# Enseñanza de la física mediante *fislets* que incorporan mapas conceptuales híbridos

# Teaching physics using physlets that incorporate hybrid conceptual maps

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**Palabras clave**
Física, mapas conceptuales híbridos, tecnología educativa, ontosemiótica

## RESUMEN

Este trabajo presenta los resultados de la primera etapa de una investigación cuyo objetivo es desarrollar un *fislet,* que consiste en la animación de una situación física problematizada activada mediante los elementos de un mapa conceptual híbrido. La metodología considera la selección de situaciones físicas problematizadas en las que participa la noción física a ser enseñada, la resolución de esos problemas por parte de un grupo de profesores, la elaboración de los mapas conceptuales híbridos y los fislets mediante el software Java y MATLAB y el apoyo del enfoque ontosemiótico. Los resultados sugieren que los alumnos consideran el fislet como una herramienta didáctica que les permite explorar el proceso de resolución de los problemas físicos, reflexionar sobre los supuestos y procedimientos, y analizar las interpretaciones de las representaciones, entre otros aspectos. La investigación contribuye a la tecnología educativa mediante la propuesta del diseño de un fislet novedoso que se apoya en la noción de representación y la interpretación ontosemiótica de los mapas conceptuales híbridos. Concluye que el fislet contribuye a que los estudiantes visualicen los objetos físico-matemáticos que participan en la práctica de resolución de un problema físico.

***Keywords***
*Physics, hybrid conceptual maps, educational technology, ontosemiotic*

## *ABSTRACT*

*The aim in this paper is to present the results of the first stage of an investigation that has the objective of developing a fislet that consists of the animation of a problematized physical situation activated through the elements of a hybrid conceptual map. The methodology considers the selection of problematized physical situations where the physical notion to be taught is involved, the resolution of such problems by a group of teachers, the elaboration of hybrid conceptual maps and fislets through Java and MATLAB software and the support of the ontosemiotic approach. The results suggest that students consider the fislet as a didactic tool that allows them to explore the process of solving physical problems, reflect on assumptions and procedures, and analyze interpretations of representations, among other aspects. The research contributes to educational technology through the proposal of the design of a novel fislet that is based on the notion of representation and ontosemiotic interpretation of hybrid conceptual maps. It is concluded that the fislet allows the students to visualize the physical-mathematical objects that participate in the practice of solving a physical problem.*

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## INTRODUCTION

The learning of physics poses a series of difficulties for students of different educational levels. It is possible to find works that suggest the use of *applets* or *fislets* (from the English *physlet*, word referring to *physics* and *applets*) as tools to foster the learning of physics. Physlets are interactive, visual, flexible applications (in the sense that they can be used to address any topic on mechanics) to mention only a few of their attributes, which convert them into a tool of great value for science education (Belloni & Christian, 2003).

*Physlets* have been developed to support teaching in different fields of school physics. Cox, Belloni, Dancy and Christian (2003) have used them for the learning of thermodynamics and to motivate the solution of problems through a conceptual approach. Other researchers (Dartnall & Reizes, 2011; Roldán, Perales, Ruiz, Moral and De la Torre, 2018) have pointed out the advantages students have in carrying out *physlets* programming to assimilate the contents of Newtonian mechanics and thermodynamics.

Wee Kang (2012) proposes using a *physlet* that shows the animation of the collision of two mobiles in combination with algebraic expressions to motivate the students in making predictions and developing data tables to analyze the temporary dependence of the moment and the energy. Singh (2008) presents interactive tutorials supported by graphs and simulations to promote the active learning of the contents of quantum mechanics, while Parra and Ávila (2017) point out that the response to questionnaires based on the reflection on the experimentation carried out by means of a simulation of the phenomenon of the photoelectric effect allows the students to reorganize their knowledge in regard to this content.

Belloni and Christian (2003) suggest the JiTT (*just in time teaching*) pedagogical approximation that attends the educational needs of the students based on the analysis of the tasks supported by the use of *physlets*. Proposals have also been made to develop animations without the need of advanced programming knowledge through the use of software such as Interactive Physics for the learning of speed and acceleration (Jimoyiannis & Komis, 2001) or Modellus for teaching the laws of black body radiation or the movements of fluids (Neves, Neves & Teodoro, 2013).

Likewise, the characteristics of some *physlets* have been described for the teaching of physics. However, the *physlets* design is not supported by any educational theory or the results of research on the learning of physics; e.g., the different physical-mathematical objects intervening in the practice of problem solving have not been taken into consideration (Moreno, Font and Ramírez, 2016) neither has the ontology that students could attribute to physical concepts (Chi & Slotta, 1993) being represented in the animations, nor the difficulties posed by working with different semiotic registers and different representations (Oviedo, Kanashiro, Bnzaquen & Gorrochategui, 2011). Actually, most *physlets* have been developed based on the beliefs and the disciplinary knowledge of their authors. However, as several studies point out, this knowledge does not suffice for the students to achieve learning and acquire the proper competences.

In this paper, we describe the first part of a research aiming at developing a *physlet* which we have coined as fislet-MCH (*physlet* supported by the hybrid conceptual map technique) for teaching the notions of school physics. This part of the research considers the design of the fislet-MCH – more specifically to teach the notion of the force of friction. Fislet-MCH consists of the animation of a problematic physical situation in which the force of friction is relevant to its solution, synchronized and controlled through the elements of the hybrid conceptual map (MCH, [Spanish acronym]). The development of fislet-MCH is based on the onto-semiotic approach theory (EOS [Spanish acronym]), that allows interpreting MCH and the animation as the practice of solving the problematic physical situation from a visual perspective.

*Some theoretical elements of the onto-semiotic approach*

The development of fislet-MCH is based on EOS (Godino, Batanero and Font, 2007), a theory developed in the field of educational mathematics and which, recently, has been adapted to the context of school physics (Moreno *et al*., 2016) for the interpretation of didactic phenomena related to teaching and compression of physical notions.

From the EOS perspective, given a problem of school physics, the realization of a sequence of actions subject to physical and mathematical rules that lead to the solution of a proposed task (Moreno *et al*., 2016) is understood as practice. In this practice, a set of physical-mathematical primary object intervene: language, symbols, algebraic expressions, pictorial representations, among others; concepts, physical as well as mathematical; properties that link concepts and can be physical and mathematical; procedure that links with a series of steps to solve a problem; and arguments, those propositions used to justify the solution procedure used. From the EOS perspective, physical-mathematical primary objects can be visualized, i.e., besides being observed, they can also be interpreted, manipulated (visual operations) and related through practice (Godino, Gonzato, Cajaraville & Fernández, 2012).

According to EOS, in practice, certain cognitive processes are carried out, such as idealization, making the subject go from the concrete to the abstract, e.g., a physical body considered as a particle (the materialization process can be understood as a reverse process of idealization); generalization, that allows considering the system under study as any ideal system that can be solved based on Newtonian laws; significance, semantic relations are established between observable representations (symbols, algebraic expressions, pictorial representations, among others) and physical-mathematical objects; and argumentation, through which properties or propositions are enunciated that justify the solution procedure used, to name a few.

On the other hand, the meaning in EOS is understood as a semiotic function through the correspondence between an antecedent (expression) and a consequent (meaning or content) established by a subject (person or institution) according to certain criteria (agreements, physical-mathematical rules). The role of antecedent or consequent can be assumed by a pair of primary physical mathematical objects.

*Graphic representation of the solution of a physical problem*

The conceptual map (Novak, Gowin & Johansen, 1983) is a network of concepts hierarchically arranged and interconnected by means of links or lines and through "link phrases" that, when read, make up a sentence. As a whole, these relationships are a network of propositional structures where the meaning of a sentence is not found only in the relationship between one concept and another, but it depends of the relationships these concepts have, in turn, with other concepts. The implementation of the conceptual map in other fields of knowledge has prompted other developments such as MCHs which are a "fusion" of the hierarchical network of concepts (characteristics of the conceptual map) with the graphic representation of processes (characteristic of a flow diagram).

From the EOS perspective, the MCH [Hybrid Conceptual Map] can be interpreted as a graphic representation of the practice of solving a problematized physical situation (Moreno, 2017) or, similarly, as a graphic representation of the configuration of primary physical mathematical objects since it considers: language that allows representing ostensively objects non ostensive (concepts by means of names or symbols, properties by means of mathematical expressions, etc.); concepts organized hierarchically in MCH; properties expressed by reading routes that make up enunciations about concepts (algebraic or geometric properties); procedure, represented by means of procedural component of the flow chart in the conceptual map; and arguments, obtained from the different reading routes that constitute enunciations that validate or explain sentences and deductive or other type of procedures.

*The fislet-MCH from the perspective of the onto-semiotic approach*

The *physlet* described in this paper shows the student an animation that consists of two parts: one that presents the MCH and the other that represents the animated physical situation at the bottom or together with the MCH.

From the EOS perspective, the fislet-MCH represents an organization of visual type physical mathematical objects. The fislet-MCH shows the physical mathematical object simultaneously in MCH as well as in the animation of the physical situation which allows establishing explicitly a semiotic function or semantic relationship between both types of representation register.

A concept in MCH can appear as a symbol ( $\vec{F}$, $m$, $\vec{a}$, among others) or as an algebraic expression through icons (Filloy, Puig & Rojano, 2008), which consist in the overlapping of indexes (letters) and symbols ($+$, $-$, $>$, to point out a few). Although symbolic inscriptions are not considered visual type, since they are signs in which the relationship between the representative and the represented object is conventional; in fislet-MCH, these act as indexes (and also as buttons in MCH that activate animation elements) when pointing out positions or objects in the physical situation evoked in the animation. On the other hand, in the animated physical situation, the same concept can appear as a type of material representation (animated pictorial representation) or as a figural concept by mean of visual language (e.g., the Cartesian representation system) which includes, in turn, concept of visual and spatial nature (up, down, right, left, among others).

Properties expressing the relationship between concepts are presented by means of propositions (which are not of the justifying type) and can be read in some of the MCH reading routes. In the latter they appear through iconic type visual language represented by algebraic expressions ($f = \mu N$, $\vec{F} = m\vec{a}$) and, as for concepts, they also perform as indexes in the sense that they are shown in the animation as properties of the visual procedures, e.g., the conservation of the direction of the action of certain forces throughout the displacement of a body in the animation, or, the simultaneous growth of two arrows that have the same direction but in opposite direction (which represent the mechanical equilibrium of forces).

In the same way, in fislet-MCH, procedures or visual operations are presented, on the one hand, in MCH by means of icons represented by algebraic expressions throughout the mathematical treatment process (component of a flow diagram in MCH) and, on the other hand, they are visualized in the animation by moving or sliding bodies along one direction by transforming visual representations into other representations (e.g., by transforming a pictorial representation in a point) or by means of decomposition ( e.g., a vector represented as an arrow being projected in direction $x$ and $y$). The visual procedure motivates the realization of the idealization and argumentation processes.

There are also arguments or visual justifications that can be seen through some MCH reading routes that have to do with the justification of the procedure used. In animation, these are visual justifications of the properties or procedures; e.g., the movement (falling or sliding) of a body as a result of fulfilling some physical condition.

The passage from one hierarchy to another in fislet-MCH suggests the performance of some processes indicated by EOS; e.g., the process of idealization is motivated when a point appears in the animation that represents the body under study, and in MCH, the idealization is suggested when the concept "body under study" is connected with the concept of particle. The generalization process is noticed in MCH when using Newton's second law to represent the mechanical equilibrium or movement condition while, in animation, it appears with the joint action of forces on a particle that is experimenting movement, or rest. The materialization process is manifested in the ostensive (observable) representation of the physical mathematical concepts, e.g., the representation of the forces by means of arrows. The argumentation process is suggested by means of the different reading routes that can be followed in MCH.

## DESIGN

### *Research Design*

The research methodology envisions two stages: the first (which we are now reporting) implies the Fislet-MCH design and test; subsequently, one the adjustments and other necessary developments have been made, we will test the *physlet* and its impact on the student learning through the application of a pretest and a posttest to compare the control and the experimental control.

### *Fislet-MCH Development*

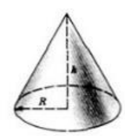
The development of fislets-MCH was carried out in four phases: the selection of problematized physical situations based on a textbook commonly used by teachers and students; the resolution of physical situations by a group of teachers; the development of MCHs that represent in a graphic manner the practice of problem-solving by the teachers; and the development of fislets-MCH through Java and MATLAB. These stages are described below:

a) The selection of problematized physical situations

We chose a set of three physics problems in which the notion of the frictional force plays an important role in their solution (See Figure 1). These were chosen from a series of problems proposed in a physics textbook commonly used in the institution where we conducted the research (Resnick, Halliday & Krane, 1999, pp. 139-140). These are everyday situations called the cone problem, the runner problem and the block problem. The cone and runner situation becomes problematized in regard to the optimization of the volume and acceleration respectively, while the block situation became problematized in reference to the prediction of the movement of the body based on certain initial conditions.

The solution to these problems poses a great challenge for the students, e.g., to solve the runner's problem, the idealization process (Moreno *et al*., 2016) is fundamental to think of the runner as a particle located in one point of contact between the sole of the shoe and the ground, on which acts the weight, the normal force and the reaction force when trusting the runner; however, the idealization process is suggested explicitly through the graphic representations and the animation shown in fislet-MCH.

**The Sand Cone**. A person wants to stack sand on a circular area in his yard. The circle radius *is* *R*. Sand should not be stacked in the part around the circle. Prove that the largest volume of sand that can be stacked in this way is $\pi \mu_s R^3/3$ where $\mu_s$ is the coefficient of static friction of sand against sand. (The volume of the cone is *Ah/3*, where *A* is the base area and *h* the height.




**The runner.** What is the greatest acceleration at which a runner can reach if the static friction coefficient between the shoes and the road is 0.95?

**The Block.** A horizontal force *F* of 12*lb* pushes a block weighing 51 *lb* against a vertical wall. The static friction coefficient between the wall and the block is 0.60 and the kinetic friction coefficient is 0.40. Assuming that the block is not moving initially.,(a) Will the block start moving? (b) What force is the wall exercising on the block?

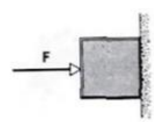



**Figure 1.** Problematized Physical Situations.

b) The solution of problematized physical situations

The solution of the three problems described was proposed to three professors of physics that had taught Static and Dynamics at the Universidad Autónoma de San Luis Potosí [San Luis Potosi Autonomous University], Mexico. Each professor solved a different problem using an electronic pen, Smartpen (Livescribe Echo) that digitalizes audio and writing synchronously. Figure 2 illustrates the oral and written production of the professor that solved the block problem. The professor's written production is shown in green, and the text in the boxes represents the oral production enumerated to indicate the discursive order.

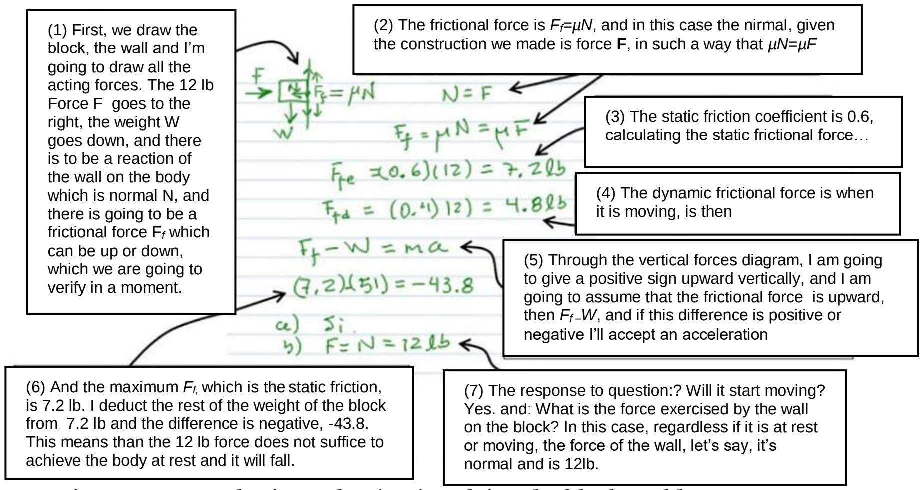


**Figure 2.** A teacher's production in solving the block problem.

## c) MCH Development

MCH was developed through the process reported in Moreno (2017). To do so, we designed a table of primary physical mathematical objects to classify the elements of the oral and written production in some of the categories indicated by the EOS, depending on whether they are concepts, properties, arguments or procedures.

Based on the table, the development of MCH begins with the situation-problem concept as focus question. Material concepts appear in the second hierarchy, which refer to interacting bodies. Subsequently, also in the second hierarchy, concepts describing the attributes of the interacting bodies (mass, volume density, among others), connect with concepts that account for the mode in which the teacher molds said bodies (bodies considered as particles, movement in one dimension) and how they interact (the action of the forces on the body under study).

In the following hierarchy, properties appear enunciated by means of propositions having reading routes in MCH in which the solution procedure is not justified but it does establish a physical mathematical relation between concepts; e.g., one of the properties used in *physlets* is Newton's second law which connects the mass concepts of a body, the acceleration and different concepts that merge under the name of force (gravity force, frictional force, normal force). This property sets off the mathematical treatment, primary object of this procedure.

The procedure performed by the subject in solving the problem is incorporated to MCH through the component of the flow diagram which shows the application of a series of properties at times physical (Newton's laws, empiric type properties such as $f = \mu_s N$) and at others, mathematical (algebraic properties, substitutions, clearances, sign laws, etc.) that guide the subject toward the solution of the problem.

The oral argumentation provides the justifying component of the procedure employed represented by means of the route nexus of map reading.

d) Fislets-MCH development

The fislet-MCH shows the animation of a problematized physical situation that synchronizes with the MCH already developed. Some of the MCH elements function as buttons that activate specific parts of the animation. In general, three fislets-MCH are developed to teach frictional force; the sand cone problem was developed in Java language while the two others were developed through MATLAB software. We should point out that the *physlet* in Java allows changing the speed of evolution of the animation, play it forward or backward or freeze it. The *physlet* in MATLAB is presented in two stages and facilitates studying in detail every stage of the problem solving process; however, it does not allow backwarding or forwarding the reproduction until all the developments have been shown. Fislets-MCH reported in the paper may be consulted online in video format (UASLP, 2017).

To develop the fislet-MCH for the sand cone problem, we used the Processing software which instructions are based on the Java language. We resorted to the Processing software given its ease in managing graphs and animations, in addition to having a tool to convert the developed programs (called *sketchbook*) into applets. The MATLAB software is a research-oriented programming language with advanced functions that helps carrying out complex calculations and multi-variable graphing functions. MATLAB is not designed to generate applets, hence, representing MCH and animations of physical situations is done through the rendering process with the help of mathematical functions indicating what to draw and where to draw them with pixels on the screen; this is a drawback in development time.

In spite of the fislet-MCH development time drawback in MATLAB in comparison to Java, we can highlight two fislets-MCH important aspects: the characteristics of the software used and the theoretical support. In regard to the first, since MATLAB is a scientific software, it offers the advantage of performing complex calculations in a simple way that could be required in developing other fislets-MCH; and through Java, a popular language to develop apps, since it has the advantage of being portable, fislet-MCH could be executed from a web page or a cell phone.

In regard to the second aspect, the theoretical support guides the development of the fislet-MCH, since it points out to the physical mathematical objects that participate in the practice of solving the problematized physical situation and considers a visual perspective of these objects to visualize simultaneously the animation of the situation and the MCH.

*Fislets-MCH Characteristics*

a) Sand cone fislet-MCH
Figure 3 illustrates the fislet-MCH developed in Java corresponding to the cone problem. Together with the *physlet*, we present a scheme of its main components.

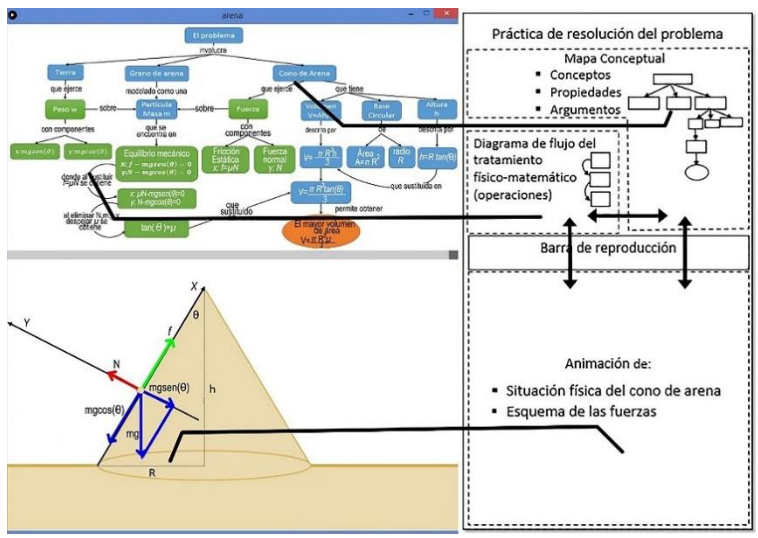



**Figura 3.** Fislet-MCH describing the practice of solving the cone problem

When executing fislet-MCH, the first MCH hierarchy appears at the top of the screen and shows material concepts of the physical situation (ground, sand cone, grain of sand) that act as symbols/indexes that indicate their visual components in the animation that appears at the bottom of the screen through the iconic representation of these concepts (visual concepts).

The second MCH hierarchy presents concepts indicating geometric attributes of the cone (volume, base area and height) and the particle concept referring to the way in which the grain of sand is interpreted which suggests to the user the performance of the idealization process. Next, by pressing the “ground” concept, other concepts are displayed indicating the action of the gravitational force and the cone on the “particle” that point to the completion of the argumentation process through different reading routes. When pressing on “procedure”, the third MCH hierarchy appears which reveals the decomposition of the forces in the components (visual operation) and, in the animation, these forces are represented by means of colored arrows (materialization process). Algebraic expressions appear in the animation as icons/indexes that link these objects with the third hierarchy.

Subsequently, when activating the reproduction bar (See Figure 3) or press the particle concept, other concepts of the third hierarchy appear and suggest the generalization process: mechanical equilibrium concept (acting as symbol/index/icon), referred by Newton’s second law and attributes mathematical expressions. Simultaneously, the size of the arrows in the animation increases (visual operation) and maintains perpendicularity and direction (visual property). The friction coefficient in function of the angle formed by the base radius and the generatrix are expressed through the treatment process, and lastly, when the arrows acquire their maximum size, the cone maximum volume is presented which solves the problem.

c) The runner problem Fislet-MCH

The runner fislet-MCH is illustrated in Figure 4. The *physlet* was programmed in MATLAB. In its upper part the MCH is displayed and at the bottom, the animation. The animation shows arrows representing forces and one extremity of the runner resting on the ground.

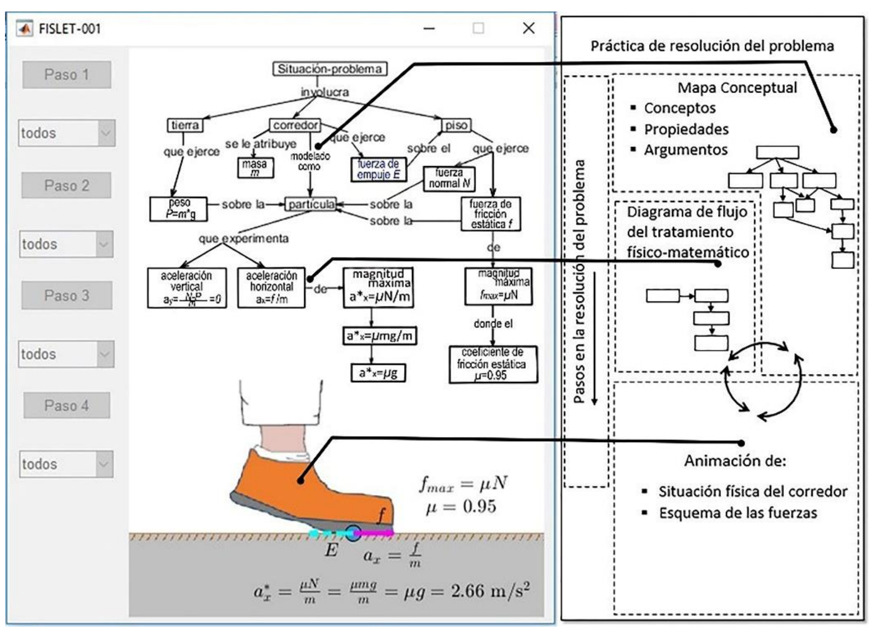



**Figure 4.** Fislet-MCH describing the practice of the solution of the runner problem.

In the runner *physlet,* the animation is controlled from a set of buttons (steps button 1 to 4 in Figure 4) positioned on a vertical bar on the left of the animation. The elements in the animation appear as if they are in the same MCH hierarchy. The animation explicitly presents the semiotic relationship between the MCH concepts and the visual component of those objects in the animation. The animation highlights more specifically the visual procedure that consists in the growth of the arrows representing the runner's thrust force and the ground reaction force.

c) The block problem fislet-MCH

This *physlet* was also developed in MATLAB and has the same mechanism (a set of buttons positioned on the left of the fislet-MCH vertical bar) as the runner *physlet* that describes in detail the concepts that appear in each MCH hierarchy. Since the problem situation requires performing more mathematical operations, the MCH covers the upper as well as the bottom part of the screen and leaves a space on the right for the animation (See Figure 5).

When executing the block problem fislet-MCH, pressing the "Step 1" button, material concepts / indexes (ground, wall, block and external agent) appear in the first MCH hierarchy simultaneously to its visual component through icons in the animation. In the animation, the external agent pushes the block (yellow box) to the right against the wall represented as a gray vertical bar.

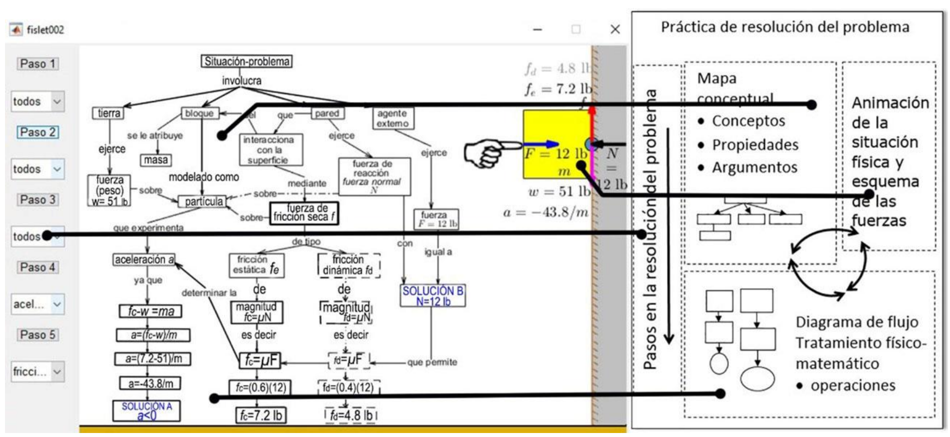



**Figure 5.** Fislet-MCH describing the practice of the solution of the block problem.

The "Step 2" button shows the second MCH hierarchy and also suggests the realization of the idealization process. The concepts presented indicate the interpretation of the block as a particle (visual operation) and the forces acting on the particle (weight, frictional force, normal force, force of the external agent) are represented visually in the animation through arrows (materialization process). The "Step 3" button indicates the physical mathematical treatment based on Newton's third law (property that suggests the generalization process); subsection b) of the problem is solved. The "Step 4" button, that resolves subsection a), suggests the generalization process by using Newton's second law. Lastly, even though it was not used to solve the problem, the "Step 5" button determines the dynamic frictional force. The results of the previous calculations act as indexes that indicate their corresponding visual component in the animation.

### d) Fislet-MCH Implementation

Fislets-MCH were tested with a group of university students with the object of enquiring about their opinions on the *physlet* utility, advantages and disadvantages. The implementation was carried out in a workshop consisting of five one-hour sessions and which took place in the computer center of the faculty with the purpose of letting every student manage the fislet-MCH individually. In the first session, the students' previous knowledge was assessed by means of five questions and the solution of a problem (Resnick *et al.,* 1999, p.140) related to the frictional force (See Figure 6).

**Questions:**
1.- What is the frictional force?
2.- What is the $\mu_s$ static friction coefficient?
3.- What is the $\mu_k$ static friction coefficient?

**Problem:** A *7.96 kg* block is resting on a 22° slope horizontally, as shown in the Figure below. The static friction coefficient is 0.25, while the kinetic friction coefficient is 0.15 (i). What is the minimum force F, parallel to the plan that will impede the block to slide downward? (ii) What is the force *F* necessary to move the block upwards at a constant speed?

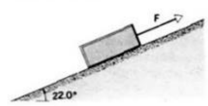



**Figura 6.** Question and problem to assess the students' previous knowledge.

Each one of the probelmatized physical situation was addressed in the three subsequent sessions through the support of the corresponding fislet-MCH and a sequence of activities consisting of solving the problem individually with a pencil and paper; discussing the solution of the problem in pairs; executing the fislet-MCH and analyzing the solution process; verifying if the solution obtained matched the fislet-MCH solution and discussing their findings with the researcher. In the fifth session, the test of the first session was applied once more and we enquired about the opinions of groups of students on the work with fislets-MCH.

Eight students between the ages of 18 to 20 from the Universidad Autónoma de San Luis Potosí, Mexico, attended the workshop. The students were studying Statistics and Dynamics (principles of Newtonian Mechanics and the notion of frictional force).

## RESULTS

The students' responses to the questions posed in the first session (See Figure 6) showed they have an inadequate conception of the frictional force and the friction coefficient. Some students considered the force and the friction coefficients as properties of the body. Others claimed that the friction is "the resistance capacity an object has when being moved by a force or capacity that has an object impeding the other to slide on it", and coefficients $\mu_s$ and $\mu_k$ are "the resistance value an object has to be detained" or "the resistance or reaction force an object has at rest". Other students mentioned that friction is a force that opposes the movements of bodies, which is not valid in different physical situations. On the other hand, none of the students solved the problem correctly.

In the last session, the students' responses to the questions were essentially the same; however, their solution to the problem improved. Three students solved the problem correctly and the others showed some advancement. Figure 7 shows the case of a student who solved the problem correctly. In the first session, the student formulates a "substitute and solve" type of approach (See Figure 7 [a]), but he makes a mistake when trying to equal the weight $wsen\theta$ of the horizontal component with the normal force "$n$" and he confuses the use of $\mu_k$ and $\mu_s$. In the last session, the student solves the problem accurately (See Figure 7[b]) through a conceptual-type approach that allows him to describe the block mechanical state (from rest to constant speed) through Newton's second law. Unlike the first session, the student's explanation in the last session in regard to the solution proposed reveals a more structured knowledge supported by an interpretative process of the problem.

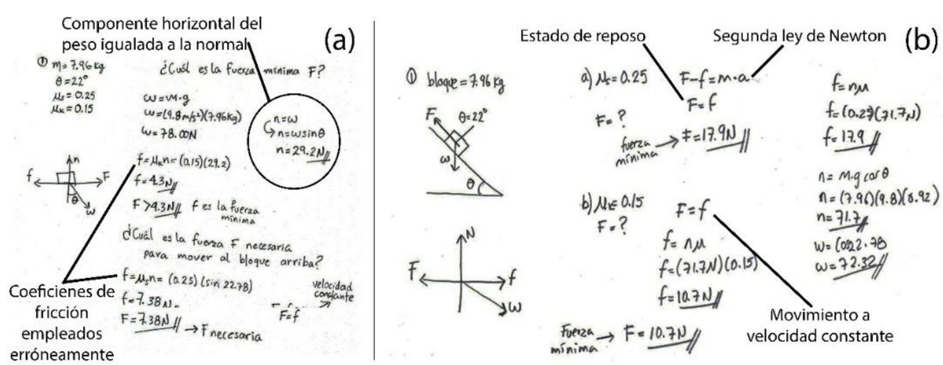



**Figure 7.** The solution of the block problem on the 22° inclination slope (a) Solution at the beginning of the workshop (b) Solution at the end of the workshop.

The previous results indicate that the students' conceptions on the frictional force did not change while working with the fislets-MCH; however, they achieved an improvement in the solution of the problem. On the other hand, the students' opinions and suggestions about working with the fislets-MCH are as follows:

*Synchronization of the MCH with the animation*

> I liked the way in which the map shows the solution to a problem and that this program shows the result; it is very practical. The only thing is that when the sand cone *physlet* in reproducing simultaneously the map with the animation, it was difficult to see what was going on in the animation, i.e., one either pays attention to the map or to the animation. This does not happen with the other animations since with them, it goes step by step and one can see the objects one by one.

*Use of color in the MCH*

> Interesting, since it made me reflect on how to attack the problems. The animations make ideas clearer. It would be good if colors were used, we could observe the map better.

*Fislet-MCH to learn to solve a problem*

> It is a very didactic explanation to solving problems. The way the information is drafted allows us to identify the elements of the problem more easily and arrange them to solve them when knowing where the equations and the results come from. It is also useful to visualize accurately the situation causing the problem.

## DISCUSSION

According to the results, the fislet-MCH contributed to improve the practice of solving a problem given, but it is not so when changing the students' conceptions about the frictional force. This aspect, which in essence it is the core of the second stage of the research, goes beyond the fislet-MCH development process. There is the hypothesis that a more adequate comprehension of the physical notion could be achieved through proposing tasks in a set of prototypical physical situations that allows the student attain a holistic perspective of the physical notion to be learned. Some physical situations show clearly some properties of the physical notion to be learned but others do not. One of the ways to consider this epistemological axis could be by selecting more pertinently physical situations in the first phase of the fislet-MCH development.

The fislet-MCH supported in the EOS theory poses a scientific alternative to the scenario in which the professor-programmer develops the *physlet* based on his beliefs or experiences. Hence, it is not our intention to ignore the professor's experience but to highlight the importance of the theoretical support to develop the fislet-MCH systematically and use it as an interpretative theoretical framework to analyze the learning achieved by means of this tool.

On the other hand, the students' observations show areas of opportunity to improve the fislet-MCH at a technical level. On the one hand, it is about highlighting with colors the different physical mathematical objects that appear in the MCH and the animation to attain a more adequate visualization of the organization of the objects. On the other hand, synchronizing the MCH with the animation of the physical situation would help the student perceive the effect on the animated situation caused by activating some of the control buttons.

## CONCLUSIONS

The fislet-MCH allows the students to visualize the set of primary physical mathematical objects (language, concepts, properties, procedure and arguments) that intervene in the solution of a problematized physical situation. From the EOS perspective, the primary objects being represented in the animation and in the MCH of the *physlet*, appear as icons, symbols or schemes, and by performing also as indexes, they allow establishing semantic relationships between the MCH elements and their respective visual components in an animated physical situation.

The proposal of using the EOS to design the fislet-MCH is relevant for the field of educational technology. The *physlet* theoretical support allows taking into consideration the visual component of the physical mathematical objects that participate in the practice of problem-solving, which can also be used as interpretative framework to enquire on the learning of the students through working with fislets-MCH.

Fislets-MCH could be used as a resource for teaching through the virtual modality or as a support for face-to-face courses. By taking into account that the fislet-MCH theoretical support comes from educational mathematics, the *physlet* could also be implemented to teach mathematics, e.g., learning through mathematical modeling.

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