A problem-based teaching and learning sequence aiming at interpreting spectra in quantum physics introductory courses

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Abstract. Physics education research has revealed persistent difficulties in students' learning of atomic spectra. To overcome that difficulties, we designed a problem based teaching and learning sequence and implemented it in the last High School Physics course. The results show a statistically significant impact on students learning.

1 Introduction

Different studies on gas spectra and energy quantization have revealed persistent difficulties in students' learning, especially with regard to the interpretation of spectral lines' frequencies in emission spectra [1-3]. In this work we present a teaching and learning sequence (TLS) aiming at constructing a quantum model of emission and absorption of radiation which allows students to explain the frequencies and intensities of the spectral lines in emission and absorption spectra.

2 Context of the study and methodology

The TLS was implemented in the High School final year Physics course. During that course, students' training aims at gaining access to university studies in science or engineering. The Physics program for the course is similar to the America college standards. To assess the effectiveness of the TLS we compared the results obtained by 74 experimental students who followed the TLS with the results obtained by 67 control students who studied quantum physics in a traditional way.

The students were administered a similar pre-test and post-test (the post-test coincides with the questionnaire presented in [2]). Each of them contained three questions, the first one asked about the radiation that can be absorbed by hydrogen atoms, the second one about the frequencies of the hydrogen emission spectrum and the third one about the intensity of the spectral lines.

At the beginning, the TLS sets out the problem of establishing a scientific model to explain the emission and absorption of radiation. After familiarizing the students with the phenomena that we want to interpret (spectra, photoelectric effect, fluorescence and phosphorescence, among others) we ask them to construct a model that explains the hydrogen emission spectrum. Thus we build a first model that we test and modify addressing other phenomena (photoelectric effect, Franck and Hertz experiment and Compton effect). Finally, we use the last established model to explain how leds, lasers, energy-saving light bulbs or fluorescent and phosphorescent materials work, among other examples. The Spanish version of the TLS and the teacher's guide can be downloaded at [4, 5]. Examples of the TLS activities will be presented in the meeting.

3 Results

No student answered correctly to any question of the pre-test. This was an expected result, since no student had previously studied quantum physics.

Table 1 shows the percentage of correct and incorrect answers, as a percentage, for the experimental and control groups. The last row includes the value of p obtained using the statistic χ^2. We obtained significant differences in all cases. In addition, we highlight that no question was answered correctly by more than 10% of the control students, while the correct answers rate in all questions exceeds 50% for experimental students.

Table 1. Percentage of correct and no correct answers given by 74 experimental students (E) and 67 control students (C). The last line shows the value of p calculated with the χ^2 test.

	Q1: absorption		Q2: emission		Q3: intensity	
	E	C	E	C	E	C
Correct answer	66	9	59	7	65	9
Not correct answer	34	91	61	93	35	91
P (χ^2)	$3{,}37 \cdot 10^{-11}$		$9{,}47 \cdot 10^{-11}$		$9{,}10 \cdot 10^{-12}$	

When comparing the number of correct answers given by experimental and control students we obtain the results shown in Table 2. The differences between the two groups assessed through the statistic χ^2 are statistically significant, with $p=3{,}04\text{-}10^{-14}$. The effect size achieved when applying the TLS is 0.99, which means that the intervention can be considered as very effective.

Table 2. Percentage of experimental and control students by the number of correct answers.

Correct answers	0	1	2	3
Experimental students	17,5	17,5	24,5	40,5
Control students	77,5	19,5	3,0	0,0

4 Conclusions

In this work we proposed to design and evaluate a TLS to improve the teaching and learning of quantum physics in introductory courses. In accordance with the results, we have achieved a significant improvement in students' learning when interpreting atomic spectra. We are currently working on assessing the TLS impact on the interpretation of other quantum phenomena.

References

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