



# Experimental physics through the Internet

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## Abstract

The title of this work conveys a sort of contradiction: Experiments in Physics must require real instruments, devices and materials, and experimental settings must concern observations and measurements that occur in nature. However, in this work we deal with the question of teaching high school physics by using an online course that contains experimental activities. Such a course is available on the Internet and has been designed by following guiding principles that take into account recommendations coming from researches on Science Education. The online course contains the following features: (1) detailed instructions for building simple and inexpensive apparatuses for home made qualitative demonstrations, (2) deep analysis of videos showing low cost experiments where precise measurements can be made and, (3) guidelines for representing and interpreting results obtained by the students. The course also have other components such as: the syllabus indicating the content to be learnt; the calendar of activities describing what, when and by whom; instructions concerning how to study and collaborate among students; notes prepared by the teacher and links for useful documents as well as references accessible in the Internet; remarks on history and epistemology; use of spreadsheets, graphs and tables; a selection of available computer-based simulations and videos; questions and discussions of answers in a student electronic forum; and a collection of assessment instruments such as questionnaires, exercises, home work problems, and tests. We report on the consequences of teaching mechanics and electromagnetism by using this online course and comment on the reactions of the students, their learning problems and their achievements.

**Keywords:** Active learning, individual knowledge, social interaction.

## Resumen

El título de este trabajo conlleva cierta contradicción: Los experimentos en Física requieren de instrumentos, dispositivos y materiales reales, así como de arreglos experimentales que impliquen observaciones y mediciones de lo que ocurre en la naturaleza. Sin embargo, en este trabajo nos referimos a la cuestión de enseñar Física en el bachillerato en un curso a distancia que contiene actividades experimentales. Tal curso está accesible en Internet y ha sido diseñado siguiendo principios orientadores que toman en cuenta recomendaciones derivadas de trabajos de investigación en enseñanza de las ciencias. El curso a distancia tiene los siguientes elementos: (1) instrucciones detalladas para construir aparatos simples y baratos para realizar demostraciones caseras de tipo cualitativo, (2) análisis detallado de videos que muestran experimentos de bajo costo con los cuales se pueden hacer mediciones precisas y (3) indicaciones para representar e interpretar los resultados que serán obtenidos por los estudiantes. El curso también contiene otras componentes tales como: el temario indicando el contenido que deberá ser aprendido; el calendario de actividades describiendo qué hay que hacer, por quiénes y cuándo; recomendaciones para estudiar mejor y colaborar con los compañeros; notas preparadas por el profesor y enlaces a documentos útiles y referencias accesibles en Internet; aclaraciones de tipo histórico y epistemológico; uso de hojas de cálculo, gráficas y tablas; selección de simulaciones computacionales y videos; preguntas y discusiones de las participaciones de los estudiantes en el foro electrónico, así como una serie de instrumentos de evaluación tales como cuestionarios, ejercicios, tareas, problemas y exámenes. También reportamos acerca de las consecuencias de haber enseñado mecánica y electromagnetismo con este curso a distancia y comentamos acerca de las reacciones de los estudiantes, sus problemas de aprendizaje y sus logros.

**Palabras clave:** Aprendizaje activo, conocimiento individual, interacción social.

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## I. INTRODUCTION

Nowadays the Internet is a very useful tool in education. Among some other uses, it provides information, helps in communications and serves for representing and interpreting data. It is an essential ingredient of modern

applications of Information and Communication Technologies (ICT) [1, 2, 3].

This is not the place to review results of using ICT in Physics Education. We just refer to the workshop reports and contributed papers presented in the Second GIREP *Seminar on Quality Development in Teacher Education and*

Training [4], in particular the following chapters: New Technology in teacher training, Multimedia in teacher training, Distance teacher training, and Laboratory and ICT in teacher training.

In this work, we describe an online Physics course that has been designed by following five guiding principles derived from the analysis of Science Education publications [5, 6]. Those guiding principles are the consequences of addressing the following critical questions (Q):

- Q<sub>1</sub>. Why is it convenient to organize our teaching of Physics by inverse planning?
- Q<sub>2</sub>. What specific competences are required for representing and interpreting physical facts, data and knowledge?
- Q<sub>3</sub>. What does it mean to be an active learner?
- Q<sub>4</sub>. What is important in Physics Education from an epistemological point of view?
- Q<sub>5</sub>. What are the main roles of teachers?

In the next coming section we present our answers to each one of the previous questions and in the third section we describe the characteristics of the high school Physics online course developed by the first author of this paper.

## II. GUIDING PRINCIPLES FOR PREPARING OUR ONLINE COURSE

The answers to questions Q<sub>1</sub> to Q<sub>5</sub> consist in two parts: a short text taken from a Science Education publication that gives a frame for answering the question, and the corresponding guiding principle (GP) to be used in the preparation of the course. In some cases, quotes are indicated in a cursive format.

### Q<sub>1</sub>. Organizing teaching of Physics by inverse planning.

Inverse planning corresponds to a threefold process in which teachers participate as architects of knowledge [7]: to define what do we want our students to learn in terms of knowledge and develop according to required skills and attitudes; then to identify the means and instruments for detecting what has been accomplished, and finally, to prepare and test all that is required to make everything possible. The details of content are the outcome results of this planning process, not the income reference.

GP<sub>1</sub>: Start with student's cognitive needs, then make sure the students learn what was intended for, and finally prepare the appropriate materials.

### Q<sub>2</sub>. Specific competences for representing and interpreting physical facts, data and knowledge.

Among other characteristics, the ISLE project [8] considers the following implementation factors (F): F<sub>1</sub> - *students learn physics by engaging in processes that mirror the activities of physicists when they construct and apply knowledge*; F<sub>2</sub> - *students are assessed for conceptual understanding, for problem-solving ability, and, most importantly, for their use of various scientific abilities*, and F<sub>3</sub> - *concept construction consistently mirrors scientific practice, multiple representations are emphasized at all stages of concept construction, and the focus in assessment refers to scientific abilities in addition to content*.

GP<sub>2</sub>: Prepare learning activities corresponding to the following processes: observe, find patterns, build and test explanations of the patterns, and use multiple representations to reason about physical phenomena.

### Q<sub>3</sub>. Promotion of active learning.

We assume that an active learner is a member of a Learning Community (LC). A LC is a group aiming to accomplish four goals [9]: *to be informed, to organize communications, to obtain and apply knowledge, and to accomplish transformation activities for specific learning purposes*. The members of a LC will be active learners depending on the maturity and effectiveness of their participations in agreement with next four pedagogic principles [10]:

GP<sub>3</sub>: Make knowledge accessible, make thinking visible, learn one from each other, and promote continuous learning.

### Q<sub>4</sub>. Importance of epistemological considerations.

According to Piaget and Garcia [11], four aspects characterize a scientific theory: *the type of questions that are formulated, the type of non-demonstrated assumptions or premises that are accepted implicitly or explicitly, the type of relationships among experiments and theories, and the role of mathematics in the formulation of the theory*.

The same authors indicate that three factors define the functioning of a physical theory: *the methodology or procedures for analyzing facts and verifying hypothesis, the characterization of general concepts in agreement with experimental facts, and the construction of a coherent system that logically integrating facts and concepts*.

GP<sub>4</sub>: Take into account previous epistemological aspects and factors in order to obtain clarity in the reasoning process, coherence in the discourse of representations and interpretations, as well as relevance concerning building knowledge.

### Q<sub>5</sub>. Roles of teachers.

Teachers play the interconnected roles of modeling and instrumentation as a consequence of being trained in collaborative problem solving [12]: *Teachers motivate and help in building concepts in their role of modeling; they also develop reasoning forms characteristics of the discipline and works on the identification, interpretation and application of different representations of the thematic content in their role of instrumentation*.

GP<sub>5</sub>: Work on abstraction processes that go from the exploration of facts to the description of contexts (modeling role) and also apply and evaluate understanding of facts, concepts and contexts by working on recognition processes that start in the presentation of evidences and lead to the formulation of consequences (instrumentation role).

## III. EXPERIMENTAL PHYSICS THROUGH THE INTERNET

In this section, we describe the eight components of the online course, indicate where the guiding principles have been applied in the design of such components, and

comment on the response of the students. The components (C) of the course are:

*C<sub>1</sub>- The syllabus and the calendar.* The following topics have been considered: Mechanics: motion with constant speed and variable speed, vectorial character of forces, equilibrium of forces, Newton’s laws; Electromagnetism: electrostatics, electric current, electric circuits, magnetism, magnetic induction. The calendar describes what needs to be done and when.

*C<sub>2</sub>- Recommendations for students.* These are specific suggestions for improving study habits through the development of learning activities for the comprehension and communication of concepts, conceptual relationships and models.

*C<sub>3</sub>- Notes and links.* It contains specific materials prepared by the author of the course and supplementary readings, commented lists of available computer-based simulations and videos, as well as suggestions for useful links providing information or presenting applications.

*C<sub>4</sub>- Remarks on history and epistemology.* It concerns brief considerations of the human and social contexts in which critical explanations were developed, as well as the corresponding cognitive problems that were faced and solved under such circumstances.

*C<sub>5</sub>- Demonstration and experiments.* It is the core of the course. The experimental activities are of two types: simple experiments that start by building at home inexpensive apparatuses used to make observations and measurements required to answer a set of motivating questions, and detailed demonstrations that allows the students to observe a phenomenon in a video and make precise measurements, to represent in tables or graphics quantitative relationships among obtained data, to interpret

the physical meaning of their results, and to solve simple problems.

Two examples of these experimental activities are the following: the building of an electroscope, and the analysis of the video of an object moving in an inclined plane with small friction, with the intention of connecting this movement with what happens in a free fall of the same object.

*C<sub>6</sub>- Iconographic tools: simulations, videos, spreadsheets, graphs and tables.* Specific instructions and examples are provided for interpreting different types of representations of physical phenomena. This component of the course is closely related to the previous one (C<sub>5</sub>) and mostly concerns the use of spreadsheets, graphs and tables, as well as appropriate excursions in the virtual world of computer simulations.

*C<sub>7</sub>- Electronic forum.* This an open scenario for the exchange and discussion of points of view, questions, doubts, answers and projects. It is mainly related to what is happening in the course and includes answers to homework problems en tests.

*C<sub>8</sub>- Assessment instruments.* It consists in the application of questionnaires, exercises, home work problems, and tests. These instruments serve for diagnostic, follow up, reinforcement or remedial purposes.

In the following Table I, we describe for each Guiding Principle (GP) the elements defining the structure considered in Section II; columns C<sub>1</sub> to C<sub>8</sub> correspond to the eight components of the online course.

We indicate with a dot (●) those cases where an element of the structure of the Guiding Principles has been applied in the planning and development of each one of the eight components of the course.

TABLE I. Structure of the guiding principles.

GUIDING PRINCIPLES	ELEMENTS OF THE STRUCTURE	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	C <sub>5</sub>	C <sub>6</sub>	C <sub>7</sub>	C <sub>8</sub>
GP <sub>1</sub> Inverse planning	E <sub>11</sub> -Start with students cognitive needs.		●			●			●
	E <sub>12</sub> -Make sure the students learn what was intended for.			●		●	●	●	●
	E <sub>13</sub> -Prepare the appropriate materials.			●		●	●		●
GP <sub>2</sub> Competences for representing and interpreting	E <sub>21</sub> -Observe.		●			●	●		●
	E <sub>22</sub> -Find patterns.		●			●	●		
	E <sub>23</sub> -Build and test explanations of the patterns.			●	●	●	●	●	●
	E <sub>24</sub> -Use multiple representations to reason about physical phenomena.			●		●	●	●	●
GP <sub>3</sub> Active learning	E <sub>31</sub> -Make knowledge accessible.	●	●	●	●	●		●	
	E <sub>32</sub> -Make thinking visible.					●	●	●	●
	E <sub>33</sub> -Learn one from each other.					●		●	
	E <sub>34</sub> -Promote continuous learning.		●		●	●	●	●	●
GP <sub>4</sub> Epistemological considerations	E <sub>41</sub> -Clarity in the reasoning process.			●		●	●		●
	E <sub>42</sub> -Coherence in the discourse of representations and interpretations.			●		●	●		●
	E <sub>43</sub> -Relevance concerning building knowledge			●	●	●	●	●	●
GP <sub>5</sub> Roles of teachers	E <sub>51</sub> -Exploration of facts.			●		●	●		●
	E <sub>52</sub> -Description of contexts.			●	●	●	●	●	●
	E <sub>53</sub> -Presentation of evidences			●		●	●	●	●
	E <sub>54</sub> -Formulation of consequences.			●	●	●	●		●
GUIDING PRINCIPLES	ELEMENTS OF THE STRUCTURE	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	C <sub>5</sub>	C <sub>6</sub>	C <sub>7</sub>	C <sub>8</sub>

By following the structure of an online course on mechanics and electromagnetism, a group of 35 students was involved in the following activities: reading of materials, participation in the electronic forum, solution of problems in home-works, realization and discussion of experiments, analysis of measurements made in videos, presentations of topics, and solution of quizzes.

The main results were the following:

- The activities served for understanding and applying concepts through discussions in the forum or through questions and answers in the classroom.
- The students were very much motivated in building and using their own apparatuses in order to ask and solve concrete problems.
- The students enjoyed and developed their reasoning skills and appreciated the opportunities for communicating and defending their own points of view. Briefly, they learned by doing.
- The students found the learning activities quite amusing, interesting and illustrative.
- Although the core of the course was mostly related to components C<sub>5</sub>, C<sub>7</sub> and C<sub>8</sub>, components C<sub>3</sub>, C<sub>4</sub> and C<sub>6</sub> were not extensively used and the materials need further improvement.

The Guiding Principles (GP) were very useful; nevertheless, two categories can now be established: those principles that are difficult but doable, like GP1 (Inverse planning), GP3 (Active learning) and GP5 (Roles of teachers), and those principles that require a more careful revision in terms of their practical applicability, like GP2 (Competences for representing and interpreting) and GP4 (Epistemological considerations).

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