Introductory Physics course for Civil Engineering students: a curricular proposal based on Physics Education Research

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Abstract – **The Bologna process is assumed as an opportunity for change in European Higher Education, namely with the implementation of teaching methods which promote active learning and student autonomy. These changes are even more important in Engineering Education, since the labour market demands new skills from future engineers, whose development has been proved to be more effectively achieved with active learning methods than with traditional ones. Using the results of Physics Education Research (PER), we have applied a Problem-based Learning (PBL) method in the teaching of General Physics, for Civil Engineering freshman at the College of Technology and Management of Oliveira do Hospital. From the conclusions of this research, we propose a program for introductory physics courses, adapted to a Civil Engineering degree, which promote the adoption of strategies based on the solution of real problems.**

Index Terms - Active learning, Civil engineering education, Curricular development, Physics education research, Problem-based learning.

INTRODUCTION

The Bologna Declaration (BD), signed in 1999, marks a path of convergence for the various Higher Education systems existing in the European countries, belonging or not to the European Union (EU). The diversity of systems observed, in some cases, inside the same country, has been an obstacle to student mobility and accreditation within the European Higher Education Institutions (EHEI), and ultimately a large obstacle for European citizens' employability.

The harmonization and compatibility of homologous European degrees is seen as the solution. Furthermore, if the EU is to become a stronger economy, significant effort must be made in innovative technology qualification and scientific research, which will demand an improvement in Science Education, particularly engineering, where failure and drop out rates remain a major concern. Decreasing the rate of non-success in engineering courses, namely in introductory physics courses, and the need for development of a greater number of skills, like those associated with real problem solving, has given space to the emergence of active learning methods. Among these we can find the Problem-based learning (PBL) method, which has been applied in this work.

In the first part, the reasons for choosing PBL in substitution of the traditional teaching method are presented. Secondly, design implementation and evaluation of the formative sequence, centred upon the optimization of buildings' thermal efficiency is described. Finally, after the analysis of this sequence, a curricular proposal is presented, constituted by seven instructional units, approaching scenarios related to the student's future career and facilitating the implementation of the PBL method.

PHYSICS TEACHING ON EUROPEAN CIVIL ENGINEERING 1ST CYCLE

The Bologna process is on the march: the reorganization of the three main degrees (Bachelor, Master's and Doctorate), the implementation of an European credit transfer system (ECTS) and the creation of a common evaluation system for all EHEI, are the most visible changes.

As in Portugal, many other countries must adapt their systems to this new paradigm, which means a change not only in first degree structure (in most cases it becomes shorter – 3 or 4 years), but also the adoption of pedagogical systems that valorise the student's total working time needed to achieve defined aims. This implies a greater autonomy in students' acquisition of knowledge, abilities, attitudes and values, which will be possible only if EHEI change their learning methods, becoming more open to students' active participation.

This curricular proposal seeks not only to define essential content for introductory physics programs for civil engineering students, but also aims to exemplify how curricula can facilitate the adoption of learning methods that stimulate student autonomy.

I. Which physics should we teach?

In 2006 we analysed the program of introductory physics courses within seven EHEI Civil Engineering degrees and observed two tendencies [1]:

- To make available contents which will support a deeper study in engineering technology courses;
- To provide knowledge and ideas, namely of Modern Physics, which are useful *per se* but also contribute to the development of new technologies and to

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construction of a global and structured vision of the World (macro and micro-scale).

As a consequence of BD, there are emerging synergies in the elaboration of new curricular proposals which makes possible the harmonization, compatibility and comparison of the courses offered in the so called European Higher Education Area. One of the synthesis works led by Thematic Network E4, integrated in the SOCRATES programme, designated "Innovative Curricula in Engineering Education", elaborates a proposal about the general skills and the academic knowledge that engineering students from the 1st cycle (degree) must privilege. Relative to physics, we indicate below the contents that they propose for all first cycles of engineering degrees [2].

"The engineering graduate should be able to:

- use the relevant laws of kinematics and dynamics to solve problems of rotational and lateral movement;
- explain harmonic oscillations, damped oscillations and forced oscillations and treat such oscillations mathematically;
- describe waves mathematically and explain the concept of wave lore;
- explain the first and second law of thermodynamics and solve problems applying these laws;
- explain the principles of electric and magnetic fields and apply the basic laws of electric circuits;
- explain the basic principles of quantum theory."

The curricular proposal presented in this work was planned and based on the suggestions of Thematic Network E4 and it fills an intermediate position concerning the role of physics in an engineering student's academic formation.

II. How should we teach physics?

Beyond solid technical knowledge, employers demand from 21st century engineers a large range of skills that have been defined in large part by professional associations. Abilities related to real problem solving, communication, work group research, analysis and evaluation, are examples of skills requested.

According to physics education research (PER), their acquisition/development can hardly be achieved employing traditional teaching methods. PER (for example, see [3]) concludes that teaching methods should include:

- Student centred learning;
- Interactivity (teacher-student and student-student);
- Contextualization;
- Diversification of tasks;
- Adoption of multiple criteria, besides the logical ordering of concepts, about the structure of contents taught.

Among the numerous active learning methods that appeared beginning in the nineties (for example, see [4]), we have selected the problem-based learning (PBL) method to implement the formative sequence described in the next section. This choice is supported by the studies reported in [5]. In a PBL environment the formative sequence always starts from conceptually ill-structured problems, related to the student's future professional career, motivating the learning of concepts and laws needed to find meaningful solutions. Activities implemented are student centred, promoting active learning and group work, facilitating the development of numerous skills, namely those related to real problem solving. Central to all the PBL models the following can be highlighted: contextualized learning, interactivity, meta-cognition and autonomous learning. Problems are central to PBL as the starting point of the learning process, where concepts and laws are introduced and applied to solve real problems [6].

DESIGN, IMPLEMENTATION AND EVALUATION OF A FORMATIVE SEQUENCE APPLYING PROBLEM-BASED LEARNING

The formative sequence, applying PBL, was implemented in the General Physics class, for Civil Engineering freshman, at the College of Technology and Management of Oliveira do Hospital (CTMOH) for a period of 20 hours.

I. Formative sequence design and implementation

In this implementation, a rigid distinction between lectures and tutorials was purposely not established. Consequently, at any time or in any class, there could have moments of explanation, resolution of numerical exercises, and solution of real problems involving laboratorial activities or even oral presentation by students. The whole project was based on real problem solving, with relevance for student interests, which required the learning of concepts, laws and models, as well as the planning of experimental activities or numerical problem solution.

The problematic situations created were based on the following principles:

- Open-endedness; that is, their solution is not immediate, implying research, experimentation, and not necessarily requiring a numerical answer.
- Relevance to the civil engineering student;
- Demand the planning and performance of laboratorial activities;
- Can be easily broken down into simpler problems.

The tested PBL model evolved through the following stages:

- The overarching problem is presented to students;
- They read the problem and clarify words, physics concepts or equations that don't understand;
- Pupils try to simplify the initial problem;
- Easier questions are subsequently presented;
- Teacher initiates the search for the answer;
- Physical concepts and laws underlying the needed answers (through students' research and teacher intervention) are clarified.
- The Oriented Experimental Activity (OEA), investigational in character, is given to student work groups;
- Students work in the planning of OEA;

- OEA is implemented;
- Various OEA developed by work groups are presented to the class, fostering discussion followed by the elaboration of a written report.

Oriented experimental activities (OEA) were an essential element during the curricular module, because it allowed the development of a set of skills related to the planning and leading of experiments, as well as the analysis and interpretation of experimental data and the development of team cooperation in solving real problems. The themes under investigation during these activities were always connected to the overarching problem, helping students consolidate related concepts and laws, thus facilitating the problem's solution. The transcription of an overarching problem with the three other simpler questions sequentially used in the solution process is presented in Figure 1.

	Formative situation 2 How does it process energy transfer between the building and the surrounding environment?	
Formative situation 1 Why do we use mercury on the older thermometers and not other substance, taking into account that it is a toxic substance? Is it possible to replace the mercury by water?	Overarching situation During the usual visit to Serra da Estrela you had to stay overnight in the old hotel Serratur. Talking with to the manager he demonstrated some care about the building heating costs. There was a boiler, supplied by gas oil which assures the central heating. The successive rises in fuel prices are compromising the hotel's competitivity. How to reduce the energy cost maintaining guests' confort?	Formative situation 3 Why are the old houses from Beira Interior, builded with granite, so fresh in the Summer?

FIGURE 1
SCHEME OF THE FORMATIVE SEQUENCE.

II. Global valuation of sequence implementation

To evaluate the implementation of the described formative sequence we used the following instruments/techniques:

- Heat and Temperature Concept Evaluation (HTCE) [1];
- Maryland Physics Expectation Survey (MPEX) [7];
- Interviews;
- Teacher's observations in class.

HTCE is a concept test that evaluates the understanding level of concepts like heat, heat capacity, temperature, heat transfer, heat flux and the comprehension of some aspects of heat conduction phenomena. The results before and after the implementation revealed a random increase of 18% in student comprehension.

MPEX is another validated test that measures student's understanding of the tasks that must be completed to succeed in a physics course. Comparing the MPEX results of CTMOH physics' students with other investigations [7] we observed significant improvements in students' perception about physics' connection with reality (favourable increase of 7,5%), showing students that what they learn in physics class is relevant in many real situations.

Concerning student beliefs about learning physics, we also witnessed a favourable increase (16,1%). A favourable attitude involves an active process of reconstructing one's own understanding.

In spite of the absence of quantifiable data, teacher observations lead us to believe that some tasks can raise the development of relevant skills associated with real problem solution: planning experimental activities, information research using several sources, cooperative work within and between groups.

CURRICULAR PROPOSAL FOR INTRODUCTORY PHYSICS DISCIPLINES DIRECTED TO THE CIVIL ENGINEERING COURSES

The curricular proposal here presented, corresponding to two introductory physics courses for Civil Engineering students, aims to develop the following general skills. Its chance for success depends upon the adoption of teaching methods that take into account the implications of PER, previously reported.

So, this proposal facilitates the implementation of methodologies which demand:

- Autonomy and responsibility of students in the construction of their knowledge through task-based activities with specified aims for each unit;
- Interactivity teacher-student and student-student; adoption of topics relevant to the students and related to their future professional activity, oriented experimental activities (OEA) and group work;
- Interdisciplinary approach; some of the proposed contents touch other areas (geology, computation,…) promoting the connection between physics and other areas of knowledge;
- Task diversity – planning of experimental activities, collecting data and information from various sources, communication to and within the group.

I. General skills

Next, the general skills students must acquire/develop along the proposed course are described:

- To acquire and apply physics and mathematical knowledge;
- To acquire a vision of what science is and what can be done with it;
- To develop autonomy in the learning processes forming capacities and attitudes to facilitate life-long learning;
- To develop the abilities of team cooperation in solving real problems;
- To increase the capacity of planning and conducting experiments, as well as analysis and interpretation of experimental data;
- To increase the capacity to identify, formulate and solve problems;

- To develop capacities to communicate making use of scientific language;
- To acquire skills in information technologies;
- To become sensitive to the social and environmental problems of society and analyze sustainable solutions based on science and engineering.

II. *Structure of the curricular proposal*

The proposed curriculum is divided into seven units. In each unit an overarching problem necessitates the learning of concepts and laws necessary for the solution of the problem. It also contains some other simpler questions that can orient students along the formative sequence.

Each core problem was formulated according to the following rules:

- Open-endedness; that is, problem solution is not immediate, implying research, experimentation, and not necessarily requiring a numerical answer.
- Relevancy for the civil engineering student;
- Demand the planning and implementation of experimental activities;
- Divisible into simpler problems/tasks;
- Elaboration avoids scientific language, approximating the speech used by the student in his daily life.

Moreover, each unit begins with an introductory text justifying the relevance of the chosen topics, a diagram with the scheme of the advised formative sequence, the concepts and laws to be learned, the specific outcomes, some practical activities and, lastly, one (or more) OEA related to the proposed thematic problem.

A synthesis of the curricular proposal is presented in Table I. All seven units are described with the respective teaching contact hours, totalling 150. In parentheses are the recommended contact hours for each topic sequence. According to our findings, the contact hours need contain no distinction between lectures, tutorials or laboratory classes, permitting the teacher to decide upon the best way to manage the sequence time available.

TABLE I
SYNTHESIS OF CURRICULAR PROPOSAL

Unit	Advised sequence	
Unit A A building's thermal efficiency	**1.** Thermometer functioning (6) **2.** Energy transfer of a building (7) **3.** Thermal inertia of a building (6) Oriented experimental activities (OEA) A1, A2, A3 (6)	25
Unit B Water distribution – an amazingly simple process	**1.** Water distribution by gravity (6) **2.** Water pumps and siphons (3) **3.** Water flowing through pipes (6) OEA B (2)	17
Unit C Materials and their mechanical properties	**1.** Static equilibrium (5) **2.** Impulse and energy (6) **3.** Effect of forces over deformable solids (7) OEA C (2)	20
Unit D Earthquakes and their impact on buildings	**1.** Scientific description of earthquakes (7) **2.** Propagation of seismic waves (7) **3.** Detection and analysis of earthquakes (2) **4.** Diminishing earthquake effects (2) OEA D (2)	20
Unit E Production, transport, distribution and usage of electric energy	**1.** Simple electric circuits and the circuit breaker system (6) **2.** Consumption and production of electric energy (6) **3.** Transport and distribution of electric energy (2) **4.** Alternating current and ac rectification (12) OEA E (2)	28
Unit F Electronics: sensors and controllers	**1.** Introduction to Quantum Mechanics (8) **2.** Models of electric conduction in solids (6) **3.** Semiconductors (6) **4.** Logic gates and microprocessors (5) OEA F (2)	27
Unit G Optical fibres and their application in illumination	**1.** Light propagation (4) **2.** Light interaction with obstacles (5) **3.** Optical fibre (2) OEA G (2)	13
	Total contact hours	150

CONCLUSIONS

In this paper we have described the implementation of a formative sequence based on PBL method. The evaluation of the physics module (Unit A), using various instruments and techniques, lead us to believe that the used method presents advantages in the development of skills associated with real problem solution. Besides, students' perception about physics' connection with reality had a significant favourable increase.

The presented curricular proposal, corresponding to two introductory physics courses for Civil Engineering students and based on the results of the implementation, is structured to facilitate the adoption of teaching methods defended by PER.

In the future we intend to implement and evaluate the entire curricular proposal, pursuing for better learning results in introductory physics course.

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