Motivating, guiding and assessing active learning in quantum physics

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Abstract

We report on specific actions undertaken to promote active learning in an introductory course on quantum physics that presented the following challenges: (1) quantum ideas surprise and contradict common sense beliefs and background knowledge; (2) it is hard to study the interactions of matter and radiation with an appropriate balance of the phenomenology and the formalism; (3) nowadays understanding a huge diversity of systems such as atoms, molecules, solids, nuclei and particles has attained extraordinary results but also addresses very difficult questions, and (4) modern physics can be studied from very different perspectives: the mathematical treatment, the history and epistemology of the evolution of concepts, models and theories, as well as the interconnections between the experimental devices and procedures, the representation of measurement of strange properties, their important technological applications, and the implications of the scientific enterprise in economic, social, political, environmental and cultural aspects. As a reaction to traditional teaching, we focused on the following objectives: to promote and ensure active learning, to prepare and make available appropriate learning materials, and to assess the student performance with a rewarding but strict system. We implemented a teaching strategy that changed the role of the teacher from a transmitter of information to a guide of learning actions. In order to support such a strategy we created an integrated system for active learning containing the following components: The syllabus, the calendar, the notes, the home works, the questionnaires, the tests, the web page, the presentations, and the assessment criteria. Our teaching strategy worked in the direction of "less quantity and better quality", looking for the application of four pedagogic principles: to make thinking visible, to make knowledge accessible, to help one each other learning, and to learn all the time. We evaluated the success of our support system by analyzing how the students reacted to different components of that support system in the context of the four pedagogical principles into consideration.

Key words: Introductory Quantum Physics, Active learning, Teaching strategies.

Resumen

En este trabajo reportamos acerca de las acciones específicas emprendidas para promover el aprendizaje activo en un curso introductorio de física cuántica que se ha enfrentado a los siguientes retos:(1) las ideas cuánticas sorprenden y contradicen las creencias del sentido común y el conocimiento de base; (2) es difícil estudiar las interacciones entre la material y la radiación con un balance adecuado entre la fenomenología y el formalismo; (3) hoy en día la comprensión de una gran diversidad de sistemas tales como átomos, moléculas, sólidos, núcleos y partículas ha alcanzado resultados extraordinarios pero presenta preguntas muy difíciles, y (4) la física moderna puede estudiarse desde muy diferentes perspectivas, según: El tratamiento matemático, la historia y la epistemología de la evolución de conceptos, modelos y teorías así como las interconexiones entre los dispositivos y los procedimientos experimentales, la representación de mediciones de propiedades extrañas, sus aplicaciones tecnológicas y las implicaciones de la actividad científica en los aspectos económicos, sociales, políticos, ambientales y culturales. Como una reacción a la enseñanza tradicional, nos concentramos en los siguientes objetivos: promover y asegurarse el aprendizaje active, preparar y hacer accesibles materiales apropiados para el aprendizaje, y evaluar el desempeño de los estudiantes mediante un sistema estimulante pero estricto. Hemos puesto en práctica una estrategia en donde se cambia la función del maestro de transmisor de información a guía en las acciones de aprendizaje. En apoyo a esta estrategia hemos creado un sistema integrado para el aprendizaje active que comprende los siguientes componentes: el temario del curso, el calendario, las notas, las tareas los cuestionarios, los exámenes, la página web, las presentaciones orales y los criterios de evaluación. Nuestra estrategia educativa se orientó a "menos cantidad y mejor calidad", buscando la aplicación de cuatro principios pedagógicos: Hacer visible el pensamiento, hacer accesible el conocimiento, ayudar al aprendizaje de los demás y aprender todo el tiempo. Hemos evaluado el éxito de este sistema de apoyo analizando cómo los estudiantes reaccionan a los diferentes componentes del sistema en el contexto de los cuatro principios pedagógicos anteriores.

Palabras clave: Física cuántica introductoria, Aprendizaje activo, Estrategias de enseñanza.

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I. INTRODUCTION

Learning about concepts and models requires that explanations and interpretations of facts must have the appropriate level of difficulty and complexity. It also implies a good mastery of four kinds of languages [1]: The natural one for oral and written communications, the technical one in connection with the specific discipline, the iconographic one related to all sorts of visual representations, and the mathematical one for the formal treatment of the results of observations and measurements and the precise description of procedures for calculations and demonstrations.

In what follows, we firstly consider some boundary conditions specifying the learning contexts of our Physics students and then, we describe a teaching support system for active learning in an introductory course on quantum physics and comment on some results.

II. WHY OUR STUDENTS ARE NOT EFFECTIVE LEARNERS?

Traditionally, students listen to the teacher, copy what is in the blackboard and sometimes ask questions, and after the classroom sessions, read the textbook and work on some problems, mostly before quizzes and tests [2]. In the context of our educational system, let us consider the three elements of the educational triangle that are the main factors determining the outcome of learning: the subject matters, the students and the teachers. Physics curriculum at the School of Science at UNAM consist of 39 courses distributed in the following way [3]: 13 courses correspond to mathematics and computing, and 26 to the discipline (15 theoretical courses, 7 laboratories and 4 optional courses that students can take almost in any direction). Let us accept without prove that the available syllabus has three characteristics: it is reasonable according to our present conditions (the traditional point of view insisting that if it has been working for so many years it must have some value); it is pertinent according to what exist in other schools of science (the conservative point of view opposing any change just by principle), and it is complete because it covers the essentials of what is required for the education of a physicist (the short vision point of view that cannot look for something different to be required in the near future).

Concerning the students, some figures will give us an idea of present conditions [4]: In 1968, the population of Physics students was 947 and almost doubled in 2008 when it went up to 1,558. The following percentages describe their situation during the years indicated in parentheses: 42.45% of dropouts (1980—2007), 43.09% did not finish their credits (1980-2004), and 27.35% did not present their dissertation and got their diploma (1980-2003). In the period 1980-2003, only 6.15% of the students finished their 418 credits in the 9 semesters established in the official study program, and 22.79% finished it in 14 semesters.

Among the main reasons of student difficulties and failures, we must consider that they have bad study habits, do not work in a systematic way and are not quite responsible of their own learning. Almost two thirds of our students show some sort of deficiencies in connection with their learning conditions; the main consequences are low success and restricted accomplishments. However, there are other external reasons, mostly of socioeconomic nature; for instance, 66% of the students registered nowadays at UNAM at the college level belong to families that never have had any member, parent or children, going to college.

In connection with teaching, we must recognize that the great majority of our academic personnel do know what to teach, although quite a lot are more interested in doing research than in preparing people. This circumstance is encouraged by the system that rewards the publication of research papers. According to bureaucratic criteria, the efficiency of a professor is accounted by numbers: publications, hours in front of a classroom, graduated students, participation in congresses, conferences… Furthermore, research in physics education is very low in the scale of scientifically important issues. Under these critical circumstances, teaching is less recognized and rewarded despite the fact that in the rhetoric domain the most important role of a university is teaching because teachers are architects of knowledge, in the sense that they build environments for learning that make understanding possible. As this work focuses on a support system that promote active learning, in next section we consider the meaning of such a term and describe the main actions undertaken in our teaching project.

III. SOME TEACHING ACTIONS TO PROMOTE ACTIVE LEARNING IN QUANTUM PHYSICS

It is a triviality to say that there is no learning if it does not imply active participation of the learner. However, in a report for the Association for the Study of Higher Education (ASHE), in 1991 Bonwell y Eison discussed a variety of methodologies for promoting active learning [5], in particular to develop independent learning, critical thinking and analytical capacity. Active learning means that students are the center of gravity in educational processes; the teachers, the curricula and the didactic materials must serve for guidance and support to make learning possible. We now describe each one of the nine components of our teaching support system; the first three components are descriptive in nature and the other six ones were specifically designed to support active learning.

(1) *The syllabus*. We follow the official syllabus of the course but we do not limit to quantum physics. We introduce some elements of statistical mechanics and special relativity because we want to present a more complete view of the origins and first developments of modern physics. This is a six hours per week course for

Physics students during sixteen weeks in the fifth semester. It contains four sections; a parenthesis indicates the corresponding number of weeks: I-Introduction (1), II-Phenomenology (6), III-Basic formalism (3), and IV-Applications (6). In section II quantization is considered in connection with matter (the atom), charge and angular momentum (the electron and its discrete energy states), electromagnetic radiation (the photon), and position (the matter wave function). Then in section III, we deal with Schrödinger equation and its solution for discrete potentials. Section IV concerns a general overview of atoms, molecules, condensed matter, nuclei and fundamental particles.

(2) *The calendar*. It contains the day-by-day activities with some suggestions for better learning.
(3) *The assessment*. Although homework problems are not graded, we gave points to every action we wanted the student to accomplish in time and form.
(4) *The notes.* They start with some historical and epistemological remarks, discuss in detail basic concepts and models, present derivation of equations, explain the main experiments and comment on some recent issues. Up to now, it corresponds only to the first three sections; for section IV, references are given in a textbook.
(5) *The home works*. It include problems of three types: traditional ones like those contained in textbooks, computer-based simulations and short essays responding to questions related to the context of the phenomena under consideration.
(6) *The questionnaires*. Our classroom sessions started with a self- evaluation quiz related to the topics of the day. For Sections II and III, two questions were presented to the students with four options for each question; all the options were correct answers with different approaches or degrees of correctness. We asked the students to choose one option and briefly write the reason of their selection; then we collected the papers and organized a discussion in the classroom. For Section IV a problem was presented at the beginning of the session, then the problem was discussed during the lecture.
(7) *The tests*. At the end of each chapter, we had a half hour test with questions related to the home works, and at the end of sections II and III we had a two hours test. Students must bring the solutions of their homework problems in order to have the right to present the tests.
(8) *The web page*. It contained the notes, the calendar and sections serving the following purposes: to ask questions and present doubts, to review the solutions of the tests and to indicate the corresponding grades, to register those students that have presented each questionnaire, and to describe the assignments of the homework problems and their solutions.
(9) *The presentations*. During the last month, students made two kinds of oral and written presentations; the first ones concerned a summary of a Nobel lecture related to any of the topics of the course, and the second ones addressed a problem connected with the content of the course including a possible solution.

IV. DISCUSSION OF MAIN RESULTS

Previously we have described a teaching support system for active learning with nine components. In order to have an idea of its appropriateness, we have determined the degree of response of our students to six components of the support system, by analyzing 16 criteria of application (C) corresponding to the four pedagogic principles (PP) adapted by Barojas and Lopez [6] from Linn and Hsi [7] and indicated in Table I.

TABLE I. Criteria of application of the pedagogic principles.

PRINCIPLES	CRITERIA
PP_1 *Make knowledge accessible to all.*	C_1: Stimulate the building of knowledge by starting from the students own ideas and by developing their stronger points of view.
	C_2: Focus on relevant problems and review regularly what has been understood.
	C_3: Support participation in learning activities aiming to enrich and extend the students knowledge.
	C_4: Encourage communications in order to share information and knowledge.
PP_2 *Make thinking visible for all.*	C_5: Model the knowledge building process and take into account alternative explanations of concepts and models.
	C_6: Promote explanations of their own reasoning concerning solutions to problems.
	C_7: Provide multiple visual representations for their argumentations.
	C_8: Sponsor systematic recording of acquired knowledge through active learning.
PP_3 *Facilitate learning from each other.*	C_9: Develop abilities for listening and learning.
	C_{10}: Design social activities in order to promote productive and respectful relationships.
	C_{11}: Stimulate the design and review of practical criteria of performance.
	C_{12}: Organize multiple social structured activities.
PP_4 *Promote continuous learning.*	C_{13}: Commit all the students to review their own ideas and actions and to think about what their classmates are doing.
	C_{14}: Endorse critical approaches regarding the analysis of information and knowledge.
	C_{15}: Stimulate the participation of all in active learning procedures.
	C_{16}: Establish search procedures looking for better results concerning active learning.

In what follows we consider how the first three pedagogic principles (PP) were applied by using certain components of the support system; the fourth principle was instrumental as a sort of follow up procedure. More details will be published elsewhere.

PP1: Make knowledge accessible to by studying the notes. This was critical for understanding key phenomena, models and approaches, as well as for showing the development process of understanding fundamental physics concepts and theories. More references for supplementary reading are required.

PP2: Make thinking visible for all by involving the students in home works, questionnaires and tests. These components served to communicate questions, doubts, difficulties and comments showing what the students have learned concerning concept building, data representations and calculations.

PP3: Help the members of the classroom to learn from each other by using the Web page. This was the place for communication outside the classroom sessions and for obtaining extra information concerning the course. The students participated in a limited form in dialogues and actions for inquiries and discussions and for promoting collaborative work.

PP4: Promote continuous learning among all the classmates. Although the course was only 16 weeks long, some evolution of the learning process was observed, despite the fact that nearly 20% of dropouts were produced at the middle of the course. Three categories of students have been detected according to their characteristics concerning active learning:

- Higher: Main concepts have been well assimilated, integrated and applied; frequently good questions were asked during lectures; oral and written communication were detailed and well-articulated, including references and discussions of graphics and tables.
- Intermediate: Home works reflected an appropriate understanding of the concepts, however, written contributions in questionnaires and tests contained some conceptual errors; although learning skills were deficient, student performance improved during the course.
- Lower: Minimum response concerning oral and written participations, serious conceptual misunderstandings, lack of interest and weak responsibility for their own learning; this population showed a strong risk of failure.

We conclude that because of the integration of activities, materials and follow-up procedure, the support system was instrumental to generate increased motivation and better participation that resulted in a more continuous and productive performance of the students belonging to the first two categories; almost nothing effective could be obtained with the third category.

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