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Teaching the wave concept through problem-based learning

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Abstract. The wave movements can be studied from autonomous work done by the student since they are processes in which he can appreciate and understand how the transmission of energy from one part to another without transfer of matter is. Problem-based learning constitutes a good alternative to study the concept of waves since it sequentially leads the student to structure the knowledge to use it in the context, to develop effective processes of reasoning, to develop self-directed learning skills and to motivate him/her to learn, together with the development of the capacity to work in a team and it favors the development of the mathematical physical thought. The research is developed from the multi-method methodological approach developing in-depth interviews to teachers and knowledge tests to students with the purpose of establishing both pre-knowledge and initial situations for structuring the pedagogical intervention and the evaluation of its results. The pedagogical intervention is structured on a quasi-experimental design in which the strategy of problem-based learning is applied to the teaching and learning of physics and is compared with the traditional methodology. The research allows us to conclude that applying the problem-based learning methodology to physics teaching, we obtain better educational yields than with traditional teaching, while it generates a greater motivation and a greater interest in learning. It also allows the student to integrate the knowledge into his or her context, visualize the usefulness of learning and apply knowledge to the solution of problems in his or her environment, in other words, it allows the student to achieve significant learning and therefore a development of mathematical physical thinking.

1. Introduction

The development of physical thinking in basic education students is a problem that is taking more and more interest among physics and mathematics teachers [1]. This situation is evidenced by the results of the state tests where in many cases deficiencies are identified in the levels of numerical thinking, spatial metrics and physics [2]. Based on this foundation, the research is developed, with high school students, framed in a process that involves three phases characterization, intervention and evaluation of the pedagogical proposal. The proposal developed in this research is oriented based on the guidelines of problem-based learning pointed out by Barrows [3] that sequentially lead the student to structure knowledge to use it in context, develop effective processes of reasoning, develop self-directed learning skills and motivate him/her to learn, along with the development of the capacity to work in a team.

Wave movements can be studied from autonomous work done by the student since they are processes in which he can start with the analysis of situations posed, experimentation, description of the phenomenon and proposal of solutions that he makes from problems presented, since in mechanical waves he can appreciate and understand how is the transmission of energy from one part to another without transfer of matter and, since they require a material medium, in some cases he can visualize the wave propagation path, the periodic displacement and the vibration or oscillation, around the equilibrium position [4]. Problem-based learning is an educational model centered on discussion and learning that emanates from problems based on real situations; it is based on identifying a problem situation as a starting point to learn a concept or develop a competence [3]; it favors the development of skills regarding the search for and handling of information and also develops research skills since, in the learning process, students will have to, from a statement, find out and understand what is going on and achieve an adequate solution.

This active method based on the development of competences is understood as the ability to face problematic situations, leading to think about whether the traditional task of problem solving allows the student to reach his/her learning objectives and to develop the competences intended by the basic standards from the interpretative, argumentative and propositional level [5]. It is about creating in the student the need to learn, so it is a constructivist educational model centered on the student that is based on the fact that learning is acquired when interacting with the environment, that is, the understanding and contextualization with respect to a real situation, arises when interacting with the environment and that the cognitive conflict is a strong stimulant of learning and determines the organization of what we learn, so when facing a new situation the will to learn is guaranteed [6].

Problem-based learning involves active, cooperative, student-centered learning, associated with independent learning, simultaneously stimulates autonomous and team work so that students achieve goals in a timely manner [7]. Problem-based learning increases student motivation, achieves meaningful learning, develops critical and creative thinking, improves information retention, develops lasting skills and competencies, encourages the activation of prior learning in small groups, and provides opportunities for the development of that knowledge; to do so, the problems raised must be authentic, must be adapted to the level and context of the students, must promote discussion among students, and must be learning oriented and of interest to the students [8,9]. Several research works take this approach as a starting point and apply it in different situations for the acquisition and integration of new knowledge in physics and other related disciplines by stimulating independent learning and practice to address complex situations and identify their own gaps in the learning process, develop research activities and describe their suitability in the development of mathematical physical thinking [10-12].

The research hypothesis is formulated in the sense that problem-based learning applied to the study of waves allows better development of physical thinking and therefore achieves better learning of physics in high school seniors than with the traditional teaching method. The final purpose of the research is to design didactic strategies for high school physics teachers to generate problems related to mechanical waves, contextually focused, that motivate the student to investigate, share experiences with his or her peers, identify variables, elaborate models [13], propose possible solutions, and evaluate them in order to find the solution to the problem posed, which will be socialized before his or her educational community, leading to significant learning and the development of mathematical physical thinking.

2. Methodology

The project is part of a multi-method approach [14] and is developed in three stages: stage 1: characterization, stage 2: intervention and stage 3: impact assessment. In the first stage, from the qualitative approach, in-depth interviews are conducted with teachers to identify the current situation in terms of attitudes and willingness of students to address the methodology. At the same time, knowledge tests are applied to students in order to establish the level of pre-knowledge. For the second stage, firstly, the proposal of pedagogical intervention is elaborated as a result of the information contributed by the first stage; quasi-experimental work is carried out with control and experimental groups, within which the pedagogical intervention is applied to the experimental group and the traditional methodology is worked with the control group. Later, in the third stage, post-test work is carried out to determine levels of learning and evaluation of the methodology employed.

The procedures necessary to carry out the research in depth, will be based on the methodology of problem-based learning, through understanding supported by the thematic axes, goals of cognitive and cognitive understanding, understanding performance and continuous assessment, which are the theories developed by David Ausubel and David Perkins [15,16]. Autonomous learning is encouraged [17] and, from the social point of view, collaborative learning [18], in which everyone is responsible for the learning of his or her group. The student must not only solve the problem but, by means of the elaboration and exposition of a physical or conceptual model he will have to communicate his experience, as much during the process of formation as of the results obtained in the solution of the problem.

The sample is made up of 375 students located in four high schools in the city of San José de Cúcuta, Colombia, selected by the researchers, so that the physics teacher in the last grade would be in charge of two groups of students, so that one would be an experimental group and the other a control group. Two public and two private educational institutions were selected. The sample was made up of four groups with 201 students in the experimental group (Pu1A, Pu2A, Pr1A and Pr2A groups) and four control groups (Pu1B, Pu2B, Pr1B and Pr2B groups) with 174 students; in each case two groups in public schools and two in private schools. In each institution, the two groups (control and experimental) work with the same physics teacher.

In a first phase, teachers are interviewed about students' willingness to work collaboratively, expectations and creativity. In this phase of the research, teachers are trained in relevant aspects of problem-based learning. We do not work with students in order to avoid contaminating the study. In this phase, teachers are trained in the methodology of problem-based learning and, with their participation, problems related to mechanical waves are identified and defined for the students. In this phase of the research, students are given a test of knowledge and skills [14] to establish both the development of numerical skills, reading comprehension and abstract reasoning, and to verify homogeneity in the groups of each institution. The test is evaluated by means of the item response theory [20] and the results obtained are compared by means of Bartlett's variance homogeneity test and Fischer's test to establish significant differences in averages for independent groups.

The second stage is constituted by the pedagogical intervention, each teacher develops the methodology of problem-based learning in one of the groups while in the other one continues with his traditional work based on experimentation, laboratories, conceptualization and evaluation. Finally, in the third stage, the learning is evaluated by means of a post-test elaborated under similar parameters to the pre-test but with two components, in the first one there are problematic situations and a second one of application of physics to the solution of a problem previously identified to evaluate creativity in the proposal of solution of problems and physical and mathematical argumentation of results with the purpose of identifying levels of learning and comparing the two methodologies [21,22].

3. Results and discussion

A test of previous knowledge was applied to all students in the sample with the purpose of establishing initial characteristics of the students, homogeneity among groups in each institution and levels of mathematical aptitude and reading comprehension to approach the pedagogical intervention.

The rating of the questions was adjusted to a scale between 0 and 10 points so that the final individual score was in the range of 0 to 100 points. The item response theory [20] is used in the assessment of the test. The final result corresponds to the aggregate of the scores obtained in each component. Finally, the scale is adjusted to reach normality. Figure 1 shows the box diagrams corresponding to the results in the test; in the control group an average of 55.1 points with standard deviation of 8.3 was found. In the experimental group the average was 56.5 points with standard deviation of 8.4. The analysis of variance was carried out to compare the mean of the four courses that make up each group and it was found that the averages did not differ significantly. Bartlett's test by means of approximation by chi-square distribution, indicates with a value of χ^2=5.32 and 7 degrees of freedom that the p-value is 0.62, which allows concluding that the eight groups have results with similar variance. An analysis of variance test is applied and a value of F=1.32 and a p-value of 0.24 is obtained, from which it can be inferred that the averages of the results of the pretest are similar in the eight groups being worked on.

Figure 1 shows the box diagrams corresponding to the total test results for the eight courses participating in the research. Homogeneity is inferred in terms of average and medians in the groups of each educational institution; variability presents slight variations among courses, but is within acceptable limits, so it does not affect the research. There are some atypical students with respect to their course.

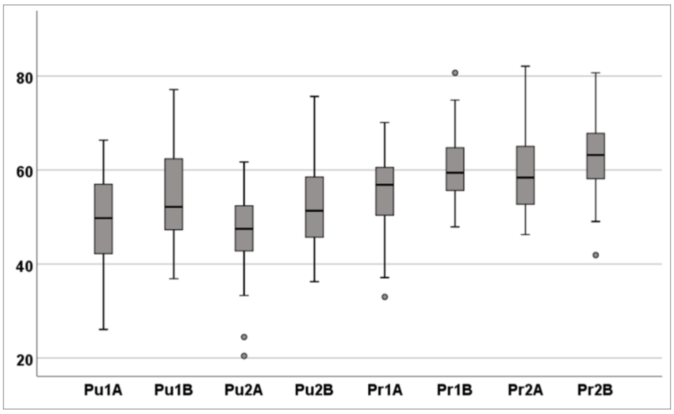

Figure 1. Pre-test results for the courses in the study.

The results of the test applied in the pretest were disaggregated by components, numerical skills, reading comprehension and abstract reasoning. In each group, quartiles 1 and 3 are calculated in order to identify cut-off points for the 25% with the highest scores and the 25% with the lowest scores, the remaining 50% being considered as average scores. Based on these values, they are projected, using optimal multivariate scaling, to define the two main axes of the Cartesian plane schematized in Figure 2. The coordinates of each course are calculated from the results of the students that make up the course and are projected on the map along with the levels of each of the components evaluated. It can be seen in Figure 2 that all the courses are located in the central part of the map, which allows us to infer homogeneity among them, since none of them is a determining factor in the definition of the components. A similar case occurs if analyzed from the assessment levels of each component, the great majority are located near the courses, being indicators of homogeneity in the results.

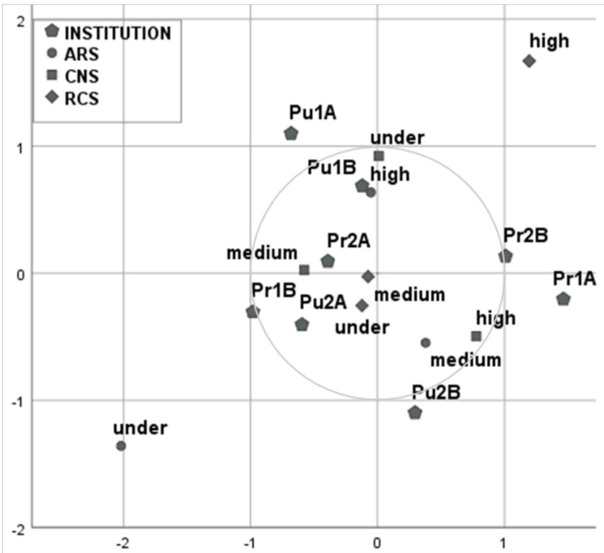

Figure 2. Pre-test levels by course.

The pedagogical intervention is made from the selection by the teachers of the experimental group in each institution. Students in the four experimental groups are given basic information about the problem-based learning methodology but are left free to discover it for themselves. Then, problems related to mechanical waves are presented, among them: after experimenting with springs in the classroom to visualize and describe the waves that can be generated, it is observed that cars are suspended over different types of springs, the observation of different vehicles and the description of the waves is proposed so that the student can deduce the role played by the shock absorbers, complemented with documentary information; in the riverbed, what type of waves can be observed, they are described, their properties are calculated and complemented with documentary information to find, if there is one, their ecological function and also socialization and argumentation of results. Problems related to sound, vibrating strings, membranes, percussion and others are presented.

After the application of the pedagogical intervention and development of the didactic proposal, a new test of cognitive evaluation was applied, focused in this phase of the research to evaluate the concept of mechanical wave, its applications and the competences developed by the students. This test was made up of problematic situations in which the student had to describe it in context, identify possible alternative solutions and choose the one that, according to him, turned out to be the most appropriate for his solution. He also had to identify the application of physics in a problematic situation, related to waves, previously selected. In this case, in Bartlett's test a value of χ^2=6.04 with a p-value of 0.54 is obtained, indicating that the variances of the results are homogeneous in the eight groups. Fischer's test leads to obtain the value F=2.81 with a p-value of 0.007, which allows to conclude that the averages are significantly different at the significance level of 1%. The analysis of post-hoc multiple comparisons, carried out by means of Tukey's test, leads to the identification of two groups, one conformed by the courses that received traditional teaching and the other by those that worked with problem-based learning, thus proving the research hypothesis

The results allow us to infer a significant difference in the average of the experimental group with respect to the control group, since in the experimental group an arithmetic mean of 66.2 with standard deviation of 9.3 was obtained, while in the control group the average was 57.8 with standard deviation of 8.2. Figure 3 shows a box diagram of the results disaggregated by course, it is also evident a significant difference in medians and intervals of variation of the results of the courses of the experimental group with respect to those that conformed the control group.

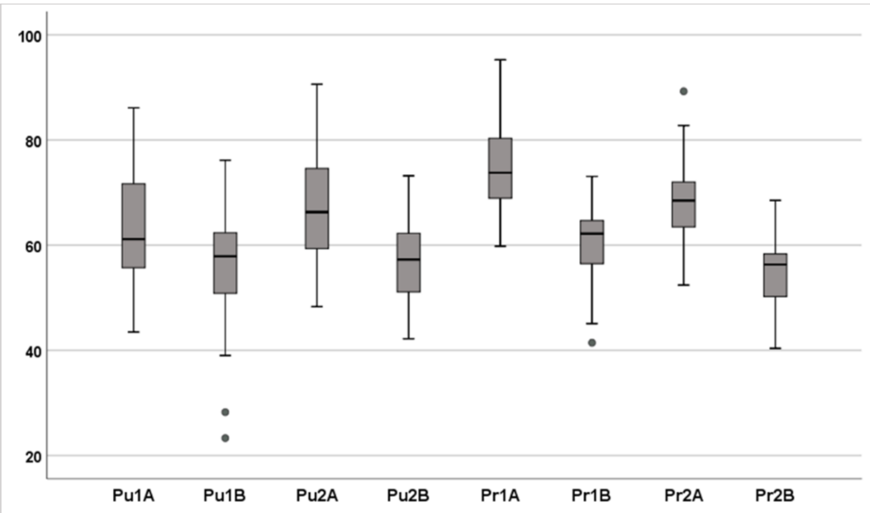

Figure 3. Post-test results for the courses in the study.

On the other hand, a qualitative evaluation test was also applied to the didactic experience carried out in the development of the contents corresponding to mechanical waves. In all items, the assessment of the students in the experimental group was significantly more favorable than that obtained by the control group. The participants valued that the methodology of problem-based learning favors independent study, stimulates interest in learning physics, allows the application of concepts to contextual situations, favors the active participation of the student, encourages teamwork and develops skills to discuss, synthesize and socialize results. Similar results are found in the two groups in terms of favoring the concept with respect to the data and in the experimental group they stated that more time should have been assigned for the realization of the activities. Both students and teachers agree when they give a favorable opinion about the amount of content, the depth of the subject, the evaluation method but they reveal deficiencies in the bibliography of the institution, but not in the virtual one and they state that the academic activity of other subjects limited the academic performance in the learning activities carried out.

The results show that the methodology of problem-based learning is a very good alternative for learning physics, these results coincide with those obtained by [6,11,23]. Part of the success obtained in the work developed in the framework of the research was due to the motivation and training of the four teachers who voluntarily agreed to participate, also to the motivation and preparation of the students before tackling the process; this makes the resulting proposal particularly different from other proposals developed in the same sense [12,24]. The fact that the students showed through the pretest a good level of mathematical skills and reading comprehension is also a pillar for the success of the work. It is important that other studies involve the capacity of expression and the capacity of creativity and innovation in the students. One of the biggest impact effects of using problem-based learning was the degree of student satisfaction compared to their traditional classroom peers. The methodology was equally well received by students from public and private sector educational institutions.

The research brings significant results to the pedagogical practices of teachers in the region since it explores a field of work in which both teachers and students are trained. From the interviews with teachers, it is evident that the teacher transforms his pedagogical practice and experiences changes in his academic and social attitude acquiring a greater commitment with the student, he experiences a joint experience with his students. On the other hand, the student sees that his sense of responsibility increases, that his creativity is stimulated and that the joint work with his group becomes a social situation that stimulates learning.

4. Conclusions

The results of the research allow us to infer that the methodology of problem-based learning is an efficient alternative for the study of physics, since it allows the student to integrate the knowledge into his or her context, visualize the usefulness of the learning and apply knowledge to the solution of problems in his or her environment, in other words, it allows the student to achieve significant learning and greater development of mathematical physical thinking.

The methodology not only facilitates the knowledge of physics, but also stimulates autonomous learning, since the student must discover by himself the theoretical foundations and apply them to the solution of problems and the collaborative learning, since, in most of the problems must be approached in work teams to find their solution, but it is responsibility of all, the success of the realized work. Through this research it can be concluded that teaching physics to high school students using problem-based learning methodology leads to better educational performance than traditional teaching while generating greater motivation and interest in their learning. The methodology of problem-based learning not only allows for better levels of learning and development of physical thinking, but also stimulates collaborative learning, facilitates social interaction of teachers and students, stimulates creativity, reasoning and argumentation.

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