Use of PBL in teaching the principles of dynamics in high school

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Abstract

Problem Based Learning (PBL) has been used in the teaching of different scientific areas and the obtained results show that it helps in the learning as well as in the development of a number of important skills and abilities. We take into account the PBL principles and the curriculum of the Physics I course to design three PBL didactic sequences to help the conceptual learning and the development of problem-solving abilities. These sequences were explained in the Physics I course of the curriculum of two High Schools at the México State. In each High School we have two experimental groups and one control group. The effectiveness of PBL teaching sequences was evaluated with the Force Concept Inventory (FCI). Our results show that: PBL is a teaching method more effective than the traditional method, PBL promotes: the active participation of the students, critical analysis and resolution of problems arising in Physics, the interaction among the students, as well as autonomous learning.

Keywords: PBL didactic sequences, Force Concept Inventory, Teaching of Mechanics.

Resumen

El Aprendizaje Basado en Problemas (PBL) se ha utilizado en la enseñanza de las diferentes áreas científicas y los resultados obtenidos muestran que favorece el aprendizaje y el desarrollo de varias habilidades intelectuales. Tomando en cuenta los principios del PBL y el programa de estudio del curso de Física I curso diseñamos tres secuencias didácticas PBL para ayudar al aprendizaje conceptual y el desarrollo de habilidades para la resolución de problemas. Estas secuencias fueron desarrolladas en el curso de Física I de dos Escuelas Preparatorias en el Estado de México. En cada Escuela Preparatoria tuvimos dos grupos experimentales y un grupo control. La eficacia de las secuencias de enseñanza PBL fue evaluada con el Cuestionario sobre el Concepto de Fuerza (FCI). Nuestros resultados muestran que: PBL es un método de enseñanza más efectivo que el método tradicional. El PBL promueve: la participación activa de los estudiantes, el análisis crítico y la resolución de problemas que surgen en la Física, la interacción entre los estudiantes, así como el aprendizaje autónomo.

Palabras clave: Secuencias didácticas PBL, Cuestionario sobre el Concepto de Fuerza, Enseñanza de la Mecánica.

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I. INTRODUCTION

The teaching of Science in the preuniversity level is a fundamental factor in the student's training, because this aspect promotes the responsibility and appropriate action [1]. Within the high school level curriculum, Physics is a core subject, their knowledge-oriented concepts, methods, and procedures are useful for solving everyday problems and for a rational understanding of the environment.

The High School at the State of Mexico are pre-university level institutions where the teaching of Physics tries that the students "understand the physical behavior of Nature and they acquire the ability to understand and speak the language of Science" [2]. For this reason the curriculum emphasizes that "the teacher should design activities in order to develop collaborative learning, as well as motivate to the students to apply in their daily life the lessons learned" [2]. However, everyday experience tells us that traditional teaching practices are still in use and they limit the achievement of this purpose.

Knowledge of Physics is important in understanding the Universe and the phenomena that occur in it. Therefore, one of the main objectives of research in Science Education is to make the teaching of the Science more efficient for achieve the learning of the students. According Campanario [3] "Students have various difficulties in the process of learning Science". It has been found that the main obstacles to learning Science is the logical structure of the concepts, the background of students, and lack of skill in solving problems [4, 5, 6].

Problem solving is one of the main aspects that are evaluated in the learning of physics and a high percentage of time in the Physics courses is devoted to its instruction, and resolution. However, it is one aspect where arises a problem that is still poorly understood [3, 5].

The theoretical and methodological researches that have studied the process of solving Physics problems and published in the last decades of the twentieth century (documented from the 70's by Fávero & Gomes [7]) were intended to improve the performance of students in solving the problems. In the period from 1970 to 1999 we found at least 72 papers were published. In these papers we find the results of researches on problem solving in Physics. The research lines correspond to the comparison between experts and beginners or novices, analysis of methodologies, didactic proposals and factors influencing the correct solution of problems in the classroom. The latest proposals on solving Physics problems focus on the development of methodology based on active learning that promotes cognitive development, active participation, and collaborative work of students [6, 8, 9, 10]. Thornton and Sokoloff [11] assert that in recent years the teaching of Physics has promoted the use of active learning strategies; methodologies that motivate to the students to construct their own knowledge of Physics concepts by means of direct observations of the physical world. Among the alternative proposals for transforming the teaching of physics we find the PBL.

PBL is an approach to solving problems and in the process to achieve the learning of the concepts of Science. In the College of Medicine at McMaster University, Ontario Canada, initially it was used to teach Medicine, but its application has been extended to other areas in higher education and other educational levels [10, 12].

The results of research in Science teaching show that PBL is a didactic strategy that develops skills and positive attitudes to the learning of Science. However, its application in the teaching of Physics has been limited, especially in the High School level. In the case of Physics teaching, the researchers have been developed especially in university level [3, 13, 14, 15]. We do not find reports of the application of PBL in pre-university level in México.

This paper discusses the process and the results of the implementation of PBL in teaching Physics in the pre-university level. We develop and use three PBL sequences on the topic “Principles of Dynamics” of the Newtonian Mechanics Section of the Physics I course. The implementation of the proposed PBL sequences was conducted in two High Schools at the State of México, México: High School Attached to Normal Atlacomulco (School A) and the High School No. 166 (School B).

The effectiveness of the PBL sequences was evaluated with the test “Force Concept Inventory” (FCI in what follows) designed to determine the level of student understanding of the basic concepts of Newtonian Mechanics and in particular to determine the level of knowledge among students about the concept of force, a fundamental element of the Newtonian Mechanics in the introductory courses of Physics [11, 15, 16.18, 19, 20, 21]. Generally, the FCI is used as a diagnostic tool to evaluate the previous ideas of the students about the concept of force in Newtonian Mechanics. It can also be used as a test to determine the level of knowledge of students about the Newtonian Mechanics and to classify them in groups. Another use is to evaluate the effectiveness of a teaching strategy in the courses of Classical Physics. In this case it is applied as pre-test at the beginning of the course and as post-test after the development of a methodological proposal [16, 22].

The main objective of this study is to apply the PBL methodology to teaching the topics: the principles of Dynamics and Newton's Laws of the Newtonian Mechanics section in the Physics I course. Thus we obtain results of its feasibility and effectiveness for achieving student´s learning.

This article consists of five sections. Section II describes, briefly, the PBL teaching method. Section III presents the methodology developed in the research. In Section IV we show the results of the Hake factor. These results are obtained using the FCI. Finally in Section V the main conclusions are reported.

II. PROBLEM-BASED LEARNING

PBL focuses on developing collaborative skills, promoting a significant learning, and improving the skills of analysis and deduction [3]. The nature of PBL methodology is constructivist, it is an innovative alternative, based on the use of real life problems that students solve by means a collaborative learning, the students work in teams of three to twelve participants in coordination with a tutor [23].

In PBL students are faced with problems that are found in the real world, characterized by being complex in their structure, require reasoning, bibliographic research, and these are a challenge to the intellect of the students [15]. Epistemology of PBL is based on the formulation of a series of questions about a situation, phenomenon or event that needs to be clarified or solved under a conceptual foundation. The planning of teaching is not oriented only to the content and learning objectives, but in the process of acquisition and construction of knowledge [24].

The working model of PBL considers a sequence of stages; they vary in their structure and depend on the author. Thus, we find a model with seven steps [12], a cycle of three phases [25], the eight steps model [23], the five basic steps [26] and others [13, 23, 24]. However these proposals agree on the following points: the identification of what is known, what the students need to know (predictions, hypotheses), the formulation of a plan to resolve the issue (discussion and assignments) and the presentation of solution (outcome assessment). In this work, the implementation of the PBL methodology is based on the work cycle of three phases by Lasry & Abbott [25].

III. METODOLOGY

The PBL method as a learning strategy begins with the reading and analysis of the problem, it proposes to the students of the working groups to study systematically the problem, using the coordinated work of the students and the teacher, then the different phases involved in the process are carried out to solve the problem of PBL type [12, 23].

A. Didactic sequences PBL

Based on the PBL we design teaching sequences with three PBL type problems, these were the focus and motivation for learning. The problem was a challenge for the students, each is structured on a real context. The solution of problems is made in three phases: Phase I raised the questions, posed hypothesis; we determined what it is known and what it is needed to know. Then in phase II was integrated the strategy of solution, it was investigated and solved the problem in the end. In phase III it is presented a report with the results and the analysis of the process developed in the PBL sequence.

B. Implementation of the PBL in teaching the principles of Dynamics in High School level

The study of the implementation of the instructional sequences begun with the analysis of socio-educational context of the students in the experimental and control groups of the two schools where the research took place.

In order to determine the state of knowledge of the students about the Newtonian Mechanics, the FCI was applied as pre-test to the six groups under study [16, 22]. Later, based on PBL strategy the teaching sequences were developed in the experimental groups. Finally we turned to apply again the FCI as post-test to assess the degree of progress of the students in understanding the fundamentals of the Principles of Dynamics and analyze the effectiveness of PBL teaching strategy in the learning and teaching of Physics. We also compare the results with those obtained with the traditional method for teaching of Physics.

In the instruction with the PBL learning strategy in the four experimental groups we developed a series of teaching sequences and in the two control groups we expound the same themes of the PBL sequences in the traditional way.

In the experimental groups, randomly were formed teams of 5 to 6 students, then to the experimental groups the teacher presented to students a problem of PBL type to solve during the assigned sessions (4 to 5 sessions of 50 minutes). This presentation was followed by the reading of the problem of PBL type in an individual way, and then the students discussed their predictions on the solution of the problem. During the process, issues in Physics that would allow the solution to the problem were investigated and analyzed. In the next phase, it is designed the solution strategy and the problem is solved. It was required to specify the physical quantity to calculate, the topics to study in order to understand the phenomenon and therefore to explain the solution process. It was investigated in Physics books and online. Finally, in the closing phase, each team presented the solution to the PBL problem by exposing to the group the followed procedure and the outcome.

IV. RESULTS FOR THE HAKE FACTOR

One of the main objectives of this work is to compare the results obtained by experimental and control groups of both institutions, in order to evaluate the effectiveness of the strategy with the results obtained by students in the FCI that was applied before the instruction PBL teaching strategy and thereafter.

From the results obtained in the FCI we determine the Hake Factor or gain of conceptual learning (normalized gain g) [27],

$$g = \frac{S_f - S_i}{100 - S_i}, \quad (1)$$

where S_i and S_f are the result in the pretest and posttest, respectively.

The quantity g is used to determine the conceptual learning achieved in the implementation of a teaching strategy, that is, the results of an evaluation determines the impact on the assimilation of conceptual knowledge. In the implementation of a teaching strategy, it is possible to measure the changes in the different dimensions of the FCI, as well as the levels of achievement (low $g \leq 0.3$, $0.3 \leq g \leq 0.7$ medium, and high $g \geq 0.7$). Notice that the factor g is related to the level of conceptual mastery of the stages of FCI [28].

The Figs. 2 and 3 show the results of the evaluation of g for the full FCI. In these Figures we see that students do not pass Phase I of the FCI. The students do not distinguish the difference between the concepts of velocity and acceleration, they do not consider speed as a vector quantity, they believe that there are other factors that influence the movement (as well as different types of forces), they are unable to determine the influence of passive and active agents of force on an object, they have a biased and inconsistent notion of the concepts of force and motion [16].

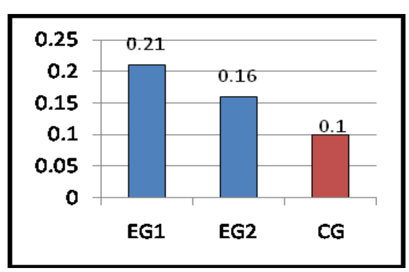

FIGURE 1. Results (normalized gain g) in the School A, experimental groups (blue) and the control group (red).

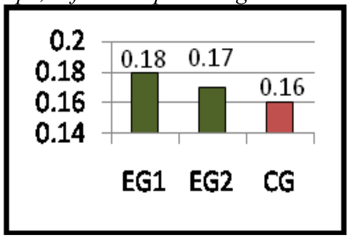

FIGURE 2. Results (normalized gain g) in the School B, experimental groups (green) and the control group (red).

In general, considering the value obtained for g, the result is low, $g \leq 0.3$. But it is convenient to note that the strategy under consideration was used only for a short period of time, since only three sequences were implemented based on PBL (three weeks), we believe that the gain g is appreciable in the FCI questions that have a direct relationship with sequences developed. We think that this fact is the reason for which the difference in the results of the relative gain of conceptual learning was not significant for full FCI test, since this test examines issues and concepts that were not studied in the three PBL sequences developed in this research.

The PBL didactic sequences developed in the course of this research are mainly focused on the analysis of the concept of force, the types of force, Newton's laws and the principle of superposition of forces. This means that our PBL sequences studied only some aspects evaluated by the FCI. Therefore to study the degree of effectiveness of the implementation of the PBL sequences designed in this work we carried out the analysis of the Hake gain of ten questions of the FCI (questions 4, 6, 8, 10, 11, 15, 16, 22, 29 and 30). These questions are related to the content of the problems in the PBL teaching sequences, and refer mainly to study of the concept of force, the types of forces, Newton's laws and the principle of superposition of forces.

The results of the average return of these ten questions are found in Fig. 4. We note that the results of questions that are directly related to the PBL sequences developed in the experimental groups, the gain achieved is located in the range $0.3 \leq g \leq 0.7$. Considering these ten questions, the results for the average Hake gain of the experimental groups of each institution and the control groups show a difference between them (see Fig. 3).

Although the results are not very high, for the Newtonian dynamics issues on which we designed and implemented the PBL teaching sequences we find that the experimental groups obtained a greater Hake gain than the control groups. The gain g in the experimental groups is greater in School A, the average of both groups in the ten questions under study is 0.28, while School B is 0.24 (Fig. 3). Meanwhile, in the control groups the gain g in School A is 0.19 and in School B is 0.09.

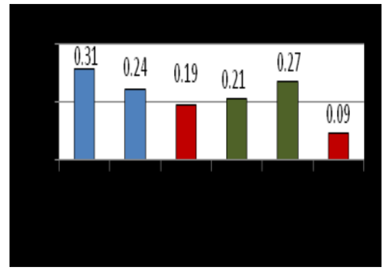

FIGURE 3. Results of the averaged Hake gain in School A and in School B of the experimental and control groups obtained in questions 4, 6, 8, 10, 11, 15, 16, 25, 27 and 28 of the FCI.

At the end of the development of the PBL sequences we inquiry the opinion of the students on their views on the teaching sequences and on the PBL method. The students expressed that the sequences PBL: "There is a better understanding", "it is easier to learn", "learn better", "funny", "you get better performance", "thinking is encouraged", "interesting", "is more dynamic and fun class", "may share ideas and knowledge" and "there is a thorough analysis of the issue".

V. CONCLUSIONS

With the results obtained from the implementation of PBL sequences in teaching Newtonian mechanics in the High Schools A and School B, we can establish that it is possible to apply the learning strategy of PBL in teaching physics in the high school level, by using sequences with PBL problems that are designed based in problematic situations of the student's life. For the preparation of the sequences used in this paper we considered the characteristics of PBL teaching strategy and the known issues in the teaching of the principles of Dynamics and Newton's laws of the Physics course I.

The implementation of the PBL teaching sequences in the classroom yielded a better conceptual learning of the subjects studied. Fig. 3 of Section IV shows that the experimental groups of Schools A and B School have a better result for the Hake gain of conceptual learning. The average gain of the experimental groups was 0.28 in School A, while in School B is 0.24, whereas in the control groups was 0.19 in School A and in School B was 0.09 (Fig. 3).

During the development of the PBL type teaching sequences it was achieved that the students critically analyze the problematic situation in the regular sessions of the course, investigate the information needed to solve the problem and establish results on the basis of Newtonian Mechanics. The PBL method would enhance learning, and also supports the development of metacognition, a key aspect in learning (to understand the learning process).

Another aspect that is important to note. At the conclusion of the research carried out and during the analysis and interpretation of results in an educational research, we should study the appropriate data. That is, we must implement a process of analysis according to the objective of the study, the development of the study and the results obtained as a product. In the case of this research in order to make a more detailed and accurate analysis, it was necessary to consider only a part of the test questions of the FCI.

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