PHYSICS EDUCATION FOR STUDENTS:
AN INTERDISCIPLINARY APPROACH

Editors:
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Physics Education for Students: An Interdisciplinary Approach

Edited by

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PREFACE

The Special Issue titled *Physics Education for Young Students* is mainly addressed to new approaches and trends in teaching and learning specific topics of Physics to young university students. It is well known that, from a general point of view, Physics teaching and learning cover, with different extents, several fields, such as for example Laboratory activities, Mathematics, Philosophy and History. These distinguished areas can generate complexities and difficulties for students in learning some concepts since the same topics are often presented following approaches that do not highlight the existing correlations among the involved disciplines. Therefore, in order to enrich topics with high value meanings, it is important to propose and to promote integrated and interdisciplinary approaches where Laboratory activities in a wide sense, pose themselves as fundamental tools to improve the knowledge of some topics which interest different aspects of Physics, Mathematics, Philosophy and History.

In fact, it is well known that, especially in a teaching context, interdisciplinarity consists in "bringing together at least two disciplines, in order to develop an original representation of a notion, a situation, a problem" [1]. An interdisciplinary approach can provide a solution to many student comprehension problems and can bring a deeper understanding and appreciation: the more the students learn, the more they find common basis for all the interested disciplines; in other words, they learn more and improve their basis to tackle all disciplines. Furthermore, interdisciplinarity promotes the development of higher cognitive skills such as critical thinking, spirit of synthesis and integration, reflexive skills, understanding of difficult concepts and conceptual memory [2-4].

In this framework, the main aim of the proposed special issue is to promote Laboratory activities and Mathematics contents for Physics courses addressed to young university students, as well as to put into evidence the importance of an historical and philosophical approach which is a recurring topic nowadays due to the fact that scientific activity constitutes by itself a historical and a philosophical process.

In this framework the papers collected in this special issue are addressed to the understanding of the best practices involved in some specific topics teaching through an interdisciplinary approach, which requires the employment of different and complementary methodologies.

More in details, the issue is divided in 6 chapters.

In chapter 1, the authors explore the design and implementation of laboratory courses starting from the analysis of student’s interviews and coursework considered as the best practice for the implementation of introductory Physics laboratory courses when seeking to adopt an interdisciplinary approach [5].

In chapter 2, the authors highlight the concept of active learning as first research experience of university students. For this purpose they believe that the development of students’ research skills should be carried out both within the class hours and within out-of-class studies through complementary activities. Furthermore, they believe that such tasks make it possible to expand the scope of students' active-learning activities, to broad students’ scientific horizons, and to form the skills of a researcher [6].

The author of chapters 3 and 4 raises the question about which educational and didactic strategies, based on self-responsibility, are the most suitable for spreading a humanitarian culture based on science. To answer this question, at first, the author proposes two didactic approaches for strengthening self-responsibility in students: the approach called “3 x 7 = 21” and the approach called “jet principle”; then, in chapter 4, the author explains the five-level structure of rules and provides a few results on resulting social dynamics in student groups. All the considered approaches rely on the dialogue and the confrontation of learners with their peers and are suitable for advanced physics students in any transdisciplinary setting [7-8].

The authors of chapter 5 present a proposal for a lecture on optical spectroscopy as dealt in a secondary school. In particular, they designed an educational path for secondary school students encompassing experimental approaches while, from the theoretical point of view, they designed intervention modules in which interpretative issues are problematized using Inquiry-Based Learning strategies [9].

Finally, in chapter 6, the authors present a lecture addressed to first year Physics students on a system of coupled oscillators. In particular, they point out how in order to improve the understanding of this Physics topic, it is important to integrate theory with experiments. For this reason, they first describe the dynamics of the system from a theoretical point of view, then describe the experiment execution and finally analyze the results by comparing the Fourier transform and the Wavelet transform approaches[10].

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CHAPTER 1

Expansive Framing Produces More Vivid Introductory Physics Labs

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Abstract: Expansive framing, which positions students as participants in larger conversations that span time, place, people and disciplines, can be a valuable approach for designing curricula and learning experiences, to help students learn physics through an interdisciplinary approach. This chapter reports on the efforts to use expansive framing as a guiding principle while transforming and revitalizing an introductory physics laboratory class. This chapter, describes student experiences with two central elements of the lab course that are strongly influenced by the concept of expansive framing and related to interdisciplinary learning. First, we sought to incorporate and emphasize experiences related to the students' real-world and professional experiences, such as connections between biology and physics, that will be interesting for the health-science majors who take the lab. Second, we sought to promote discussions between students and their graduate student instructors about the epistemology of experimental physics, which we refer to as the nature of science, which is an important interdisciplinary goal for the lab class. We explore the need, design, and implementation of these two elements of the lab course by analyzing student interviews and coursework. Consequently, we propose that using expansive framing for the design of student learning should be considered a best practice for implementing introductory college physics laboratory courses when seeking to adopt an interdisciplinary approach to student learning.

Keywords: Expansive framing, Nature of science, Physics education.

INTRODUCTION

What does it mean to learn something? One answer involves the concept of transfer, or the ability to take the knowledge learned in one context and applying it in a different context [1]. Based on the goal of improving transfer, expansive framing is an approach to curriculum and learning activity design that focuses on the need to situate learning and learning contexts within the broader scope of learners' settings, roles, disciplines, and experiences [2].

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To understand expansive framing, it may be useful to start off with its antithesis, bounded framing. Learning activities that employ bounded framing presume that the concepts students learn are relevant only for limited contexts. These limited contexts might include specific places, times, and participants. For example, physics learners might perceive that Newton's laws of motion apply to physics problems, but are not relevant in the physical world, in their other classes, or in their future studies or career. Such a perception might develop if student learning concentrates on solving problems set in artificial contexts, regardless of the instructor's intentions or their own perspective that the laws of physics are general and broadly applicable. Bounded framing may also limit the intellectual role played by students, situating them at the periphery of the learning process [3, 4].

By contrast, expansive framing promotes students' understanding of concepts by connecting different contexts, developing links between settings and roles to create intercontextuality [5]. Intercontextuality empowers learners to make connections and transfer knowledge between different learning contexts (including time, location, and participants), roles, and topics. Intercontextuality supports transfer by helping learners connect learning context to the transfer context by way of the encompassing context. In this view, if student learning is supported with expansive framing then students may begin to make connections between the content, the learning context, and the encompassing context. Later on, when students are asked to transfer their understandings, the intercontextuality makes it easier for them to connect ideas from the learning context and encompassing context with the transfer context [2].

In an experiment with high school biology students, Engle, Nguyen, and Mendelson found that students who were tutored with an expansive framing demonstrated substantially better transfer of their learning to a new context [5]. In this experiment, students were provided with tutoring about the cardiovascular system on day one, and then asked to transfer their understanding to the respiratory system on the other day. Students received the same tutoring, but different kinds of framing. Students in the control group experienced tutoring that was framed in a typical way, while students in the experimental condition experienced tutoring with expansive framing that focused on context, topic, and roles. When interacting with students in the experimental condition, the tutors provided an expansive framing to the context of tutoring by describing the experiment as a multi-day study (rather than two separate days), located at the university (rather than contained in the specific room), and conducted with a team (rather than with just one tutor). The tutors also described the topic of the study as "body systems" (rather than the cardiovascular and respiratory systems separately) and they emphasized that the participants were authors responsible for their own ideas (rather than recipients of ideas from others). These modest changes to the framing of the learning scenario produced dramatically improved transfer from students [5]. Another study by Engle found that an expansive framing helped 5th grade students in a science lesson [6]. In this case, the two important aspects of expansive framing were temporal connections with other contexts and the roles of the learners as members of a larger community of people interested in the topic.

Related studies in physics education have analyzed the roles of framing and scaffolding [7] when students solve isomorphic problems [8 - 11], categorize problem types [12 - 15], and self-diagnose their answers to quizzes [16 - 18]. these studies' results serve to underline the difficulty of knowledge transfer for introductory physics' students while suggesting that both scaffolding and framing could play a valuable role in improving transfer [19 - 22].

Expansive framing can be a useful approach to interdisciplinary education. By bringing a focus to transfer and intercontextuality, expansive approaches to lesson and curriculum design encourage educators to think about how learners can make meaningful connections between the physics they learn in their classes and their personal interests and career goals [23]. Likewise, the nature of intercontextuality calls educators to ask increasingly fundamental questions about the learning goals of their courses, which may result in questions and issues that are broader than the scope of any one course, or even any one discipline.

In this chapter, we will outline how expansive framing was used in the design of student learning activities in an introductory physics lab course. First, we will consider how expansive framing was used to guide the development of lab-work. By seeking to make learning meaningful for students, many on health-science career tracks, we created opportunities for students to demonstrate transfer. This included both bringing ideas and skills from their other studies and interests into the physics lab, as well as applying physics concepts in the context of their other studies and interests. Second, we will examine how we used expansive framing to improve student learning about the nature of science during the lab course. As a fundamentally interdisciplinary topic, the nature of science is a good example of intercontextuality. This allowed for ample opportunity for students to reflect on elements of the nature of science in the context of the physics lab as well as in other contexts.

PHYSICS LABS

The introductory physics lab has long been a cornerstone in college education [24]. Traditional approaches to physics lab instruction rely on highly-structured experimental work [25, 26]. In this approach, students carefully follow instructions in a lab manual to conduct an experiment that has been designed for

CHAPTER 2

Active Learning in Studying Physics as the First Research Experience of University Students

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Abstract: Modern educational standards impose high requirements on the qualification of higher education graduates majoring in engineering and technical areas. The development of professional competencies is carried out both through students' educational activities and scientific research work. Research activities allow students to acquire the skills necessary to perform scientific research, develop independence and initiative, intensify students' cognitive activity, and contribute to creative thinking of a future engineer.

The authors of the article, being university lecturers in physics, mathematics, and English, share the experience of involving first-and second-year students of the Institute of Physics and Technology in research work through out-of-class activities. At the beginning of studies, students go through a period of adaptation to university environment; they have different levels of initial training and lack experimental skills. Nevertheless, during this period of study it is very important to give a student the opportunity to get a "feel" for science, so that a student has a chance to try and solve a task independently, even if it is not difficult enough, and, thus, to experience the joy of learning. Students' enthusiasm for learning should be taken into consideration as an important factor for the development of research skills. Teaching staff members need to take into account students' interests, give them the opportunity to develop their abilities, so that first- and second-year students could determine their own individual learning paths, despite the different levels of initial training in the subject and degrees of motivation. One way to solve this complicated problem is to involve students actively in learning.

Student's research work should be a comprehensive, goal-oriented and a methodically justified system, in which the complexity of the tasks being solved is consistently increasing. The authors believe that the development of students' research skills should be carried out both within the class hours and out-of-class studies through the following activities. In-class activities include performing mini-research projects, analyzing and processing results during laboratory work, preparing scientific reports for seminar presentations, involving students to perform a physics demonstration experiment in lectures. During extracurricular time, as part of out-of-class independent studies, stud-

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ents are encouraged to participate in a wide range of additional activities: conducting research for interdisciplinary projects, preparing a research report in a foreign lanuage as well, and creating working models of devices that demonstrate physical phenomena and processes. Such tasks make it possible to expand the scope of students' active-learning activities, broaden students’ scientific horizons, and form the skills of a researcher.

As a result of ongoing work to involve first- and second-year students in research activities, the number of students participating in student scientific conferences and those awarded scholarships for successful participation in scientific research has increased. Student involvement in the educational process makes them an active part of it, enhances their personal capabilities, contributing to the formation of the required competencies, creating an atmosphere of development of scientific and creative potential, and laying the foundations for future research work in later years of study.

Keywords: Active learning, Foreign language, Individual learning paths, Interdisciplinary connections, Mathematics, Physics, Project-based learning, Students’ research work.

INTRODUCTION

Modern educational standards impose high requirements on the qualification of higher education graduates majoring in engineering and technical areas. All over the world, there is a real need for professionally competent, socially active and competitive specialists who are ready to effectively conduct engineering activities at an interdisciplinary level, master advanced technologies in a short time, and are able to predict the consequences of their activities. Engineers are required not only to know a particular subject area but also to possess a system of fundamental and professional knowledge and skills to solve complex technical and technological problems. This means that the training of such specialists requires optimization of the university educational process, which includes the introduction of new educational methods (technologies) designed to develop both professional and general cultural competencies. One of the ways to improve the educational process, according to the authors, is the development of active learning methods aimed at acquiring research skills, self-organization and self-education skills, intensifying students’ cognitive activity, and contributing to creative thinking of a future engineer.

It should be noted that the foundation of engineering education is, first of all, the proper level of mathematical apparatus, knowledge and understanding of the basic laws of physics, which are practically implemented in modern technology. Mathematics is a specific general education discipline since the knowledge obtained in mathematics is the foundation for studying other general education and special disciplines. On the other hand, mathematics is not a major subject for most areas of university training, and students, especially first- and second-year undergraduates, perceive it as a kind of abstract science. To change this situation, it is necessary to constantly show the connection of mathematics with problem-solving in the chosen field of study, since first- and second-year students do not yet have sufficient knowledge of special subjects and are not able to assess the value of knowledge and application of mathematical methods to solve these problems [1, 2].

In addition to sciences, due attention should be paid to humanities, one of which is a foreign language.

Thus, the training of engineering specialists requires a comprehensive approach to integrate physics with other disciplines taught to first- and second-year students. The article considers the experience of implementing an interdisciplinary approach in teaching physics, mathematics, and a foreign language.

Over the past few decades, an increasing number of educators and researchers in the field of education have noted in their works that students have difficulty learning physics [1, 3]. This is due to the falling interest in the exact sciences in general (including physics) and engineering disciplines. In many countries, the proportion of young people choosing these subjects is declining. As a result, applicants have insufficient training in physics and mathematics. When planning measures to improve the educational process and introduce new educational methods, it is necessary to take this fact into account. first of all, don't follow towards increasing the complexity or the amount of educational material, but towards increasing students' engagement in active learning and involvement in the knowledge attainment process.

These circumstances prompted the authors to search for active methods of teaching physics that ensure the intensive development of cognitive motivation and interest, and contribute to the expression of creative abilities in learning.

According to the authors, one of the promising directions in the development of active learning is students' involvement in research activities, starting from the first year. At the beginning of studies, students go through a period of adaptation to the university environment; they have different levels of initial training and lack experimental skills. Nevertheless, during this period of study it is very important to give a student the opportunity to get a "feel" for science, so that a student had a chance to try to solve a task independently, even if it is not difficult enough, and, thus, to experience the joy of learning. Students' enthusiasm for learning should be taken into consideration as an important factor for the development of research skills. Teaching staff members need to take into account students' interests, give them the opportunity to develop their abilities. Therefore,

CHAPTER 3

Can Physics Education Support A Self-Responsible Society?

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Abstract: In the face of the "European Green Deal", our continent needs young cohorts of self-responsible citizens steering the globe towards responsible sustainability.

This article reflects two didactic approaches for strengthening self-responsibility in students: the approach "3 x 7 = 21" and the approach "jet principle". Both rely on dialogue and confrontation of learners with their peers – often a more stringent educational agent that contact with teachers.

The very simple method "3 x 7 = 21" sets learners into 3 phases of iterative complexity: single achievements, groups of 3 and groups of 7 while they iteratively exchange their views on complex interdisciplinary subjects.

The more elaborated method "jet principle" leads learners into framework conditions which they actually formed during their previous steps: analogous to a jet turbine, the border conditions of subsequent learning stages are the result of energetic applications of confrontations during earlier stages.

Both methods are suitable for advanced physics students in any transdisciplinary setting.

Keywords: "3 x 7 = 21", Curriculum, Dialogic learning, Discursive learning, Globalization, Global studies, Global studies consortium, Graz University, Interparadigmatic, Jet principle, Quality assurance, Transdisciplinary.

INTRODUCTION

This article presents two didactic methods, namely "3 x 7 = 21" and the "Jet Principle", based on a pedagogy of dialogue and discourse [1 - 5].

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For ten years, these and similar didactic approaches were implemented at several universities and produced a series of collaborative student articles published by students and collaborative student reports which document the results of the described didactic approaches [6 - 25].

PHYSICS LABS FIRST DIDACTIC METHOD “3×7 = 21”

Didactic Basics of the Course Design “3×7 = 21”

Based on the challenges posed by “global change”, this article proposes to train discourses in universities on how to develop a consensus that is as sustainable (*i.e.* durable and environmentally oriented) as possible, namely based on sound, interdisciplinary expertise.

A suitable rhythmised process design of consensus development includes formulating and rethinking everybody’s own point of view and then “weaving” it into an overall consensus.

This concrete course strategy means interdisciplinary training in a “3 x 7 = 21” architecture which creates changing intradisciplinary and interdisciplinary encounters among learners. The method “3 x 7 = 21” fills the theoretical requirements of a dialogical and discursive didactic approach with real life and on a practical level provides cooperative seminar papers by students on individual and a collective bases which may also be used for assessment of students’ achievements including very targeted grading. For universities, the overall question is how best to respond to “global change” and to take into account its environmental impact, but also its social and economic structural changes. Thus, in general, this innovative method can be carried out well in courses where students from different disciplines (and from different countries of origin) come together.

Considering Several Value Systems Means An Inter-Paradigmatic Approach

Stepwise approaches to complex inter-paradigmatic problems such as global (climate) change are useful when divided into single days with individual, then intradisciplinary collaboration, then interdisciplinary collaboration, as explained in the following example of a course plan established with “3 x 7 = 21” didactics.

At first, each teacher of a team of teachers or lecturers starts with teaching their own basic concepts as perceived by each presenter. In practice, this may be a block of 2 hours for each lecturer. Then, the students carry out their own written work assignment or (literature) search on a selectable subtopic of the overall theme (*e.g.* technical, geographic, economic, or social aspects of global warming). This written work is presented (*e.g.via* an online learning platform), then discussed face-to-face during the 2 hours of a subsequent university course and then these views are balanced within the group of colleagues.

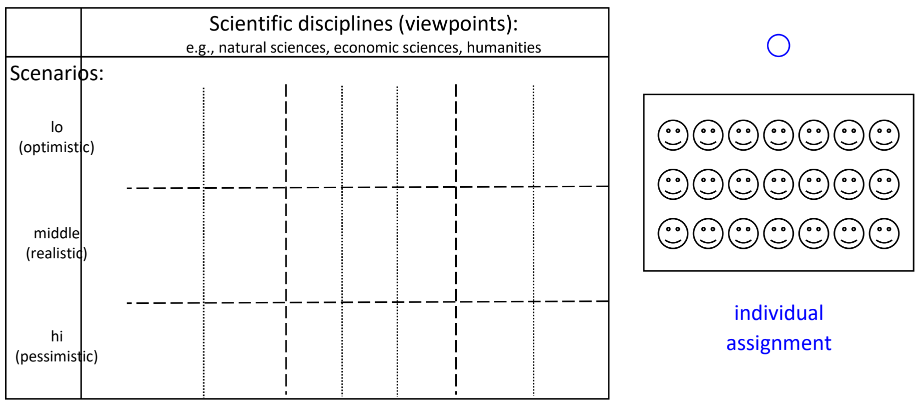

Fig. (1). Matrix-like overall structure of a "3 x 7 = 21" course: 3 groups of disciplines (according to those of the lecturers but also the students, horizontal) and three scenario inclinations (vertical).

In a next step of work, the students discuss and revise their work in intra- and interdisciplinary dialogue with the appropriate accompaniment of lecturers (see the diagrams in Figs. (**1** to **3**)). Then follows an in-depth block by each lecturer; these may clarify in-depth questions which emerged as a result of student discussions. Thereby, all advantages of e-learning are made use of on all levels of communication, namely content provision, discussion forums, online quizzes and mutual feedback.

The Concrete Didactic Process of "3 x 7 = 21"

Through the characteristic organizational structure in groups, the concrete didactic procedure develops step by step as follows:

- Generation of empathy and collection of the emotional impressions (anonymous, *via* the learning platform) in order to determine where the students should be "picked up" emotionally, and what their initial level of knowledge is.
- Then there should come one block by each specialised lecturer, in which each lecturer presents material & content (*e.g.* as a PowerPoint or oral presentation,

CHAPTER 4

Dialogic Best Practice for Dissemination of A Scientific Culture

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Abstract: In the face of globalization, the question arises which didactic and educational strategy based on self-responsibility is best suited for dissemination of a science-based humanitarian culture.

This chapter reflects one pedagogic approach to strengthen self-responsibility within students, namely the approach "Surfing Global Change" (SGC,© G. Ahamer) which relies on dialogue while confronting learners with their peers – a much-needed training event when it comes to real-live professional situations.

This article portrays the 5-level rule structure and offers graphic implementation and moreover some results on emerging social dynamics within student groups.

This method is suitable for advanced physics students in any transdisciplinary setting.

Keywords: Curriculum, Dialogic learning, Discursive learning, Globalization, Global studies, Global Studies Consortium, Graz University, Interparadigmatic, Quality assurance, Transdisciplinary.

SURFING GLOBAL CHANGE

Pedagogic Foundation of the Negotiation Game "Surfing Global Change"

The pedagogic goal of this negotiation game SGC (© G. Ahamer) is to teach students how to take on a proactive and technically responsible role for sustainably building a global society. Didactic and pedagogical principles are described in detail in the published literature [1]. This succinct overview presents the SGC rules in the typically used graphic design of SGC.

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This entire 5-level game “Surfing Global Change” has the learning objective to master consensus building as practiced and demanded in many developed societies [2, 3].

In more detail this means five levels [4, 5] (compare Fig. **1**). At the same time, the following figures inform about the graphic design which was developed for SGC by the information graphics expert Chris Schrei in Graz (www.definite.at).

Fig. (1). The levels of the entire game SGC (© G. Ahamer) are founded on each other. These lead to greater social and academic complexity and enhance suitability of the constructed consensus.

The didactic goals are further identified in Fig. (**2**).

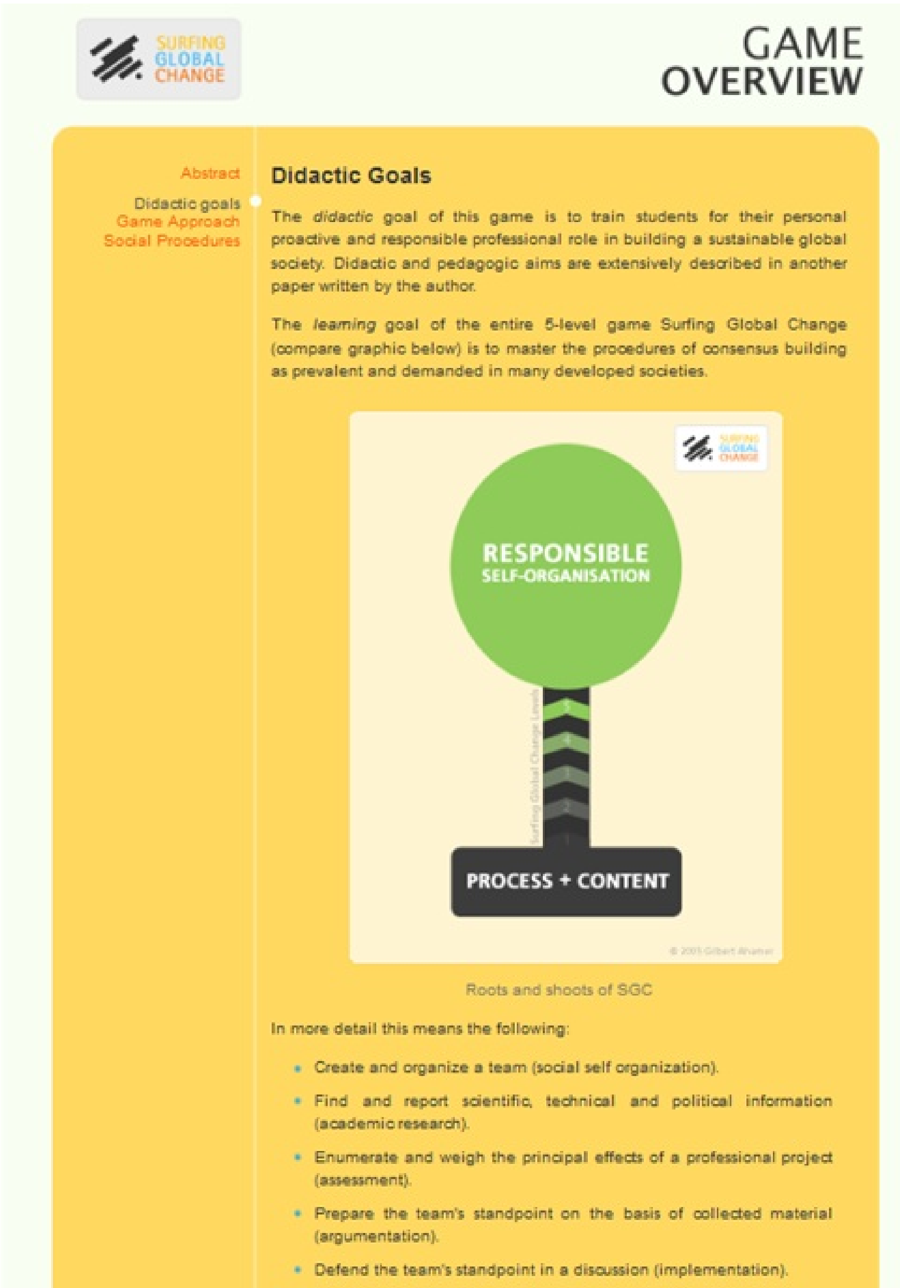

Fig. (2). The five social actions are based on the didactic goals of SGC [6].

CHAPTER 5

Research-Based Proposals on Optical Spectroscopy in Secondary School

Daniele Buongiorno[1,*] and **Marisa Michelini**[1]

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Abstract: The interpretation of spectra, particularly in the optical band, is a conceptual and historical link between classical and modern physics. It is an empiric proof of the atomic structure of matter and an experimental instrument to investigate phenomena involving interactions between light and matter. On a disciplinary plan regarding physics, it is a fundamental contribution; unfortunately, the road to embed optical spectroscopy in a coherent educational pattern is still long.

From a research perspective, the Physics Education Research Unit from Udine University focused on the design of an educational path on spectroscopy for high school students, with the aim of involving them in interpretative challenges, both theoretical and experimental, in order to recognize the connection between the microscopic energetic structure for matter and the emission of radiation, with particular emphasis in the optical band.

The Model of Educational Reconstruction framed the design of the educational path. Based on limited but significant literature on the interpretation of optical spectra by university and secondary school students, we designed different intervention modules in which interpretative issues are problematized using Inquiry-Based Learning strategies. Using Design-Based Research methodologies, seven different experimentations were carried out, monitoring learning outcomes of 208 students aged 17-18 by empirical research methods.

Keywords: Design-based research, Educational reconstruction, Optical spectroscopy, Physics education research.

INTRODUCTION

Modern physics is considered a key content in majority of EU secondary school curricula, but, nowadays issues concerning modalities, contents, instruments and

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methods to integrate these topics in the well-established teaching praxis are open problems. The current approach is quite often limited to the storytelling of the main crucial aspects and experimental contradictions with classical physics that characterized the beginning of the XX century, rather than an approach founding a scientific culture taking into account the instruments and methods of physics [1].

In the wider framework of modern physics, optical spectroscopy provides the experimental basis of the modern quantum theory and it represents an emblematic context in which physics interprets information to build a model.

A complete and coherent educational path on optical spectroscopy for high school students will be presented here: various experimental activities support the interpretations of microscopic phenomena related to light-matter interaction and actively engage the students, in order to help them develop a functional understanding of the connection between energy levels in atoms and the emitted light.

The proposal aims at overcoming the learning difficulties and preconceptions that literature evidenced.

THE RESEARCH PERSPECTIVE

The starting point for design a research-based educational proposal is the analysis of literature concerning the most common conceptual knots or learning difficulties expressed directly or indirectly, by students on the chosen topic. Difficulties in understanding spectra emerged in both secondary school and university students, and they are related to the connection between spectral lines and atomic levels, and the experimental setting that can produce a spectrum. In particular, students often associate the energy of a specific emission line in a spectrum with the energy of a specific energy level, rather than to the difference between couple of levels [2, 3]. This problem has slightly different aspects: the fundamental level is not considered a level or involved in every transition [4 - 7]. Despite spectroscopic measurements have a pivotal role in astronomy, introductory astronomy students show various kinds of preconceptions and conceptual incoherencies regarding the way in which atoms and radiation interact [8]. Research shows that, in the case of high school students, this is due to a not coherent quantum model for both matter and radiation [10]. University students believe that the energy of radiation is linked to intensity rather than to the colour [9]. Erroneous models have to be tested to highlight strengths and weaknesses in order to build a usable and coherent model describing the phenomenology [11, 12].

According to the theoretical framework of the Model of Educational Reconstruction (MER) [13, 14] the approach for teaching any topic implies that the contents have to be "reconstructed" from an educational point of view. This takes into account several aspects: the main conceptual difficulties have to be analyzed, as well as the main interpretative obstacles as emerged from the historical development of physics. This supports the design of educational sub-phases representing different stages of the educational path, in which active learning strategies produce the overcoming of the conceptual knots and the appropriation of the founding disciplinary elements by means of Design-Based Research (DBR) methods [15 - 18].

THE GENERAL STRUCTURE OF THE EDUCATIONAL PATH

In order to activate an effective learning process, a good starting point is the exploration of students' spontaneous ideas concerning simple observations [19]. The path thus starts considering the sorting of optical phenomena in three huge thematic areas concerning light: production, propagation and matter-interaction. Transmission and refraction show how different points of view are taken into account in describing apparently similar phenomena: in refraction, only the macroscopic change in direction is taken into account, while in transmission the microscopic interactions between light and matter are involved. Presenting different light sources reinforces the interpretation according to which the generation of light implies an energetic transformation (Fig. **1**) inside the source.

Fig. (1). Various types of light sources are shown in the path: a light source is seen as a system able to convert a specific form of energy into radiant energy; thus an energetic transformation is involved every time light is generated.

Students classify different sources according to their spectra: continuous, discrete and banded, using simple cardboard spectroscopes. The role of each part of the

CHAPTER 6

Normal Mode Investigation of a System of Coupled Oscillators: a Physics Lecture

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Abstract: In this work the contents of an academic lecture addressed to first year Physics students on a system of coupled oscillators is presented. More specifically, the physical system dealt is constituted by two oscillating masses interacting through a connecting spring. At first, the theory describing the system dynamics is presented by putting into evidence how the diagonalization process allows to reduce the coupled oscillation equations to formally simpler, but physically equivalent, expressions which make reference to uncoupled oscillations and how the new chosen coordinates do not refer to the positions of the real masses but describe collective properties of the system, namely its normal modes. To facilitate the comprehension of the analytical procedure, an experiment addressed to characterize the system normal mode frequencies is proposed. On this purpose, for analysing the oscillation amplitude as a function of time, a comparison between Fourier Transform and Wavelet Transform is presented. What it emerges is that, differently from what occurs for Fourier Transform which provides a value of the motion average frequency, the Wavelet Transform allows to simultaneously execute a time–frequency analysis.

Keywords: Coupled oscillators, Fourier Transform, Wavelet Transform.

INTRODUCTION

As a rule, to improve the understanding of a Physics topic, it is important to integrate theory with experiments [1 - 3]. Indeed, the process of planning and executing an experiment, which also includes the elaboration and interpretation of data, the formulation of empirical laws (*i.e.* primary model), and the comparison with a theory's outputs, is extremely formative, because it forces the student to be no longer a spectator, more or less passive, but the protagonist of a creative and significant work [4 - 9]. Therefore, the empirical dimension of Physics is a fundamental element of the teaching endeavour and experiments assume relevant

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importance [10 - 15]. For this purpose, one can assert that a scientific theory can only have the scope it has if it is in contact with the real world that proves its validity and significance. Moreover, the scientific construction consists of an incessant, mutual and oscillating connection between the theoretical moment and the experimental moment. A scientific experiment is a procedure that makes a certain effect investigable and analysable in circumstances prepared according to a severed plan and according to certain hypotheses relating to the possible effects [16 - 21].

Therefore, the main purpose of a Physics experiment is specifically to trace a significant didactic itinerary that allows reaching the law of a physical phenomenon starting from a series of measures of physical quantities, detected experimentally during a physical laboratory activity. In other words, the aim is to experimentally research the physical-mathematical correlation existing between some characteristic variables of the phenomenon under examination through inductive procedures that highlight, in a clear and significant way, the empirical nature of Physics [22 - 25]. The experiment is nothing more than a physical study of a phenomenon, obtained by analysing the phenomenon itself in terms of quantitative investigation (Fig. **1**).

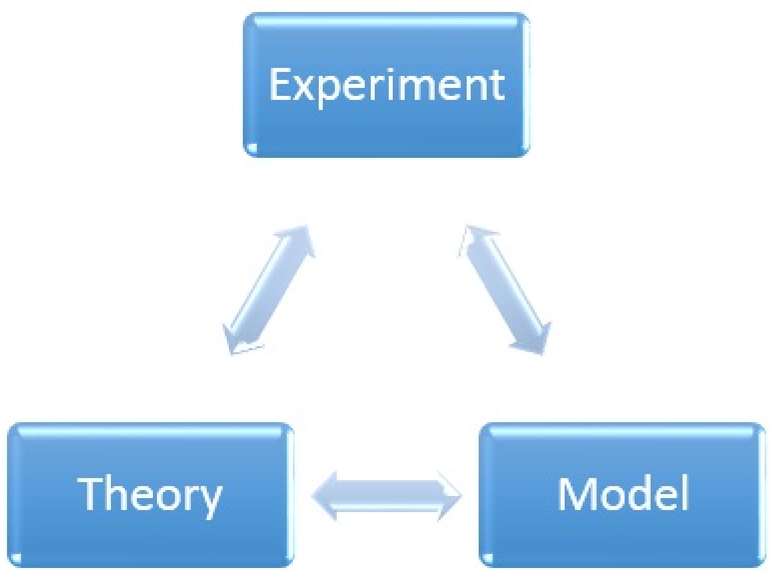

Fig. (1). A sketch of the joint employment of Theory, Experiment and Model.

Within this framework, with the aim of planning a Physics lecture addressed to first year academic students, in the present work, an integrated approach based on joint employment of theory and experiment sections is proposed. The subject of the lecture concerns a physical system constituted by two oscillating masses interacting through a connecting spring.

The developed theory and the experiment are both addressed to characterize the in-phase and out of phase normal modes of system. For this purpose, a comparison of Fourier Transform (FT) and Wavelet Transform (WT) is also presented. It will be highlighted how, FT furnishes only the motion average frequency value, while WT performs a time–frequency analysis [26 - 31]. The advantages and disadvantages of the two analysis approaches are also discussed.

THEORETICAL BACKGROUND

Let's consider two oscillating masses that interact through a connecting spring. The mass values, *m*, and the spring constants, *k*, are identical (Fig. **2**).

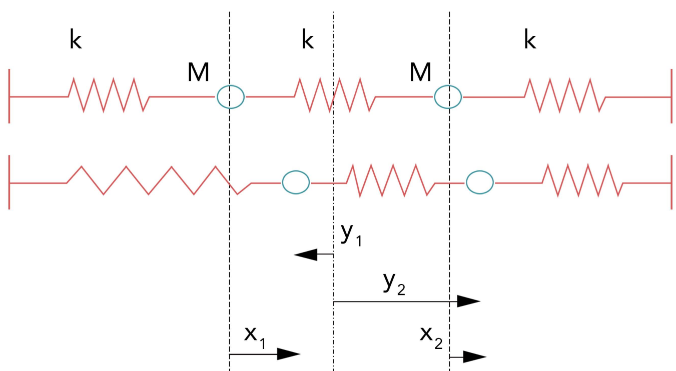

Fig. (2). System of two coupled oscillators.

Let's indicate with x_1 the displacement of the first mass from its equilibrium position, *i.e.* x_1 corresponds to the elongation or the contraction of the first spring (starting from the left); let's indicate with x_2 the displacement of the second mass from its equilibrium position, *i.e.* x_2 is the elongation or the contraction of the third spring [32, 33].

By employing Newton's second law, one can write, starting from Hooke's law [34 - 36]:

$$\begin{cases} m\ddot{x}_1 = -kx_1 + k(x_2 - x_1) \\ m\ddot{x}_2 = -kx_2 - k(x_2 - x_1) \end{cases} \quad \textbf{(1)}$$

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