Teaching strategies for physics problem solving: relations to student performance

Estrategias de enseñanza de resolución de problemas en física: relaciones con el desempeño de los alumnos

ZULMA GANGOSO[1], TERESITA MOYANO[3], LAURA BUTELER[1, 2], ENRIQUE COLEONI[1, 2], ALBERTO GATTONI[1]

[1] Facultad de Matemática, Astronomía y Física, Universidad Nacional de Córdoba
Medina Allende y Haya de la Torre, Ciudad Universitaria, Córdoba, 5000, Argentina
[2] Consejo Nacional de Investigaciones Científicas y Técnicas. Argentina
[3] Instituto de Educación Superior Simón Bolívar. Córdoba, Argentina

zulma@famaf.unc.edu.ar, mtmoyano@hotmail.com, lbuteler@famaf.unc.edu.ar, ecoleoni@famaf.unc.edu.ar, scout@famaf.unc.edu.ar

Abstract

This paper reports the results of an exploratory project that studies the relation between teaching strategies in Physics problem-solving and the students' performance of this task. The rationale for the study is based on previous research on expert-novice Physics problem-solving. The work was carried out in two parallel Physics courses for pre-service teachers. Results show that certain characteristics of their teachers' instruction models are reflected in the way that students solve problems.

Key words*: Physics problem solving, teaching strategies, student performance, expert/novice problem solvers.*

Resumen

El presente trabajo refleja los resultados de un estudio exploratorio que apuntó a estudiar la relación entre estrategias de enseñanza en resolución de problemas en física y el desempeño de los estudiantes en esa tarea. El trabajo fue llevado a cabo en dos cursos paralelos de física para estudiantes de la carrera de profesorado en matemática. Los resultados muestran que ciertas características de los modelos instruccionales del docente se ven reflejadas en la manera como los alumnos resuelven problemas.

Palabras clave*: resolución de problemas, física, estrategias de enseñanza, desempeño de los alumnos, estudiantes expertos/novatos.*

INTRODUCTION

Problem solving is a widely used instructional strategy in Physics courses. Often, problems are used as a means of evaluation, and therefore, the students pay a great deal of attention to this activity. Nevertheless, the results that they attain are often below the teachers' expectations.

Different teachers use different strategies when posing, solving and assessing problem solving in their Physics classes. These differences are not only seen in the emphasis given to particular phases of the process, but also in the role chosen by the teacher in the classroom.

Advances in the definition of performance indicators, as well as of factors influencing them would therefore represent important tools for teachers, especially when these factors are linked to possible decisions to be taken in the classroom. The possibility of generating explanatory models for student performance in Physics classrooms enhances the design of teaching strategies aimed at achieving specific instructional goals.

This work studies the relation between "strategies employed by teachers" and "student performance" in Physics problem solving. The study was carried out in a pre-service teacher-training institution in the province of Córdoba (Argentina). A reason for this choice was that it provided an opportunity to interact with those who train pre-service teachers with regard to issues concerning Physics Education Research.

RATIONALE AND BACKGROUND

Studies analyzing the differences in problem-solving performance between experts and novices assume that there are stages in the solving process. The description of such stages does not vary too much among different authors. Representative of these is the description furnished by MC DERMOTT & LARKIN (1978) and MALONEY (1994), who suggest that the process of solving Physics problems consists of the following stages:

- Reading the problem statement.
- Drawing a sketch of the problem situation.

- Qualitative analysis, which results in a representation containing abstract physics entities.
- Generation of equations.

CHI *et al*. (1982) describe the structure of the representation stemming from the third stage (qualitative analysis) as a semantic network containing certain elements and relations between them. The construction of this representation is helpful, and even necessary for the solver, for several reasons:

- It provides a basis for generating the equations describing the physical interrelations among the different variables involved in the situation.
- It provides a model that can be used to check for possible errors.
- It provides a concise and global description of the problem and its important features.
- It permits direct inferences to be drawn about certain features and the interrelations that are not explicit in the problem statement.

On this basis, several authors infer that it is this representation that, to a great extent, guides the problem solving process (LARKIN, 1983, DE JONG & FERGUSON-HESSLER, 1991, SAVELSBERGH *et al*., 2002).

NATHAN *et al.* (1992) go further in the study of this representation for the case of algebra word-problems. They propose a differentiation between the mere representation of events, the *situation model*, and another representation that is constructed with the formal relations in mind, the *problem model*. The problem model captures the algebra problem structure. Its most important feature is that it allows for quantitative predictions whereas a situation model can only provide qualitative ones. In order to generate this representation, the subjects must incorporate specific mathematical knowledge in a meaningful way.

With these considerations in mind, it is of interest to analyze some characteristics of the teaching strategies for Physics problem solving, such as:

- *Do the strategies employed in teaching Physics problem solving favor the construction of an internal representation by the students? If so, how is this done?*
- *How do the teaching strategies favor the coherence between a representation such as the one described above and generating equations?*

THE STUDY

Sixteen classes were observed in two parallel classrooms, corresponding to a General Physics course for pre-service teachers in a teacher training institution. The topics dealt with were Mechanics and Optics, in one of the classrooms, and Mechanics, in the other.

On the basis of the stages described above, a grid was constructed to guide observations. This tool was used to gather information about the characteristics of the teaching strategies set forth in each of the classrooms.

Likewise, with the aim of exploring the relation between the strategies observed and the corresponding student performance, a problem-solving activity was designed for both classrooms. This activity was presented to the students at the end of the observation period. Student performance was assessed by the analysis of the written records which they produced.

DATA ANALYSIS

Class observations

The grid presented below was used for class observations. It is possible to identify some similarities and differences between the teaching strategies employed in each of the classrooms observed.

Table 1

Grid for class observations

	Classroom A			Classroom B			
I Understanding of the situation	**Yes**	**No**	**Some times**	**Yes**	**No**	**Some times**	**Teacher role, interactive relations. Observations**
Is the problem re-expressed in other terms?	x				x		Room A: sometimes done by teacher; others done by a student.
Is the problem explained in qualitative terms?	x					x	Room A: insistence on qualitative information in problem statement.
Is the situation represented using plots, sketches, etc.?	x					x	Room B: teacher sometimes gives suggestions such as "read carefully," draw a sketch.
Is the goal of the problem indicated explicitly?	x				x		
II Analysis of the theoretical framework	**Yes**	**No**	**Some times**	**Yes**	**No**	**Some times**	**Teacher role, interactive relations. Observations**
Is there an explicit mention of the laws and principles related to the situation?	x				x		Room A: Mentioned in terms of equations and highlighting functional characteristics.
Is there an analysis of the validity of the conditions for these principles?			x		x		Room A: Teacher points out whether with or without friction.
Is the applicable principle explicitly selected?	x				x		
Is an estimate of the results performed in advance?			x		x		Room A: values that cannot be obtained are explicitly mentioned. There is an analysis of the possible sign of the results.
III Planning of the solving procedure	**Yes**	**No**	**Some times**	**Yes**	**No**	**Some times**	**Teacher role, interactive relations. Observations**
Is there a previous decision about the steps to be taken and the order in which they will be performed?	x					x	
IV Numerical Solution	**Yes**	**No**	**Some times**	**Yes**	**No**	**Some times**	**Teacher role, interactive relations. Observations**
Is there an explicit selection of formulas to be used?	x					x	Room A: (kinematics) all formulas known to the students are presented and the most convenient is selected from among them.
Are variables linked to the data available and numerical values substituted?	x			x			
Is there a decision as to the unit system to be used?			x			x	Units are used in both classrooms, although the system used is not explained.
Are the units of the result checked?		x		x			Units are not used as a first possible instance for control of results, in either classroom.
V Analysis and verification of results	**Yes**	**No**	**Some times**	**Yes**	**No**	**Some times**	**Teacher role, interactive relations. Observations**
Are results compared for coherence with previous estimates?			x		x		Room A: sigs of results are estimated in kinematics although not in the applications of Newtons Laws.
Are particular cases analyzed?			x			x	

Differences between classrooms can be observed in the stages corresponding to the comprehension of the situation, analysis of the theoretical framework and planning of the solving procedure. There are explicit actions taken in room A (and not in room B) that could favor these stages of the solving process. The strategies observed in both classes produced similar results with regard to the numerical solution stage. Both teachers are explicit about substituting numerical values or data into the corresponding mathematical formulae and in computing the corresponding results. Regarding control, the teacher in classroom A occasionally engaged in specific considerations regarding the plausibility of a result (as, for example, the sign of a certain value).

Activities presented to students

Different contents were taught in the two classrooms during the period observed and therefore, the instruments developed were designed on the basis of different specific contents[1]. These were used to evaluate the central aspects of the students' performance.

Two paper-and-pencil tasks, presenting two problem situations, were posed to the students. These written responses were analyzed according to the degree of occurrence of the following elements (taken as indicators of the solving process stages):

- Change of external representation
- Vector representation of the relevant Physics quantities involved
- Qualitative description
- Recall of problem schemas
  - Qualitative statement of the physical principles and/or laws involved in the solution of the problem
  - Mathematical formulation of the former
  - Application of these principles and/or laws
- Control of the results obtained (Are the students able to check their own work?)

The activities posed to students of classrooms A and B are shown below:

Classroom A

Problem 1

A sled of mass M=25 kg is pulled upward by means of a cable connected to an engine, on a 30º frictionless inclined plane.

The sled moves with constant speed of 5 m/s.

a) Draw the forces acting on the sled

b) Compute the magnitude of the force that the cable exerts on the sled.

When the sled is 5m above the ground, the cable is cut. From this instant on:

c) Describe the movement of the sled, qualitatively describing its characteristics

d) Compute the time elapsed from the instant the cable is cut until the sled reaches the base of the incline.

e) Plot sled speed as a function of time. Indicate the time intervals chosen for the plot.

Problem 2

A 1 kg ball is thrown vertically upward with an Ek = 50 J. At the highest point in the trajectory its potential energy has increased by 45 J.

a) Is it possible to assure that there have/have not been friction forces acting on the ball? In either case, justify your answer.

b) Under what conditions could the potential energy of the ball have been increased by exactly 50 J when reaching the highest point in its trajectory?

c) Choose an appropriate scale and draw a qualitative plot of the ball's potential energy as a function of height during all of its movement.

Classroom B

Problem 1

A sled of mass m=25 kg is at rest at the base of a 30º frictionless inclined plane. At t=0 an engine starts pulling it upward by means of a cable, exerting a constant force on the sled, parallel to the plane surface, of magnitude F=200 N, during 5 seconds.

a) Draw the forces acting on the sled.

b) Compute the variation of the sled's linear momentum during these 5 s.

At t = 5s the cable breaks. Starting at this instant:

c) Qualitatively describe the movement of the sled.

d) Compute the total variation of linear momentum of the sled from the time the cable is cut until the sled reaches the base of the incline.

f) Plot the sled speed as a function of time. Indicate the time intervals chosen for the plot.

Problem 2

A cylindrical rod is made of glass with refraction index n. The value of n is such that all light rays entering the cylinder through one of its ends are always reflected on the inside surfaces. A monochromatic light ray enters the rod through one of its ends, as indicated in the figure.

a) *Indicate the path of the light ray within the cylinder by drawing a sketch. Explain the characteristics of this sketch.*

b) *Compute the value of the angles corresponding to the subsequent reflections of this light ray, assuming n=1.52 and taking the incidence angle as 45º.*

c) *Discuss the behavior of light rays in another rod of the same size and shape, built with a material of index n' (n' < n).*

The indicators considered were valued on a three-level ordinal scale: *always* (examination papers show evidence of the indicator in both problems), *sometimes* (evidence found in only one of the problems), and *never* (evidence not found in either problem).

The indicator "Vector representation of the relevant Physics quantities involved" can only be considered in the first problem of either activity, and therefore it was evaluated solely on the basis of this problem.

The information obtained from the analysis of this activity is summarized in the following graphs.

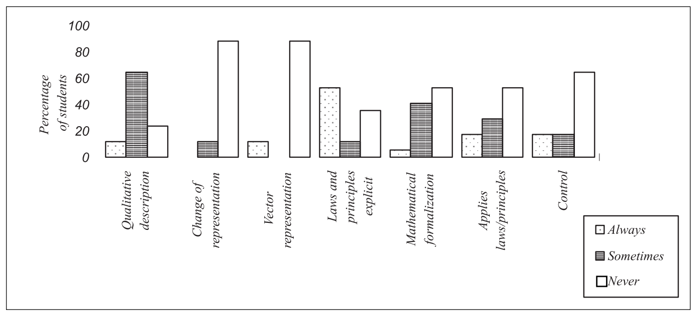

Figure 1: Results for the activity presented to group A.

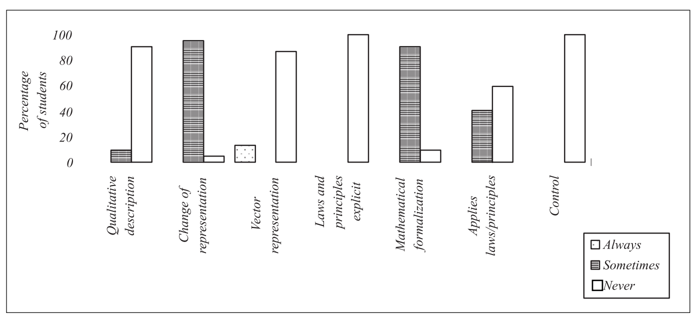

Figure 2: Results for the activities presented to group B.

Some characteristics observed in each group

Classroom A

The examination papers show that students have gone through a qualitative description stage (more than 70% of the subjects explicitly show this in at least one of the problems). Also, the physics laws involved are explicitly mentioned in the solutions (more than 50% of the subjects state them in both the problems). In the same ratio, it was observed that students apply these laws in either or both of the problems. Although the mathematical formulation for both problems is found in only a small proportion of the papers, a significant number of these (~50%) show evidence of this formulation for at least one of the problems. It is also worth noting that almost 40% of the subjects explicitly check their work in at least one of the problems. This observation is interesting, since, according to the theoretical guidelines adopted; this sort of control is possible only if the subject has previously gone through a qualitative description stage.

Classroom B

A high percentage of the examination papers corresponding to group B show that the subjects have gone through a change-of-representation stage (evidence found in 90% of the cases for at least one of the problems). Also, these papers show evidence of a mathematical formulation of the physics principles involved (evidence found in almost 90% of the cases for at least one of the problems). Subjects in this group do not show evidence of a qualitative description stage in their written solutions (except for a 10% minority, who explicitly show this stage for one of the problems). It is noteworthy that no evidence was found either for the explicit mention of physics principles or for the control of results.

CONCLUSIONS AND PERSPECTIVE

The values found for the indicators in each of the groups of subjects analyzed were found to be internally consistent. This finding can be considered to support the model adopted for the problem solving process. Also, the instruments designed for the study are found to be internally coherent. The following results found in each group serve as a basis for this conclusion.

Subjects in classroom A demonstrate that they go through a stage where they make a qualitative description of the situation. These subjects explicitly state the physical laws and principles used in the solving procedure and are able to check the consistency of the results they obtain. In terms of the theory, these subjects can be assumed to have built a situation model that enables them to incorporate the physical principles, formally expressed in equations, in a meaningful way.

Results related to classroom B do not show evidence of a qualitative description stage. In this group, equations are found to be written without an accompanying statement of the physical laws they represent. Therefore, these laws cannot be considered to have been meaningfully incorporated into the subjects' representations. At the same time, the subjects in this group do not appear to be able to check the results they obtain. These two characteristics occurring in the same group of students are in agreement with the predictions for the model adopted.

Regarding the central purpose of this study, the following conclusions can be drawn about the relationships between the teaching strategies used in the classroom and the students' problem solving performance.

In classroom A, the teacher explicitly and consistently insisted on the importance of recognizing the physical principles involved in the situation analyzed. The problem was usually re-stated and the meaning of the mathematical equations used was discussed. The teacher in classroom B focused the attention on the generation of the mathematical equations necessary to obtain the solution sought. The data collected on the students' performance show signs of these different teaching strategies and a correspondence can be inferred between the teaching strategy and the problem solving characteristics in each group.

As described above, different instructional models used in classrooms have an influence on the characteristics of the students' performance in problem solving activities. Students learn a problem solving model, even if it is not taught explicitly. The present results illustrate the relevance that teaching strategies used for physics problem solving have for the students' learning process. In this sense, the perspective is promising for the continued study of teaching strategies that could prove to be effective in improving student performance in the task of physics problem solving.

ACKNOWLEDGEMENTS

The present study was partially funded by the Secretaría de Extensión Universitaria of the Universidad Nacional de Córdoba.

Preliminary results were presented in the XIII Meeting of Physics Education. Río IV, Argentina, 2003.

The authors wish to thank the authorities, teachers and students of the teacher-training institution who participated in this study. They have been supportive of it in many instances and have kindly participated in the activities proposed.

BIBLIOGRAPHY

CHI, M.; GLASER, R. & REES, E. (1982). Expertise in Problem Solving, in STENBERG, R. (ed.). *Advances in the psychology of human intelligence*. Lawrence Erlbaum Associates. Hillsdale, NJ, 7-75.

LARKIN, J. (1983). The role of problem representations in physics, in GENTNER, D. y STEVENS, A.L. (eds.). *Mental model.* Lawrence Erlbaum Associates. Hillsdale, NJ., 75-97.

MC DERMOTT, J. & LARKIN, J. (1978). Re-representing textbook physics problems: Proceedings of the 2nd national conference of the Canadian Society for Computational studies of Intelligence. Toronto: University of Toronto Press.

MALONEY, D. (1994). Research on problem solving: physics, in *Handbook or research on science teaching and Learning.* Dorothy Gabel (ed.). McMillan Publishing Company. NY, 327-354.

NATHAN, M.; KINSTCH, W. y YOUNG, E. (1992). A theory of word algebra problem-comprehension and its implications for the design of the learning environments. *Cognition and Instruction,* 9, 329-389.

DE JONG, T. & FERGUSSON-HESSLER, M. (1991). Knowledge of problem situation in physics: a comparison of good and poor novice problem solver. *Learning and Instruction*, 1, 289-302.

SAVELSBERGH, R.; DE JONG, T. & FERGUSON-HESSLER, M. (2002). Situational knowledge in physics: The case of electrodynamics. *Journal of Research in Science Teaching*, **39** (10), 928-951.

Received: 22.08.2005/ Accepted: 3.04.2006