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THE RELATIONSHIP BETWEEN THE COMPREHENSION OF THE BASIC CONCEPTS OF MECHANICS, ALTERNATE CONCEPTIONS AND COGNITIVE DEVELOPMENT AMONG UNIVERSITY STUDENTS

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Technical Editor's Note: The authors supplied enlarged versions of several tables. These can be found at the end of this article.

Concepts are essential in science since its principles are nothing more than relationships among concepts. Thus, in science teaching concepts should receive special attention so that the principles become significant to the students. In fact, every science teaching program establishes as one of its goals to achieve that the student acquire an adequate comprehension of the basic concepts, and it is expected that such comprehension will be useful in the analysis or description of situations of scientific interest. The evaluation of the achievement of this goal, together with the factors that can hold it up, should be carefully planned taking into consideration that the traditional evaluations could poorly reflect the goal where conceptual comprehension is concerned.

Learning evaluation in physics courses at the introductory and general levels is done through tests, the content and structure of which reflect an attempt to evaluate the problem solving skill. That emphasis on problem solving is derived from the premise that to solve problems, it is necessary to understand the concepts involved in them. The following train of thought is established: if the students do well in the physics course it is because they have problem solving abilities, and thus, an adequate comprehension of the concepts. Nevertheless, some studies indicate that when concept learning is measured using tests designed for this sole purpose, there does not seem to be a strong relationship between concept comprehension and course performance.

Physics concepts can be presented at different abstraction levels. In introductory and general physics courses, in particular, the concepts and the relationships among them are typically presented at such an abstraction level that to understand them, it is required that the student possess an intellectual development that allows the student to perform formal operations. To solve physics problems, a student must have the capacity to structure hypotheses and test them, which is characteristic of formal thinkers. Although the capacity to perform formal operations seems to be a necessary requirement for problem solving, it remains to be seen whether it is enough of a requirement for concept learning within the traditional teaching context.

Recent studies indicate that people, and particularly students, describe certain scientific facts in ways that conflict with the conception that the community of experts of the concerned area has (Confrey, 1990). Before studying a subject formally, people hold in a very solid way descriptive and explanatory systems for the phenomena of the physical world. In many cases, these conceptions persist even after going through a formal learning process (Champagne, Gunstone and Klopfer, 1983; Osborne and Wittrock, 1983). Watts (1983) indicates that the reason for this phenomenon is that students' preconceptions are not simple, erroneous, isolated conceptions but that they constitute a coherent and functional system.

In physics, the studies related to alternate conceptions are centered in those conceptions related to mechanics, as it is the core of this subject. Halloun and Hestenes (1985b) have analyzed particular conceptions about the phenomenon of the motion of the bodies and have found that the common sense beliefs about motion are generally incompatible with Newton's theory and that the common sense beliefs are very stable and that traditional instruction does very little to change them.

The problem with students having conceptions different from the scientific conceptions regarding physical phenomena has been analyzed using psychological principles, along with positions sustained by science philosophers.

Some researchers have established differences between the thinking process of those students who only use information acquired through interaction with concrete objects, concrete events or situations and the mental process of students with formal, operational thought, that is, with the capacity to carry out mental operations in a hypothetical-deductive way (Renner, 1976). This is an important distinction since the conceptualization process of a physical phenomenon requires the use of the hypothetical-deductive method to construct and test hypotheses based on theories. Therefore, a coherent conceptualization requires that formal thinking be used.

Since we accept that there are differences in the thinking process of individuals according to their development, the importance of the cognitive development in the success of science teaching has been stressed upon (Lawson, 1982). Nummendal (1987) indicates that the comprehension of the majority of the concepts and principles is developed through formal thinking processes. The reason why many students do not develop full comprehension of certain concepts is their inability to put formal thinking to work. In this regard, Aarons (1976) believes that the curriculum should be organized so that it promotes the students' cognitive development.

A significant statistical relationship between performance in physics courses and the level of cognitive development has been found in different studies. It was therefore concluded that this last one has a great repercussion on the academic performance (Lawson and Renner, 1974; Lawson, 1982). Even more, other studies suggest that the students' inability to perform at a formal level is a source of failure (Cohen, Hullman, and Agne, 1978; Mc Kinnon and Renner, 1971). Nevertheless, other studies have offered evidence that there is no relationship between the level of cognitive development and the performance in physics courses. Kolody (1975) analyzed the relationship between these two variables using high school students and students in introductory science courses, and found a very low correlation between them. Barnes (1977), using college students, found that the correlation between course performance and the cognitive level is low for the group of students whose performance is high, and it is practically null between the group of students with low performance. This author concludes that other factors, different from the ability to think logically, seem to be of greater importance in performance.

Even if the level of intellectual development is an important variable in concept formation, the presence of alternate conceptions in the student's conceptual scheme can constitute an obstacle in such a process. Hence it is imperative to examine the possible existence of such conceptions and how they contribute to the conceptual comprehension.

The objectives of this study were: a) to determine the level of comprehension of concepts of mechanics among Puerto Rican students, b) to determine the effectiveness of physics courses for improving the comprehension level of these concepts, c) to determine the relationship between the comprehension level of these concepts and the performance in physics courses, d) to determine the relationship between the comprehension of the concepts and the student's level of cognitive development e) to determine the relationship between the performance in physics courses and the cognitive development of the students f) to determine whether the comprehension level of mechanics concepts is related to variables such as the campus, the type of course (with or without calculus), the major (natural sciences or not), the student's science background (one or more science courses or none) and the student's gender, and g) to examine which specific alternate conceptions students have .

M E T H O D S

Sample

The sample in this study consisted of 110 students (38 male and 72 female) registered in introductory (53.6%) and general physics courses (46.4%) in the Metropolitan campus of the Interamerican University (24.6%), the largest private university in Puerto Rico, and the Río Piedras campus of the University of Puerto Rico (75.4%), the state university. Of these students 96.4% were between the ages of 17 and 18 and only 3.6% were older than 18.

To select the sample, six sections of general and introductory physics were taken, at random stratified by campus. The initial number of students in this study was 208, however, only 110 participated in the whole study due to desertion. These students represent 16% of the population of students registered in general and introductory physics in both universities.

Instruments

In this study three instruments were used: the Diagnostic test developed by Halloun and Hestenes (1985a), which is used to measure the comprehension level of the concepts of mechanics; Longeot's test which allows subjects to be classified according to their cognitive development level; and an information sheet that allowed to record the data relative to the variables: campus, course variant, professor, students' major, science background (if the student has taken or not at least one university science course), performance in the courses and student's gender.

Diagnostic test - This test consists of 36 multiple choice items, each with five alternatives. The questions are aimed at determining the mastery of the basic concepts relative to motion and its causes. In a typical question, a physics situation is presented accompanied by a diagram and the student is asked to choose the alternative that best explains the physics situation. In general, the distracters of each question represent plausible answers based on common sense conceptions. No question requires the use of mathematics to answer it. In this study the mastery level of the basic concepts was classified according to the following scale: from 0 to 16 points - low; from 17 to 25 points - average; and from 26 to 36 points - high.

The test was translated from English into Spanish and validated with a sample of Puerto Rican students prior to its use. The reliability coefficient found in this study was 0.76, which compares favorably with the one obtained by the original authors.

Cognitive Development test - Is a Piagetian-type paper and pencil test developed by Longeot and widely used in the United States (Ward, et al, 1981). It consists of four subscales: class inclusion, propositional logic, proportional reasoning and combinatory analysis. The highest score in this test is 42 points. The subjects that score 22 points or less are classified in the concrete thinking stage, while the ones that score 23 points or more are classified in the formal thinking stage. This test was translated from French into Spanish and was validated to be used with Puerto Rican university students. The reliability of the Spanish version is 0.70 (Chavez, 1990).

Procedures

The Diagnostic test was administered to students for the first time during the first three weeks of the first semester of the 1991-1992 academic year. The Longeot test was administered between the sixth and the eighth week of the same semester.. The Diagnostic test was administered once again during the last two weeks of the semester. The students then filled the information sheet where they offered information regarding the variables: campus, course variant, professor, major, science background and gender. The information regarding the students performance was compiled in an interview with the professors during the first week of the second semester. Both tests, together with the information sheet were administered by the researchers. The course's professors did not obtain access to them until the study was completed.

R E S U L T S

Comprehension level of the basic concepts of mechanics

Table 1 shows the number of students and the percentage that classified in the low, average and high comprehension levels of the basic concepts of mechanics in the first and second administration of the Diagnostic test. As can be seen in this table, the majority of the students are classified in the low comprehension level, even after having studied in the courses the subjects covered in the Diagnostic test. Very few students are classified in the average comprehension level and practically none are classified in the high comprehension level.

Table 1. Number and percentage of students classified in the low, average and high levels in the first (pre-test) and second (post-test) administration of the Diagnostic test.

Level	Pre-test n (%)	Post-test n (%)	Change n (%)
Low	96 (87.3)	82 (74.6)	-14 (12.7)
Medium	14 (12.7)	24 (21.8)	+10 (9.1)
High	0 (0)	4 (3.6)	+4 (3.6)

Effectiveness of the physics courses in improving the comprehension of the basic concepts of mechanics

Table 1 shows the change in the percentage of students in the low, average and high comprehension categories between the first and the second administration of the Diagnostic test. The percentage of students who achieve a high mastery of the basic concepts after having completed the study of these subjects in the physics course is extremely low (3.6%). There is an increase of 9.1% in the percentage of students in the average comprehension category between the first and the second administration, while there is a reduction in the percentage of students in the low comprehension category.

The mean score in the first administration of the Diagnostic test was 11.95 points, while the score for the second administration was 13.81 points. Although the difference of 1.86 points is statistically significant ($t = 4.69$, g.l. = 109, $p < 0.000$), it is equivalent only to an increase of 5.2% in the number of items answered correctly in this test. Therefore, the learning level of the basic concepts of mechanics in the physics course is very low.

Relationship between the comprehension level of the concepts and the performance in the physics courses

Performance in the physics courses was measured through the course's final grade. Since each professor used his own criteria to evaluate his group of students, it is not possible to compare directly the performance of students who studied with different professors. With the purpose of measuring the performance of the students in a common metric, the grade distribution for each group was transformed to a distribution with a mean of 50 and a standard deviation of 10. To determine the relationship of this variable with the comprehension level of the basic concepts, Pearson's correlation coefficient was calculated between the course performance and the Diagnostic test scores. A correlation of 0.21, which was statistically significant, was obtained.

The determination coefficient r^2 is equal to 0.044, which indicates that the comprehension of the basic concepts of mechanics explains only 4.4% of the score variation for the final test. This implies that the students' performance in the physics courses holds little connection with the knowledge of basic concepts.of mechanics.

Relationship between the comprehension level of the basic concepts of mechanics and the cognitive development level

To determine up to what point the cognitive development level of the students holds a relationship with the comprehension of the basic concepts of mechanics, Pearson's correlation coefficient was calculated between the scores obtained in the Cognitive Development test and those obtained in the second administration of the Diagnostic test. The correlation coefficient in this case was 0,34, which is statistically significant ($p < 0.05$). The determination coefficient in this case is equal to 0.116, which indicates that the cognitive development level can help to explain only 11.6% of the variation in the Diagnostic test scores.

Relationship between performance in physics and the cognitive development level

To determine the relationship between performance in the physics course and the cognitive development level, Pearson's correlation coefficient was calculated.between the students' performance scores in the physics course and their scores in the Cognitive Development test. The correlation coefficient obtained was 0.30, which is significant ($p < 0.01$). The determination coefficient is equal to 0.09 which is why the cognitive development level explains only 9% of the variation in the course performance scores. The contribution of cognitive development on performance in physics is, therefore, very small.

Relationship between the comprehension level of the basic concepts of mechanics and other variables of interest

Table 2 shows the means and the standard deviation of the scores of the second administration of the Diagnostic test for the students grouped by university, type of course, major, science background and gender.

Table 2. Means and standard deviations of the score of the second administration of the Diagnostic test for the students grouped by university, type of course, major, science background and gender.

	Group	n	X	s	t	Sig.
University	public	32	13.91	4.73	0.31	n.s
	private	27	12.59	5.19		
Course	with calculus	59	13.31	4.95	0.25	n.s.
	without calculus	51	14.39	5.06		
Major	Natural Sciences	81	13.84	4.19	0.96	n.s
	Other	28	13.89	3.85		
Background	High	77	14.10	5.15	0.84	n.s.
	Low	32	13.25	4.67		
Gender	Female	72	12.72	4.19	2.96	*
	Male	38	15.87	5.79		

* - Significant at the 0.05 level.

As can be seen, there are no statistically significant differences in the means of the students registered in a private or a public university. Neither are there any significant statistical differences between the means, when the type of course, the major or the science background are considered. There is, however a significant statistical difference between the means of the scores in the Diagnostic test among males and females. Males show a better understanding of the basic concepts of mechanics than females.

Specific conceptions of students

The analysis of the items in the Diagnostic test revealed that students have alternate conceptions. A discussion of some of the prevailing conceptions among the students follows.

Position and speed

It was found that 52% of the students had the initial conception that the speed of objets, moving in a straight line, is determined by their position. Of the students, 50% retained this conception after taking the course, which indicates that it is very resistant to change.

Action of a force

It was found that 91.9% of the students initially believed that the motion of an object in one direction always implies the action of a force responsible for the motion in that same direction. Of the students, 87.3%, retained that conception after taking the course.

Of the students, 34.9% initially believed that a constant force produces a constant speed. Of the students, 50.9% had this conception after the course, which indicates that the effect was an increase in the number of students who have that conception.

DISCUSSION

The results obtained in this study indicate that the students begin the introductory and general physics courses with a very poor comprehension of the basic concepts of mechanics and that these courses are very ineffective in improving this situation. Since the correlation between the performance in the physics course and the comprehension level of the basic concepts of mechanics is low, it is evident that the tests used by the professors in the courses measure, not conceptual knowledge but skills or knowledge .

The low correlation between performance and cognitive development level seems to indicate that performance in physics barely relies in the cognitive development level. Since the majority of the students are in the formal development level, it is evident that the cognitive development level is not a determinant factor of success or failure in the physics courses.

The cognitive development level does not seem to be an important factor in the comprehension of the basic concepts of mechanics among university students neither. This conclusion is backed by the fact that 75% of the students are classified in a formal cognitive development level, while only 25% is classified as being in the concrete operational level.

Other results of this study indicate that the problem of poor comprehension of the basic concepts of mechanics is independent of the type of course, the student's science background and the student's major.

A possible explanation for the results of this study is that neither the instruction nor the evaluation of the physics courses are aimed at concept comprehension and that the possible alternate comceptions of the students have not been taken into consideration prior to instruction. On the one hand, traditional instruction overlooks the alternate conceptions that the students have, which in the absence of instruction aimed at modifying it remains unaltered. On the other hand, the performance tests focus more in memorizing terms and formulas and in the application of algorythmic formulas than in measuring concept learning.

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