Modeling in Physics: A matter of experience?

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Abstract

This study is focused on analyzing experimental results obtained due the use of different types of problem statements. It analyzes characteristics of problem-solving processes in subjects who have different levels of experience in solving physics problems. The problem-solving process is assumed as a process of modeling where different levels of representations are built. It is proposed a comprehension model for Physics problem-solving that assumes the existence of three levels of representation with different ontological elements and different levels of abstraction: A Situation Model (referential, non-abstract world representation of objects and events), a Conceptual-Physics Model (abstract, in terms of laws, principles and scientific concepts) and a Formalized-Physics Model (abstract, usually in mathematical language). The main goal of this work is to study how the problem-solving process depends on the experience the solver has in problems statements with particular characteristics. Two kinds of problems are used in the study. The difference between both statements is on the explicit or implicit presence of the Physics model that allows facing the problem and giving a solution. The results presented correspond to six interviews carried out with participants of different level of experience: 2 undergraduate physics students, 2 PhD physics students and 2 physics professors at university level. Subjects are audio and video-taped during a problem-solving interview. The records are transcribed and analyzed according to previously defined indicators. These indicators are used to determinate the number of actions and time spent in each stage of the problem-solving processes. The numerical parameters obtained are analyzed to study similarities and differences in the solving processes generated by the participants. Some findings are presented and discussed.

Keywords: Modeling, problem-solving, problem statement.

Resumen

Este estudio se orienta a analizar los resultados obtenidos en la utilización de distintos tipos de enunciados de problemas. Analiza las características de los procesos de resolución en sujetos con distinto nivel de experiencia en la tarea de resolver problemas de Física. Se asume al proceso de resolución de problemas como un proceso de modelado en el cual se construyen distintos niveles de representación de la situación. Se propone un Modelo de Comprensión para la Resolución de Problemas en Física que supone la existencia de tres niveles de representación con elementos ontológicos y niveles de abstracción diferentes: un Modelo de la Situación (referencial, representación no abstracta de los objetos del mundo), un Modelo Físico Conceptual (abstracto, en termino de leyes y principios físicos) y un Modelo Físico Formalizado (abstracto, generalmente en lenguaje matemático). El objetivo principal del presente trabajo es estudiar de qué manera el proceso de resolución de problemas depende de la experiencia del resolvedor en enunciados de problemas con características particulares. Se utilizan dos tipos de enunciados de problemas. La diferencia entre éstos se encuentra en la presencia explícita o implícita del modelo Físico que permite abordar el problema y dar una solución. Los resultados presentados corresponden a seis entrevistas realizadas con participantes de distinto nivel de experiencia: 2 estudiantes de licenciatura en Física, 2 estudiantes de doctorado en Física y 2 profesores de Física universitarios. Los participantes fueron grabados durante una entrevista de resolución. Los registros fueron transcriptos y analizados en relación a indicadores previamente definidos. Estos indicadores fueron utilizados para determinar el número de acciones realizadas y el tiempo empleado en realizar dichas acciones durante el proceso de resolución. Los parámetros numéricos obtenidos son analizados para estudiar semejanzas y diferencias en los procesos generados por los participantes. Se presentan y discuten algunos resultados.

Palabras clave: Modelado, resolución de problemas, enunciados de problemas.

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I. INTRODUCTION

Problem-solving is one of the main tasks used in physics classrooms regardless of educational level and orientation. A probable explanation may lie in the fact that for some authors, and perhaps for many teachers, problem-solving is almost indistinguishable from thought. On the other hand, problem-solving is practically the core of the professional activity of a physicist [1, 2]. In this sense, the practice of science requires not only conceptual knowledge, but also requires that graduates develop other specific skills to perform successfully his profession. Among these skills are to model situations and to interpret models [3, 4, 5]. These skills are not innate abilities in subjects and they are not part of common knowledge. For this reason, if they are not used or required in an instructional task, they do not need to be developed. A previous study [6] shows that these skills never get to be developed in many students, and one possible explanation is that they are not used in the proposed problems. On the other hand, there is experimental evidence that shows that it is possible to contribute, through specific instructional strategies, to the development of these skills required in professionals these days [4, 5, 7].

Although the problem-solving has been studied for a long time, the impact it has had in the society and in the classroom shows no evidence of such efforts. During the decades of the '70 and the '80, studies allowed to distinguished characteristics of knowledge and skills used between individuals called "novices" compared to subjects with experience in a specific area of knowledge called "experts". These studies have generally responded to different purposes. Greater impact studies are those that have been designed to generate expert systems. Hence the focus on instructional issues has been limited or nonexistent. It has been evident, in some details, the differences between novices and experts in various disciplinary fields but it has not been known the process that leads from one state to another. However, although it is not intended that students become experts, these antecedents are useful because they show what would be the result of a successful learning [8]. Then, become interesting what kind of skills are used by subjects to solve problems, how they manage the time they spent on these skills and if this change according to the kinds of statement used and to the subject's experience in the task of solve problems.

This work aims to build knowledge in order to facilitate the design of teaching strategies for physics. A basic assumption of this study is that such construction needs to be based on a cognitive model that can account for the complexity of the processes that occur during the problem-solving. Basically, it aims to characterize relevant aspects of the process of understanding and solving problems. This process is conceived to start reading the statement. We work on problem-solving interviews with a theoretical framework that aims to describe the process of understanding / solving a physics problem and a proposed classification for problem statements.

II. BACKGROUND AND THEORETICAL BASES

A. A model for problem-solving in physics

It is assumed that comprehension of a physics problem implies the construction of different level of mental representation. The problem solving process is understood as a modeling process. We work on a comprehension model for Physics that posits the existence of three levels of representation with different ontological elements and different level of abstraction: A *Situation Model* (referential, non-abstract world representation of objects and events), a *Conceptual -Physics Model* (abstract, in terms of laws, principles and scientific concepts) and a *Formalized-Physics Model* (usually, in mathematical language). Expert physics knowledge implies the construction of these three mental representations and the two-way transition from one to another. The model is based mainly on the theory of W. Kintsch [9]. The main features of the proposal are presented in Table I and Fig. 1. For further details of the proposal, they can be reviewed in [7].

This model assumes that the comprehension of an instructional physics problem involves the necessary skills for the construction and use of all the representations considered. These skills are called modeling skills, involving both the construction of representations of situations, flexible use and the possibility of (re) interpretation of those representations. Effective use of these representations involves the coordination between them, giving the possibility to recognize conflicts, check each representation and, as a result, construct consistent representations.

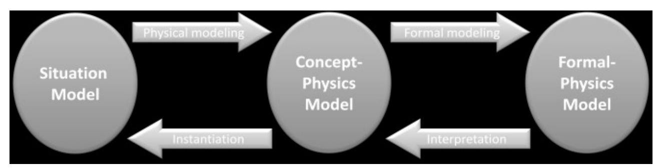

FIGURE 1. Schematic representation of the Comprehension Model for Problem-Solving in Physics.

B. A classification for problem statements

There is a great amount of research regarding the effects of instructional use of different kinds of problems. In particular, most have been related to various aspects of the use of "well-defined problems" (well-structured problems) and "ill-defined problems" (ill-structured problems) [7]. This classification is somehow related to the structure of the problem and for some authors is a relevant factor in the development of problem-solving skills. Although there are differences between different authors, the definitions for one or another kind of problem statement is made in relation to the information presented in it. One problem is "well defined" if it provides all the information needed for its resolution, and it is not necessary to perform any extra assumption.

While these categorizations of problems presented are widely used in research on problem solving in science, it is possible to find some contradictions when defining them. For this reason, they cannot be used as variables in research. It is necessary the selection of a criterion that provides clarity for a proposal of classification of problem statements in physics.

The task of delimitating a phenomenon to build a model of it, implies a simplification of the objects, interactions between objects, systems (objects with their interactions) and processes [10]. These simplifications are models of objects, models of interactions, models of systems and models of process. These are simplified representations of the components of the situation. Considering this, it is possible to categorize the problems regarding the models presented in the statement. A problem presented in terms of objects, interactions, systems and processes will be an indefinite problem, where the name refers to the undefined scientific model that describes the situation. Its counterpart, the well-defined problem, will be the one presented in terms of models of objects, models of interactions, models of systems and models of process. In this case, the name refers to the determination of a single scientific model that allows to describe the situation and to solve the problem.

TABLE I. Some features of the Comprehension Model for Problem-Solving in Physics.

	Situation Model	***Concept-Physics Model***	***Formal-Physics Model***
Components	Objects and their attributes. Events and their spatial and temporal characteristics.	Models of objects, events and features.	Abstract symbols or formal expressions that represent objects, events, their characteristics and relationships.
Guided by	Everyday principles on how the world works.	Physical principles and laws. Conditions of application or validity.	Mathematical formalism. Mathematical conditions for applicability and validity.
Ontological categories	Non abstract or perceptible to the senses or through elements of everyday life.	Abstract, theoretical representations of objects, events with their attributes and characteristics (even though their referents may be specific).	
External representation format	Concrete representations (scale models, etc.). Drawings, diagrams, charts. Symbols. Words.	Diagrams, charts, graphs (specific). Symbols. Words. (Eg conceptual maps)	Symbols. Equations.
Dimension of the representation	3-D; 2-D; 1-D	2-D; 1-D	1-D
Language	Natural	Technical (artificial)	Matematical
Allows	Describe, analyze, predict on a qualitative level.	Describe, analyze and predict in terms of orders of magnitude. Analysis of extreme, prohibited, or impossible situations.	Analyze expressions in terms of the formalism. Calculate and operate.
Explanation power	- ⟶ +		

Is interesting to note that this classification also presupposes an ontological classification too (See Fig. 2). The physical system, to which the statement refers, may be presented by concrete ontological categories (*indefinite problems*): a car driving on a road hits a truck that circulates in the opposite direction. The same physical system can be presented by abstract ontological categories (*defined problems*): a mass point moving in a straight line collides with another mass point moving in the same line but in opposite direction. It is also possible to find statements that combine different types of entities. Thus, statements that refer only to concrete entities and abstract entities are extremes of a dimension *concrete/abstract* within which it can be found various degrees, directly related to degrees of the dimension *indefinite/definite*.

C. Previous studies

Previous studies have identified indicators related to the construction and use of the different representations involved in the instructional problem-solving process [6, 11]. From these indicators, considering the domains proposed by Greeno [12] and the work of Gaigher, Rogan & Braun [13], it is possible to recognize actions that may be associated with those skills that we call *modeling skills*. Assuming that the external representations of the problem-solving process (written, graphic, verbal and even gestures) are signs of the internal representations constructed by the subject, it is considered possible that these actions can be recognized in a verbalized and written resolution process.

On the other hand, it has been developed a study in which it have been analyzed the characteristics of the problem solving process for different kinds of statements [7]. The hypothesis was that the particular statement characteristics of the problems affects the problem solving processes and then, the skills involved. The analysis of the interviews, carried out with professors at university level, supported that hypothesis. Differences appeared associated with Concept-Physics modeling skills.

III. THE STUDY

Given the background presented in the previous section, this study focuses on analyzing the characteristics of problem-solving processes in subjects of different levels of experience.

The hypotheses are:

- For the same kind of problem statement, characteristics of the pattern of the problem-solving process depend on the experience of the solver.
- The differences between the patterns of problem-solving processes are related to the type of skills used.
- The differences between the patterns of problem-solving processes are related to the time spend on the use of the skills.

A sample of two academic physics professors, two PhD physics students and two undergraduate physics students participated in this study on problem solving skills. Subjects were audio and video-taped during a problem-solving interview.

A set of two couples of experimental problem statements was used in this study. In every couple, both problems involve the same physic subject matter (mechanics) and the same suitable explicit/implicit Physics model. These experimental set was built according to the classification proposed above. In other words, one statement tells a story in terms of ordinary world terms (objects and facts) but the other statement tells the story in terms of physic concepts.

Interviews were conducted taking audio and video records of the resolution held on paper. In these interviews, each subject solved two problems: one *definite problem* and one *indefinite problem*, in that order. The role of the interviewer was as an observer with minimal participation.

Transcription and analysis tasks were performed. The actions carried out explicitly by the interviewee, whether verbal, written or gestural, were classified according to the proposed Model and the indicators constructed. This set of indicators was used to determine the number of actions and time spent in each stage of the problem-solving processes.

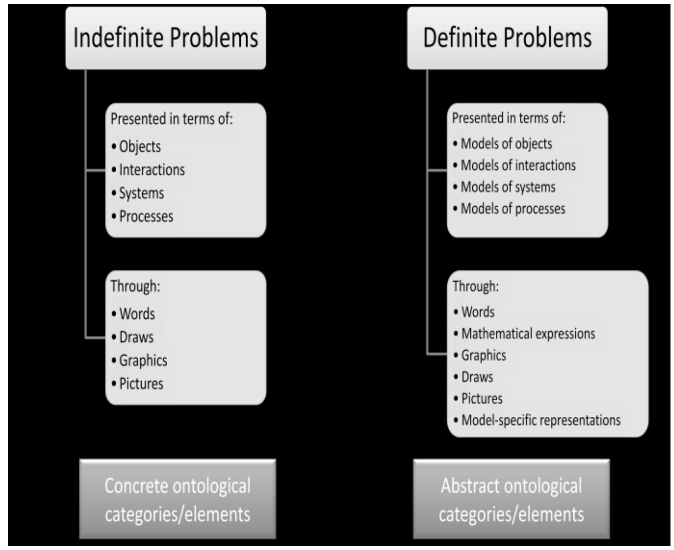

FIGURE 2. Classification of problem statements according to the scientific model that describes it.

IV. RESULTS

The results show different patterns for the distribution of the time spent in the use of the different skills. These differences are found in problem-solving processes generated by the different kinds of problems and by the subjects who have different level of experience. These results agreed with previous [7]: Defined problems generate problem-solving processes focused on building the Concept-Physics Model, Formal-Physics Model and, consequently, those skills necessary to articulate these representations; the indefinite problems trigger processes which involve all types of skills.

TABLE II. Notation for the selected actions.

Notation	*Action*
L	Reading
S	Situation Model construction
FI	Physical modeling
FC	Concept-Physics Model construction
I	Instantiation
FO	Formal modeling
FF	Formal-Physics Model construction
IF	Interpretation
P	Pause
NC	Uncatalogued

The interviews show complex construction processes of the different representations considered by the model. Characteristic patterns of these interviews are presented in Fig. 3 and Fig. 4. It is possible to observe that in the case of the undefined problems (Fig. 3), the patterns of the professor and the PhD student are similar to each other. These patterns have a wider distribution between the actions FC, FO and FF. In the case of undergraduate students, is found a strongly marked prevalence on FF actions at the expense of actions FC and FO. However, in the case of indefinite problems (Fig. 4), the patterns of PhD students and undergraduate students are similar to each other. While professors show a distribution among all types of actions, patterns of PhD and undergraduate students still have a strong presence of actions FF. For students, there are few actions of kinds FC and FO and the actions P are considerably higher.

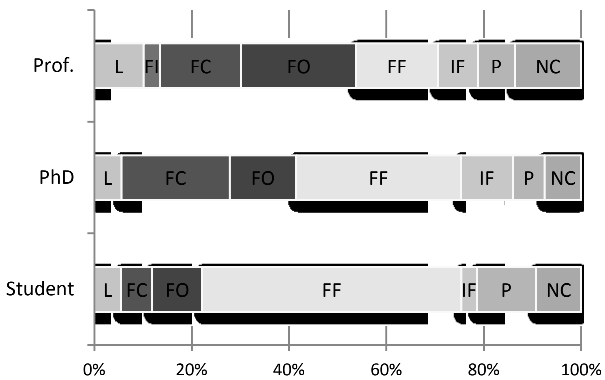

FIGURE 3. Definite problem. Percentage of total time per type of action.

It is also possible to obtain the Euclidean distances between subjects, with the time obtain for each kind of action. This is done to compare the subjects given the same problem statement. It can be seen in Table III that for the case of definite problems, doctoral students have more in common with professors. In the case of indefinite problems, Table IV, the patterns of PhD students are erratic. It can be noticed that between undergraduate students and professors there is a development for the skills: the use made by students to the skills is very different to that given by teachers.

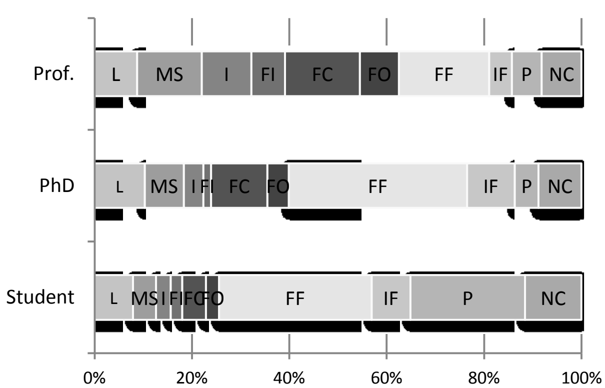

FIGURE 4. Indefinite problem. Percentage of total time per type of action.

TABLE III. Euclidean distance. Definite problems.

	Euclidean Distance		
	1:S	2:PhD	3:P
1:S	,000	26,799	41,072
2:PhD	26,799	,000	22,452
3:P	41,072	22,452	,000

	Euclidean Distance		
	1:S	2:PhD	3:P
1:S	,000	22,130	21,854
2:PhD	22,130	,000	19,915
3:P	21,854	19,915	,000

TABLE IV. Euclidean distance. Indefinite problems.

	Euclidean Distance		
	1:S	2:PhD	3:P
1:S	,000	20,516	27,318
2:PhD	20,516	,000	20,334
3:P	27,318	20,334	,000

	Euclidean Distance		
	1:S	2:PhD	3:P
1:S	,000	13,125	24,504
2:PhD	13,125	,000	22,148
3:P	24,504	22,148	,000

VI. CONCLUSIONS

The results, although they are partial, support the hypothesis of this study. The way skills are used in the problem-solving process depends on the experience of the resolver. Although this is a known result, it is important to determine how different skills are used by subjects who have different level of experience. In particular, a very important finding is that modeling skills are not fully developed in the PhD students. This highlights the fact that these skills, that professors have, are not developed during the instructional period.

Thus, the modeling in physics appears as a matter closely tied to the professional experience. However, based on previous research [7], it is considered possible to promote the development of these modeling skills from the instruction. In particular, it is proposed the problem statements as tools to guide certain cognitive processes in students.

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