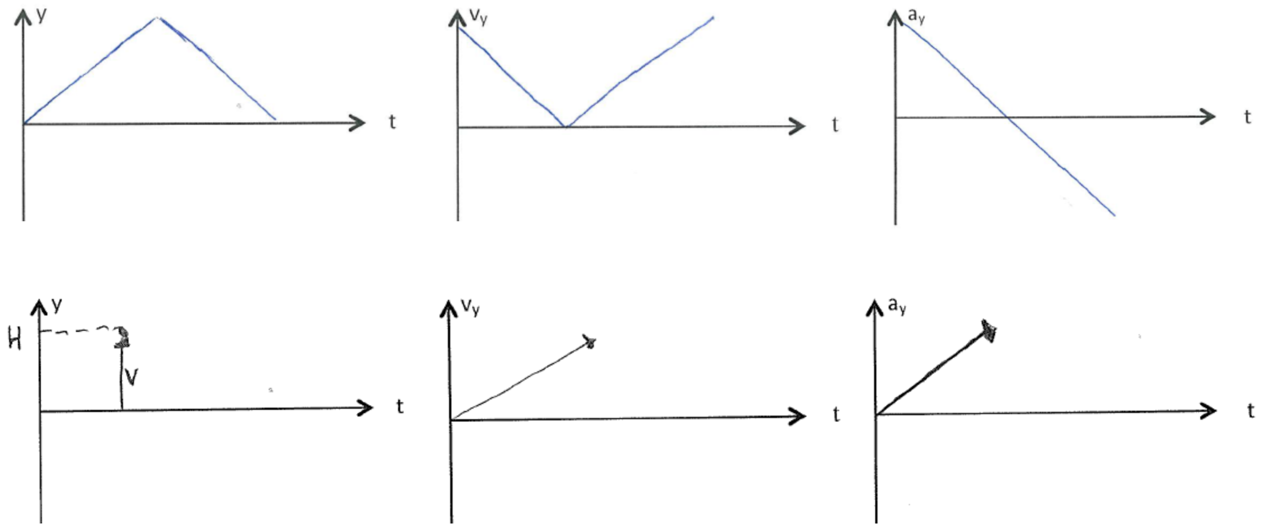



Figure 2 - Two student's pre-test results about a free fall model. An in-deep analysis of emerging categories was avoided, to concentrate on the TLS construction. Nevertheless, the examples fall into the known misconceptions.

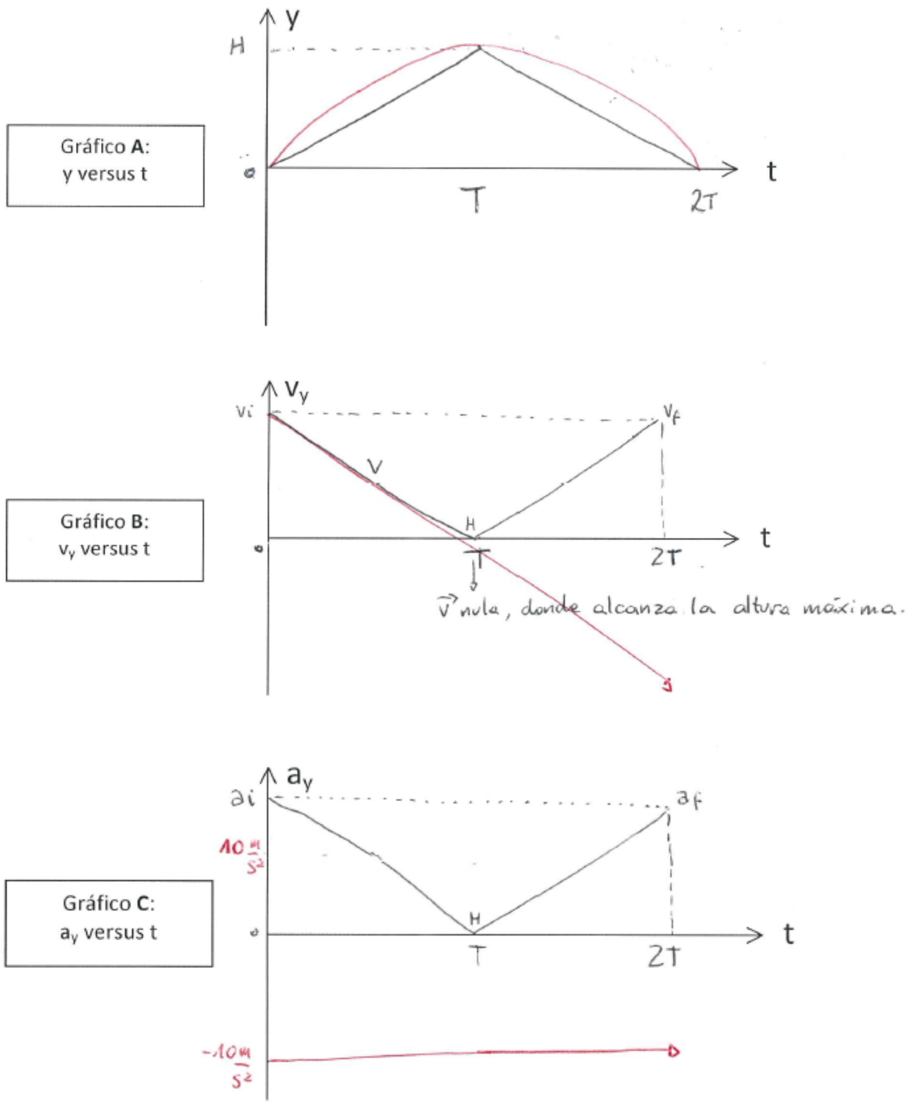



Figure 3 - Tutorial sheet, page one, for group 6. It shows the correction they performed using a red pen.

**Responde en el siguiente espacio:** El gráfico **C**, ¿es consistente con toda la explicación anterior? ¿Por qué? En caso de que tu respuesta sea negativa, corrige el gráfico **C** con lápiz de otro color (no borres el original) y señala cuál fue la equivocación.

Si consiste, porque g es constante para toda la trayectoria de un cuerpo dentro del planeta.

**Segundo Paso:** La aceleración se define como la derivada de la velocidad en función del tiempo $a_y = \frac{dv_y}{dt}$.

**Responde en el siguiente espacio:** ¿Es esto consistente con la relación entre los gráficos **B** y **C**? ¿Por qué? En caso de que tu respuesta sea negativa, corrige el gráfico necesario con lápiz de otro color (no borres el original) y señala cuál fue la equivocación.

Nos equivocamos, porque el ejercicio es de caída libre y la aceleración es constante.

**Tercer Paso:** La velocidad se define como la derivada de la posición en función del tiempo $v_y = \frac{dy}{dt}$.

**Responde en el siguiente espacio:** ¿Es esto consistente con la relación entre los gráficos **A** y **B**? ¿Por qué? En caso de que tu respuesta sea negativa, corrige el gráfico necesario con lápiz de otro color (no borres el original) y señala cuál fue la equivocación.

Nos equivocamos, porque es una línea recta.

Figure 4 - Tutorial sheet, page two, for group 6. Students took notes in the spaces, according to the application of the method.

Table 3 - Affirmations questionnaire to generate information about students' opinions and beliefs regarding their experience traditionally scored from 1 (completely disagree) to 5 (completely agree) by a Likert equally spaced scale. The most frequent value (or mode, m) is shown on the second column. N = 29.

| Affirmation | m |
|---|---|
| I was able to easily understand the step by step instructions of the tutorial | 5 |
| I consider that this tutorial is pertinent to our Course | 5 |
| I believe that the tutorial stimulated in me a cooperative working approach towards my group companions | 5 |
| I consider that I could have satisfactory answered the tutorial individually, without the help from my group companions | 2 |
| I consider that we could work really well, without the constant orientation from our Professor | 5 |
| I was able to analyze the consistency between the graphs, using the derivative concept | 5 |
| I consider that the tutorial aims to teach me a strategy for construction and check of position, velocity and acceleration graphs | 5 |
| I consider that in the future, I will be able to use the same strategy shown in the tutorial, in similar exercises, by my own | 4 |
| Previously to the tutorial, I had a strategy to construct and check position, velocity and acceleration graphs, similar or more efficient | 2 |
| I would recommend this tutorial to a friend, undergoing the same Course | 5 |

Table 4 - Frequency percentages of the questionnaire. Column A corresponds to Likert levels 1 and 2. Column B corresponds to Likert levels 4 and 5, while column C represents the neutral value. The Chi square was used in order to explore the null hypothesis. N = 29.

| Category | Affirmation | Frequency values percentage % | | | |
|---|---|---|---|---|---|
| | | A Disagreement (1,2) | B Agreement (4,5) | C Neutral (3) | p-value |
| I | 1 | 0,0 | 93,1 | 6,9 | <0,01 |
| | 2 | 0,0 | 96,6 | 3,4 | <0,01 |
| | 10 | 0,0 | 93,1 | 6,9 | <0,01 |
| II | 3 | 0,0 | 86,2 | 13,8 | <0,01 |
| | 4 | 41,4 | 20,7 | 37,9 | 0,343 |
| | 5 | 10,3 | 13,8 | 75,9 | <0,01 |
| III | 6 | 13,8 | 82,8 | 3,4 | <0,01 |
| | 7 | 0,0 | 100,0 | 0,0 | <0,01 |
| | 8 | 3,4 | 82,8 | 13,8 | <0,01 |
| | 9 | 41,4 | 31,0 | 27,6 | 0,639 |

As can be seen from Table 4, in most cases the students showed a clear inclination to a certain value (thus, disregarding H), except for affirmations 4 and 9, in which students showed a well-distributed opinion between agreement, disagreement and neutral values.

In the case of affirmation 4, only 41% agreed that they could have done the TLS without the help of their companions. This is actually a positive result, because it supports the cooperative learning approach and, in general, the active learning strategies stimulates teamwork rather than isolated work. Also, affirmation 3's high agreement also favors this cooperative approach.

In the case of affirmation 9, 41% of the students disagreed when asked about having a previous strategy on the subject; a 27,6% chose a neutral value, and a 31% agreed on previously having a strategy for the subject. This result, plus the result of affirmation 7, supports the educational value of the TLS *per se*, because it can be stated that all those students outside this 31% were, in fact, in need of a strategy. When most students consider they will use the strategy again and recommend it to a friend (affirmations 8 and 10), it is possible to appreciate the change between the before and after the TLS was conducted.

### 3.4. Second pilot group post-test result

During a scheduled assessment performed three weeks after the experience, a special question was included in a multiple choice questionnaire test, in order to evaluate if the students are correctly applying *any* strategy at all Since only a 31% of students consider they already had a strategy before the TLS experience, it may be considered as an effect of the TLS even though more research should be done to do such a claim.

From the 15 students that agreed to participate in the TLS analysis, the gain was G = 0,80, which was made comparing the pre-test and post-test.

The 29 students that actually participated in the TLS got a 77% absolutely correct answers, while students that were not present at the moment the TLS was conducted, got a 70% of correct answers, resulting in a 7% of difference.

## 4. Conclusion and final considerations

A TLS on kinematics models was made, under the theories of metacognitive skills with a cooperative learning approach. Feasible of adaption regarding the kinematic model, this TLS comprises little resources from the Faculty, and includes the four stages of the Kolb learning cycle in one session.

The participating students generally agreed on a very positive appreciation of their experience with this TLS.

Students showed evidence of recognizing the value of teamwork, while also considering their capability of performing alone.

Students recognized the lack of a strategy for checking kinematics graphs before the TLS. This is interesting, since it is a common part of the instruction and comes naturally from the definitions of velocity and acceleration per se. Evidence show, in general, a very positive educational value of the TLS.

A G of 0,80 was obtained after the experience, showing the TLS is practicable within the context of a calculus based general mechanics course for undergraduate STEM minors.

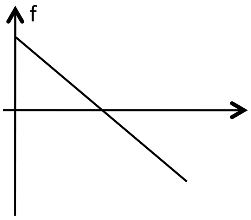
The positive G and post-test results suggest the strategy worked within the TLS might have been integrated into the metacognitive skills repertoire of the students, although clearly more in-deep qualitative research should be done in order to identify the origin of their skills.

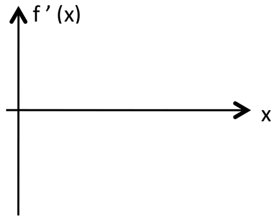
## Appendix

### A - Pre test sobre funciones y sus derivadas

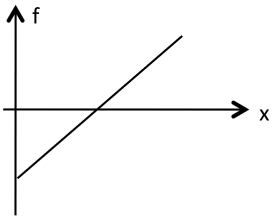
A continuación, encontrarás la gráfica de cuatro funciones. Por favor, dibuja la gráfica de la función derivada $f'(x)$ al lado derecho de cada una de ellas.

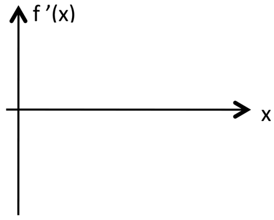
a) Función lineal y su derivada.



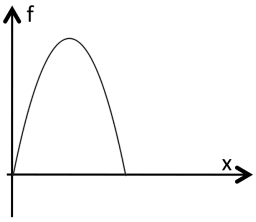



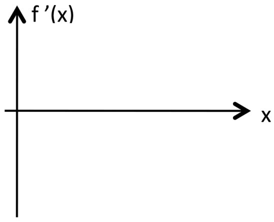

b) Función lineal y su derivada.



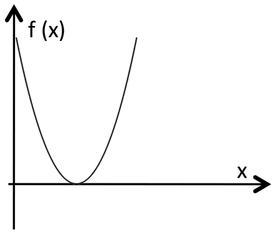



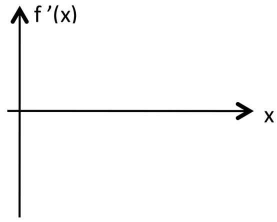

c) Función parábolica y su derivada.




d) Función parábolica y su derivada.

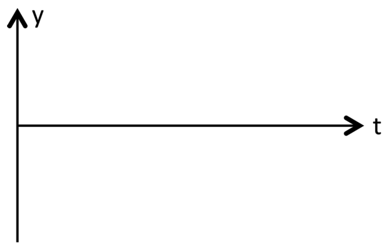


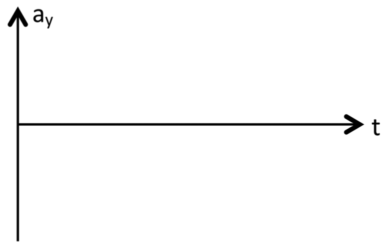

Pre test sobre caída libre.

Situación: Se lanza verticalmente hacia arriba una pequeña esfera de acero con velocidad inicial de magnitud $V$, cuya resistencia con el aire es despreciable. Para cierto tiempo $T$, la esfera alcanza su altura máxima, $H$

Dibuja CON LAPIZ PASTA los gráficos de componente de posición ($y$), componente de velocidad ($v_y$) y componente de aceleración ($a_y$) en función de tiempo ($t$) para dicho cuerpo. Incluye $V$, $H$, $T$ y $2T$ en ellos, según corresponda.








## B - Tutorial: Estrategia para revisar gráficos cinemáticos

Trabajar en grupos de 3, con lápiz pasta, sin saltarse pasos. Necesitan dos lápices de diferente color.

**Situación:** Se lanza verticalmente hacia arriba una pequeña esfera de acero con velocidad inicial de magnitud V, cuya resistencia con el aire es despreciable. Sea $T$ el instante en que la esfera alcanza altura máxima, $H$

**Ejercicio:** Dibuja los gráficos de componente de posición ($y$), componente de velocidad ($v_y$) y componente de aceleración ($a_y$) en función de tiempo ($t$) para dicho cuerpo. Incluye $V$, $H$, $T$ y $2T$ en ellos, según corresponda.

Gráfico **A**:
y versus t

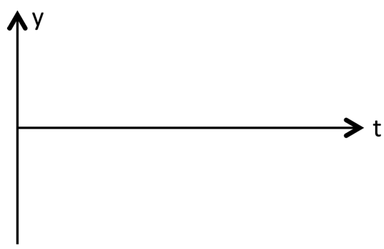



Gráfico **B**:
$v_y$ versus t

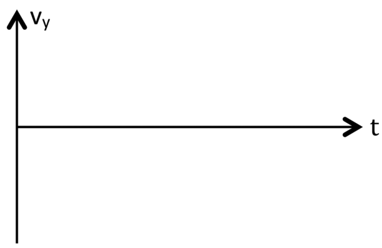
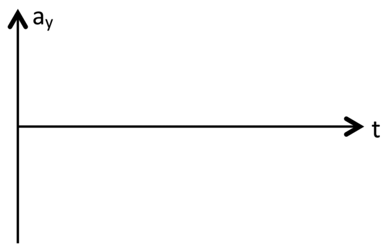
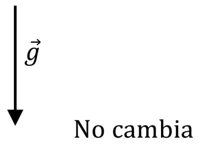



Gráfico **C**:
$a_y$ versus t



**Primer paso:** La caída libre es un modelo, en el cual el movimiento se debe solamente a la acción de la atracción gravitacional entre un cuerpo y el planeta, despreciándose otros efectos como la resistencia del aire. Al no haber más interacciones involucradas, es decir, como no intervienen otros agentes, la aceleración del cuerpo *permanece constante durante todo su movimiento*, siendo $a_y$ = - 9,8 m/s$^2$ (la aproximación a -10 m/s$^2$ también es aceptable). Recuerda que el signo es una convención relacionada al sistema de referencia XY, donde el eje Y ha sido definido como positivo en contra del sentido de acción de la fuerza de gravedad.

En otras palabras, el valor de la componente $a_y$ de la aceleración del cuerpo *siempre es el mismo, para todo instante de tiempo.* La aceleración de gravedad suele representarse con el símbolo **g** (que se lee g vector) y una flecha para denotar que apunta "hacia abajo".




**Respondan en el siguiente espacio:** El gráfico **C**, ¿es consistente con toda la explicación anterior? ¿Por qué? En caso de que su respuesta sea negativa, corrijan el gráfico **C** con lápiz de otro color (sin borrar el original) y señalen cuál fue la equivocación.

**Segundo Paso:** La aceleración se define como la derivada de la velocidad en función del tiempo $a_y = \frac{dv_y}{dt}$.

**Respondan en el siguiente espacio:** ¿Es esto consistente con la relación entre los gráficos **B** y **C**? ¿Por qué? En caso de que su respuesta sea negativa, corrijan el gráfico necesario con lápiz de otro color (sin borrar el original) y señalen cuál fue la equivocación.

**Tercer Paso:** La velocidad se define como la derivada de la posición en función del tiempo $v_y = \frac{dy}{dt}$.

**Respondan en el siguiente espacio:** ¿Es esto consistente con la relación entre los gráficos **A** y **B**? ¿Por qué? En caso de que su respuesta sea negativa, corrijan el gráfico necesario con lápiz de otro color (sin borrar el original) y señalen cuál fue la equivocación.

**Para finalizar:** Realicen un último análisis sobre la consistencia entre los 3 gráficos, si desean pueden escribirlo en el siguiente espacio. Avisen a su profesor que han terminado para revisar su trabajo.

### C - Excerpt from the final working sheet

Se lanza verticalmente hacia abajo una pequeña piedra. La altura inicial es $H$, y la componente escalar de la velocidad inicial $v_y$ es $V$. En un tiempo igual a $T$, la piedra alcanza 0 m de altura. Los efectos del roce del aire son despreciables durante toda la trayectoria.

Completa los gráficos de componente de posición ($y$), componente de velocidad ($v_y$) y componente de aceleración ($a_y$) en función de tiempo ($t$) para dicho cuerpo, desde que fue lanzado hasta que se cumple el tiempo total de viaje ($T$)

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