Differences in the attitudes and beliefs about science of students in the physics-mathematics and life sciences areas and their impact on teaching

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For this study, we compared the attitudes and beliefs about science of physical science (physics and mathematics) and life science (biochemistry and biology) students at the beginning of their university degrees using the CLASS (Colorado Learning Attitudes about Science Survey) tool. It is worth noting that both groups of students received similar physics courses during their high-school education. Through a detailed analysis of the different categories of the test, we examined the differences in performance in each of the areas that make up the questionnaire. Among other aspects, we found that a considerable percentage of life science students (higher than that of physical science students) adopted a novice type of behavior in problem solving. Finally, we discussed the possible causes of the differences found and their implications for teaching.

Keywords: Epistemological beliefs; physics students; CLASS.

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1. Introduction

It has long been recognized in the physics-teaching community that, in addition to the specific contents, certain characteristics of the students, such as their previous ideas, their personal history, the way they interact with their peers and teachers, and their expectations, determine the transformation that occurs as they move through the educational system [1]. In particular, the set of ideas, assumptions and previous conceptions about science-more specifically, its evolution, its methods, its validation or refutation-are encompassed in the concept of epistemological beliefs. These beliefs, which are generally not explicit, have a strong impact on teaching and learning [2]. Therefore, it is relevant to understand the attitudes and beliefs of our students and how educational institutions, their teachers and teaching materials directly or indirectly affect those attitudes and beliefs in the learning and teaching of physics.

In the field of Physics Education Research (PER) a set of tools have been developed for the systematic assessment of knowledge, focusing on aspects related to the discipline as well as on other less objective aspects regarding the students' attitudes and beliefs [2–4]. While the assessment of specific knowledge is mostly based on multiple-choice questionnaires, the tools oriented to attitudes and beliefs usually ask students to indicate their degree of agreement or disagreement (Likert scale) with different statements reflecting the opinion of "experts" (usually professional physicists). The questionnaires result from a design and validation process that includes repeated interactions with experts [2, 3]. The differences between the students' responses and the experts' responses constitute the raw material for analyzing the epistemological status of the group of students. Specifically, to quantify the impact of certain courses, interventions or teaching approaches, it is applied twice, once at the beginning of the course (pre-test) and once after the intervention (post-test). The comparison of results reflects changes in attitudes and beliefs as a function of demographics, methodologies and teaching strategies.

Among the standardized tests for the evaluation of epistemological beliefs, we highlight the MPEX (Maryland Physics Expectations Survey) [2], which aims to survey the expectations of students in relation to physics, the CLASS (Colorado Learning Attitudes about Science Survey) [3], aimed at assessing the attitudes of students toward learning physics, how they think physics relates to everyday life, and their opinion about the discipline, and the E-CLASS (Colorado Learning Attitudes about Science Survey for Experimental Physics) [4], which follows the same approach as the CLASS but aimed at the experimental aspects of physics.

Research on the attitudes and beliefs of students has provided valuable insights into the discipline [5]. Several studies have shown that some epistemological attitudes negatively affect learning [6,7]. For example, a student who sees physics as a set of unconnected facts and formulas will study differently than one who sees it as a network of interconnected concepts [2]. Another valuable input shows that there is a positive correlation of academic performance with the CLASS pre-test and MPEX scores [6, 8]. In addition, multiple quantitative studies have been conducted in recent years on the changes that occur in students' attitudes and beliefs as a function of their previous training, the types of courses, and the teaching strategies used, as well as on the relationship between the pre-test and academic performance, among other variables [5].

Also valuable is the work comparing the performance of different groups in questionnaires regarding attitudes and beliefs about science. An extensive meta-analysis shows that students who major in physics perform better than those who major in engineering or other sciences [5]. This study also suggests that these aspects develop in the early stages of education, although it leaves several questions to be answered as to why this phenomenon occurs. Another longitudinal study [6], followed the journey of a group of students throughout their university careers and showed that those who were determined to study physics at the beginning of the first year of college performed better than the average of their peers.

Although the application of the CLASS and other similar instruments to assess epistemological attitudes has spread to many parts of the world, Latin American countries are a step behind, as very little research has been conducted in the area [9–11]. In the particular case of Uruguay, we inquired about the epistemological beliefs of teachers and prospective high school physics teachers in Uruguay [12]. The results showed trends shared by both groups, especially in the categories related to personal effort, interest and connection with the real world. However, there were notable differences in other categories, particularly those related to conceptual understanding, confidence and sophistication in problem solving.

There are many open questions regarding the attitudes and beliefs of students, especially those related to the comparison between different groups, the causes of possible differences and their impact on learning. In this work, we compare the attitudes and beliefs about science of students of physical sciences (physics and mathematics) with others of life sciences (biochemistry and biology) at the beginning of their university degrees using the CLASS tool. Our study was conducted in the first year of the degrees, at a very early stage when the students' curricular training in physics comes mainly from high-school courses. Through a detailed analysis of the different categories into which the CLASS tool is divided, we analyze the differences in performance in each of the areas and discuss their possible causes and implications for teaching. In the following section we present the research methodology, while in Sec. 3 we present the main results. Finally, the discussion and final considerations are presented in the last two sections.

2. Research methodology

This research was carried out with university students from the School of Sciences of Universidad de la República (Montevideo, Uruguay) who were taking General Physics I in the first semester of the undergraduate courses in Physics and Mathematics and Biology and Biochemistry. It is relevant to point out that in Uruguay, primary, secondary and pre-university schools are characterized by a common curriculum framework for all the educational institutions in the country. In the last two years of high school, students are able to choose a major area of study (scientific, humanistic, biological or artistic). Those who wish to pursue university studies in scientific areas choose a path with more hours devoted to physics and mathematics courses, while those who plan to pursue degrees in life sciences, such as biology or biochemistry, have their hours split between mathematics, physics, chemistry and biology courses. It is important to point out that in both orientations, physics courses have the same weekly load and similar contents that address general topics of mechanics (kinematics and point dynamics, principles of conservation and energy) as well as waves and electromagnetism. The usual bibliography includes algebra-based "College Physics" textbooks such as those widely used worldwide [13, 14]. Upon completing high school, students can opt for different university degrees. In this work we focus on two sets of recently admitted students in the first year of the aforementioned School of Science. One set is comprised by those who pursue bachelor's degrees in Physics and Mathematics (hereinafter, "physical sciences" or "PhS") and the other by those who pursue bachelor's degrees in Biology and Biochemistry (hereinafter, "life sciences" or "LS").

With this objective in mind, we asked all the students to answer, by means of an electronic form, their degree of agreement or disagreement with the 42 statements of the CLASS test. The questionnaire was proposed in Spanish [15]. In contrast with other studies which used the pre- post-test methodology, here we applied the test only once. To compare the students' responses with those of the experts, the original 5-level scale is reduced to a three-level scale, grouping the options "agree" and "completely agree" on the one hand, and "disagree" and completely "disagree" on the other, leaving "neutral" as the midpoint. Of a total of 42 statements, 27 of them are grouped into 8 categories, while the remaining 15 are not categorized. There is no agreement among the experts on some of the latter, while one in particular is used to rule out inconsistent responses. For each category, and for the set of questions where there is agreement among the experts (36 of the 42 statements), we calculated the percentage of student responses that agree with that of the experts (favorable responses). Table I shows the number of responses obtained for each group of students.

In order to study the differences between the two samples of results, we used the nonparametric Mann-Whitney U test,

TABLE I. Number of responses recorded in the different areas of study classified by self-reported gender.

Bachelor's degree	Women	Men	Total
Physical sciences	34	45	79
Life sciences	51	18	69

which is the nonparametric version of Student's t-test [16], to test if the differences observed were statistically significant. For this purpose, we started from the null hypothesis that the samples come from the same population, rejecting it for a probability value of $p < 0.05$. To quantify the possible differences between the two groups, we calculated the effect size using Cohen's d. Typically, a large effect is considered for d values of 0.8, while intermediate corresponds to 0.5 and small to 0.2 [17].

3. Results

In this section we show the results obtained from the CLASS questionnaire, differentiating the groups of students of life sciences (LS) from those of physical sciences (PhS). In Table II, we indicate, for each category, the mean values of the LS and PhS groups and the difference between them (columns 2, 3 and 4, respectively), with their corresponding standard errors. In the fifth column we tabulate the effect size for the difference between the means, and in the sixth column we indicate the probability given for the result of applying the nonparametric Mann-Whitney U test.

We highlight some results that can be deduced from Table II. First, when considering the overall result of CLASS (All categories), we found a significant difference, with a relatively large effect size (0.8), in the degree of agreement with the experts between both groups of students. By applying the Mann-Whitney U statistical test to the samples of each category grouped by area (LS and PhS), we found that the null hypothesis (equality of mean values) can be rejected in all categories, except in Real-World Connection. The largest effect size values correspond to the following categories: Problem Solving - Sophistication (1.1), Applied Conceptual understanding (0.8), Problem Solving - General (0.7) and Problem Solving - Confidence (0.7). Both groups of students show a significant difference in their agreements with experts in the vast majority of the CLASS categories. We cannot rule out the hypothesis of equality between the central tendencies of the samples in the Real-World Connection category at the 95% confidence level (highlighted row in Table II). This is consistent with the fact that the value of the effect size of the difference is the smallest of all those obtained (0.4). The LS and PhS students surveyed start their undergraduate training with similar conceptions in this CLASS category.

In the Sense Making/Effort category, we identified a "borderline" or less noticeable situation than in the other categories in which significant differences were recorded. In that category, we observed the smallest difference in means, an effect size of the same value as in the Real-World Connection category, and a probability of p=0.02 for the U test (of the same order as our 0.05 limit). In this category, the difference between the samples (which exists according to the criterion adopted) is not as clear as in the other categories where there is a significant difference.

Although in each of the above categories we can find statements whose results differ significantly between the two groups of students, we compare the results of two particular categories: Problem Solving - Sophistication and Applied Conceptual Understanding, since these are the categories with the largest effect size. Table III shows the statements of both categories for each group of students, specifying the percentages of the responses, classified as agree, neutral and disagree. The underlined percentages allow us to identify whether the experts agree or disagree with each of the statements. For example, statement 5 falls into both categories, with the experts disagreeing with it. Of the set of statements, in statements 6 and 21 the difference between the responses of the students in both groups is less than the standard deviation of the responses, so it is not of particular interest to analyze it. In the following section we discuss the results and their possible implications for the classroom and student learning.

TABLE II. Overall results of the CLASS questionnaire discriminated by group. The columns indicate mean value and difference between the LS and PhS groups with their standard errors, effect size of the difference and probability according to the Mann-Whitney U test. The highlighted row corresponds to the case in which we cannot rule out the hypothesis of equality between the central tendencies of the samples.

-	Life sciences (LS)	Physical sciences (PhS)	LS-PhS diff.	Effect size	U test: p
All categories	49.8(2.2)	64.1(3.2)	14.3 (3.7)	0,8	0,0001
Personal Interest	51.9 (3.2)	73.7 (4.1)	21.8 (5.3)	0,8	0,0001
Real-World Connection	58.3 (3.8)	70.4 (4.9)	12.0 (6.3)	0,4	0,0542
Problem Solving (PS) - General	47.8 (2.8)	65.1 (4.1)	17.3 (4.8)	0,7	0,0004
PS Confidence	41.7 (3.3)	61.8 (5.2)	20.2 (5.9)	0,7	0,0009
PS Sophistication	27.5 (2.6)	54.4 (4.3)	26.8 (4.8)	1,1	0,0001
Sense Making/Effort	65.2 (2.6)	73.7 (3.9)	8.5 (4.5)	0,4	0,0226
Conceptual understanding	49.8(2.9)	62.7 (3.6)	13.0 (4.7)	0,5	0,0062
Applied Conceptual understanding	32.3 (2.4)	50.4 (4.2)	18.1 (4.5)	0,8	0,0004

TABLE III. Results of selected statements of the CLASS, classified by area of study (life sciences and physical sciences). Statements 5, 21, 22 and 40 belong to both the Applied Conceptual understanding and the PS Sophistication categories.

Statement	Category	Area	Agree	Neutral	Disagree
1. A significant problem in learning physics is being able to memorize all the information I need to know	Applied Conceptual understanding	Life sciences	41%	28%	32%
		Physical sciences	26%	26%	47%
5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic	Applied Conceptual understanding and PS Sophistication	Life sciences	77%	13%	10%
		Physical sciences	42%	32%	26%
6. Knowledge in physics consists of many disconnected topics	Applied Conceptual understanding	Life sciences	9%	14%	77%
		Physical sciences	5%	11%	84%
8. When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values	Applied Conceptual understanding	Life sciences	80%	19%	1%
		Physical sciences	39%	37%	24%
21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.	Applied Conceptual understanding and PS Sophistication	Life sciences	28%	17%	55%
		Physical sciences	24%	11%	66%
22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.	Applied Conceptual understanding and PS Sophistication	Life sciences	45%	35%	20%
		Physical sciences	34%	24%	20%
25. I enjoy solving physics problems.	PS Sophistication	Life sciences	20%	33%	46%
		Physical sciences	79%	13%	8%
34. I can usually figure out a way to solve physics problems.	PS Sophistication	Life sciences	29%	41%	30%
		Physical sciences	50%	34%	16%
40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own.	Applied Conceptual understanding and PS Sophistication	Life sciences	35%	35%	30%
		Physical sciences	8%	29%	63%

4. Discussion

From the results presented in Table III for statements of all categories, we note that there is a significant difference in performance on the CLASS between students pursuing degrees in physical sciences and those pursuing degrees in life sciences, with a large effect size [17]. This result, in line with others reported in the literature [6, 18, 19], supports the hypothesis that attitudes and beliefs develop during secondary education, which becomes more relevant in the context of the Uruguayan educational system, since students in both groups had a similar number of hours devoted to physics courses in their previous level of education, differing only in their training in mathematics and biology. The roots of these differences could be very diverse. A first hypothesis is that a better training in mathematics has a positive impact on attitudes and beliefs. Another possibility is that those students who have a taste for physical sciences from an early age may have received a non-formal education (through books, articles and dissemination videos) that results in a better performance in the CLASS.

As for the other categories, Personal Interest, PS Sophistication and Applied Conceptual understanding present a large effect size. This result is not surprising, since students of physical science-oriented degrees have a special interest in physics and mathematics, as emphasized by [3]. We clearly observe this in statement 25, grouped in the PS Sophistication and Personal Interest categories, which refers to enjoying physics problem solving. In the case of the LS group of students, 20 % agree with the experts, whereas the level of agreement reaches 80% among those studying PhS. In relation to the large effect size for PS Sophistication and Applied Conceptual understanding, we may hypothesize that students with a biology-oriented background have not delved into sophisticated aspects of problem solving nor into conceptual understanding in their physics courses. This aspect could be linked to a lower degree of interest in physics and perhaps to greater difficulties with the subject. These two elements may foster negative attitudes towards physics and, consequently, epistemological beliefs farther away from those of the experts. By focusing on the statements related to PS Sophistication and Applied Conceptual understanding we can better understand how different the attitudes and beliefs of PhS students may be from those of LS students and their possible impact in the classroom. Let us begin by analyzing statements 1 and 8, related to Applied Conceptual understanding, on which the experts disagree. In statement 1, 41% of the LS students agree with the statement regarding the importance of memorizing all the information in physics, while the percentage drops to 26% among PhS students. In statement 8, a large majority of the LS students (80%) agree with the methodology described for trying to solve physics problems, dropping to 39% in the other group of students. From the results of statement 8, we can infer that the majority of LS students attempt to solve problems using the “Plug and Chug” strategy [20, 21], which is a clear sign of a novice problem-solving strategy. This aspect is consistent with the results of statement 1, which gives an important role to memorization in physics learning. Statements 5, 22 and 40 have the particularity that they belong to both categories and that the experts disagree with them. These statements are closely related to each other and to the way in which students learn, apply concepts, develop metacognition and cope with physics problems. As in the previously analyzed statements, the performance of LS students is inferior to that of PhS students. The most alarming case is statement 5, where 77% of LS students recognize that they have difficulties in solving problems after considering that they have understood a topic. This is a clear sign that they have not developed metacognition habits and therefore are not able to realize that they do not truly understand the concepts. In statement 40, which evaluates a student’s ability to think of different strategies to solve a problem when they get stuck, it is inferred that one out of three LS students is not able to develop new ways of solving, while this happens to only 8% of PhS students. This result is yet another sign that the “Plug and Chug” strategy predominates in problem solving among LS students. Students who have expert behaviors develop metacognition, are able to monitor their learning, think borderline scenarios to evaluate solutions, and try new strategies based on general principles; therefore, if they get stuck on a problem, they are more likely to try to solve it using a different approach. Statement 22 refers to the need for two problems to be very similar in order to use the same solution method for both. These results once again reinforce the idea that LS students, to a greater extent than PhS students, fail to fully grasp the conceptual aspects and basic principles of physics, and instead learn physics by memorizing equations, which prevents them from approaching new situations with the confidence to solve them. Finally, in statement 34, which belongs to the PS Sophistication category and reflects students’ confidence in problem solving, only 29% of LS students believe they are able to figure out how to solve a physics problem, compared to 50% of PhS students. These results again suggest that LS students find it difficult to adopt similar strategies as the experts in problem solving, as well as perhaps a belief that they are not capable of learning physics adequately.

5. Final comments

Our students’ views on the nature of knowledge and learning work either for or against quality science education by affecting the way they learn and approach physics courses. For example, students who view learning as being basically about memorizing information will have different attitudes and strategies than those who view it as being based on understanding [22]. In this sense, one of the keys to improve learning is to promote appropriate epistemological stances. Knowing the state of our students’ epistemological beliefs is crucial in order to design activities aimed at improving them. Our work is based on the results of proposing the CLASS questionnaire to students of physical sciences and life sciences. Comparing the results between both groups, we find that the former enter university with epistemological attitudes much closer to those of experts in the respective fields. Although this result has been previously reported in the literature [5], our research differs in that the groups of students of physical sciences and life sciences had a similar academic trajectory in terms of their high school physics training. Although the question of the possible origins of this difference is yet to be addressed, the results of our study allow us to better understand the difficulties presented by life sciences students when approaching physics courses.

From the analysis of the responses in the different categories, we highlight that a significant percentage of life sciences students try to solve physics problems following the strategy of “finding the right equation and substituting”, known as “Plug and Chug”. This novice strategy is not conducive to the development of metacognitive skills. Being aware of this type of thinking allows us, as teachers, to anticipate the problems of our students, to stand differently in the classroom, and to develop actions aimed at changing this type of thinking, which will result in a better-quality science education. In this sense, it is important to keep in mind that in every action or omission that we make in the classroom (and that is part of the hidden curriculum), we are directly or indirectly affecting the epistemological beliefs of our students. Something as simple as asking our students what equation do we have to use to solve a particular problem can foster (even unintentionally) an incorrect image of science and how to learn physics, and ultimately affect the academic achievement of our students.

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