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Different approaches to research and innovation in physics education at college and university

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Abstract: In this article we report a Symposium organized by GTG-Physics Education Research at University (PERU) with different proposals that includes innovative educational approaches and research on problems of teaching-learning physics at university. In the second section, two research projects are described on teaching specific curriculum topics that present special difficulties for students. In the next section the third project on a work experience in the laboratory that takes into account the characteristics of scientific work, is presented. Finally, the fourth project presents a way to investigate the types of student reasoning. In the discussion, the importance of research projects that include not only conceptual understanding but also those areas such as laboratory work or "on-line physics courses" that involve practicing skills of scientific work, is highlighted.

1. Introduction

The university educational models in science and technology are being analyzed and questioned all over the world. The European Commission on improving the quality of teaching and learning in institutions of higher education [1] advocates the introduction of a new approach to university education that breaks radically with traditional pedagogical methods. Research on Physics Education is not only concerned with the analysis of the process of teaching and learning based on empirical evidence but also with innovation in teaching. Thus we present in this paper both proposal for improving physics teaching at classroom and laboratory and a methodology for analyzing quantitatively the students answers.

The next section presents two studies. The first work is devoted to a problem of teaching/learning in physics that has been long considered -- how to teach concepts and theories of contemporary physics. In addition, the study is situated in a context where students will not be graduates in physics, but are medical and other students. These students should know the fundamentals of contemporary physics to handle technological tools of their own profession. However, teaching and learning these concepts is a challenge for both the teacher and the students. In the study different alternatives and possible solutions are presented, using ICT tools. The second study presents a proposal based on research on the teaching and learning vector calculus in electrodynamics. Many teaching proposals at the University focus on



introductory courses. However, the work presented here focuses on second and third year courses for science and engineering students. They present a sequence of teaching/learning based on the results of students' difficulties. In addition, the proposal is rigorously evaluated in relation to the learning achieved by the students.

In the third section, the context of the classroom is changed by the laboratory. Although there is much literature on how to teach in the laboratory and how students learn, little research has been done at university level. The study presents an organization of laboratory work based on the characteristics of scientific methodology. For using scientific skills, it starts by defining a problem and guiding students in their resolution through the use of scientific epistemic episodes, such as stating of hypotheses, the analysing and measuring variables, and obtaining results. It is about familiarizing students with scientific epistemology. Fourth section presents a quantitative analysis the students' responses. One of the most fruitful lines of research in physics education research has been the analysis of student responses and their consequences for teaching. However, the analysis of the answers has been the subject of numerous discussions regarding the reliability of the analysis and the consistency of the students' responses. These questions are fundamental if one wants to obtain useful conclusions for teaching. Those problems are addressed in this study.

2. Teaching Proposals Focused on Topic-Oriented Demands

2.1. *Twenty Years of Research and Development on Teaching Contemporary Physics to Non-Science Students*

About 20 years ago we accepted the challenge to teach contemporary ideas in physics to a students who normally would not study these topics at the university. In terms of physics knowledge and mathematical abilities, these students are on the opposite end of the spectrum from those students discussed in the other sections of this paper. They are likely to be majoring in almost anything. For example, the most recent course included one business student, two philosophy students, one political science student and one secondary education student in the class.

Introducing contemporary physics to students who are not studying physics in depth has significant challenges. First, actively involving students in teaching and learning is an important conclusion of physics education research. These pedagogical strategies that use hands-on activities can be a real challenge when teaching contemporary physics to anyone and a greater challenge for our audience that has no previous experience with experiments. Second, most of these students do not have the mathematical background to understand the equations of contemporary physics. Our group has addressed these challenges with a combination of simple apparatus, written tutorials, and instructional technology.

Instructional Materials

Our goal is to enable these students to obtain a qualitative and, where appropriate, a quantitative understanding of contemporary physics. When we started, very little material was available to help non-physics students learn quantum mechanics. This lack of teaching/learning materials led us to develop, with significant support from the U.S National Science Foundation, *Visual Quantum Mechanics* [2]. In this set of teaching/learning units, interactive computer visualizations are coupled with hands-on experiences and written instructional materials. Included in the instructional materials are student-centered activities that address a variety of concepts and applications to devices such as the light emitting diode. Thus, we seek to facilitate learning so that a wide range of students begin to understand the basic concepts, implications and interpretations of quantum physics.

In recent years many other developers have created instructional materials that are consistent with our goals. Some of the most notable ones are available from the Physics Education Technology (PhET) project [3] and The Kings Centre for Visualization in Science [4]. We have integrated some of these activities into our efforts as well as attempting to include some short YouTube videos in interactive

lessons. Also, keeping up with the most interesting research has led us to include new topics which are not quantum physics such as gravitational waves.

To motivate the learning of these topics for future medical students, we completed a set of lessons that introduce some applications of contemporary physics to modern medical diagnosis. Topics such as magnetic resonance imaging (MRI) were particularly challenging because of their complex nature particularly in the human body. We addressed these challenges by using hands-on activities that were analogies to the actual application. [5]

Most recently, we have attempted to deliver an online course using many of these instructional developments. This situation has raised new challenges, particularly how to include hands-on activities. We have been partially successful but are still working on maintaining a high level of interactivity. Throughout our efforts we have based the approach on evidence from research.

Research Tools

In developing these instructional materials, we much prefer using the results of other people's research rather than needing to do the research ourself. However, we must do some research. Today, most of the research is focused on the effectiveness of the online course. We conduct clinical interviews and administer conceptual inventories. We draft lessons and go through the learning process. Then, revise the lessons and go through this process again. Sometimes we have to go all the way back and redo our research when it did not seem to work as we anticipated.. However, more often the research results seem good, but the lesson needs some work.

Several learning inventories related to quantum physics are now available. They have been developed for all levels of students ranging from non-science students to graduate-level physics students. These inventories are available in the assessment section of PhysPort [6] by selecting "Modern/Quantum." from the Subject pull-down menu.

Recent results

The online course is divided into four major units.

- Unit 1: Fundamental Forces, Conservation Laws, Photoelectric Effect
- Unit 2: Spectroscopy, Discrete energy levels in atoms, Energy bands & gaps in solids
- Unit 3: Qualitative & graphical quantum mechanics
- Unit 4: Topics in the news: Most recently gravitational waves

Each Unit has 4-10 modules. Each Module begins with a concept map. The modules can be viewed at the Kansas State University course management system Web site [7]

One aspect of the assessment is to select questions from the inventories that focus on conceptual rather than the mathematical aspects of quantum physics. Then, we further select items that are related to concepts that we cover in our course. The result is an inventory that we use as a pre- and post-test. Results of the past two years are shown in Figure 1.

These and other results that we are analyzing indicate that students in the on-line course are learning at least as well as students in the face-to-face course that we have been teaching for a long time. Combining these results with long term assessment from the teaching of others who have used our materials shows that one can successfully teach the basic concept so quantum physics to non-scientists.

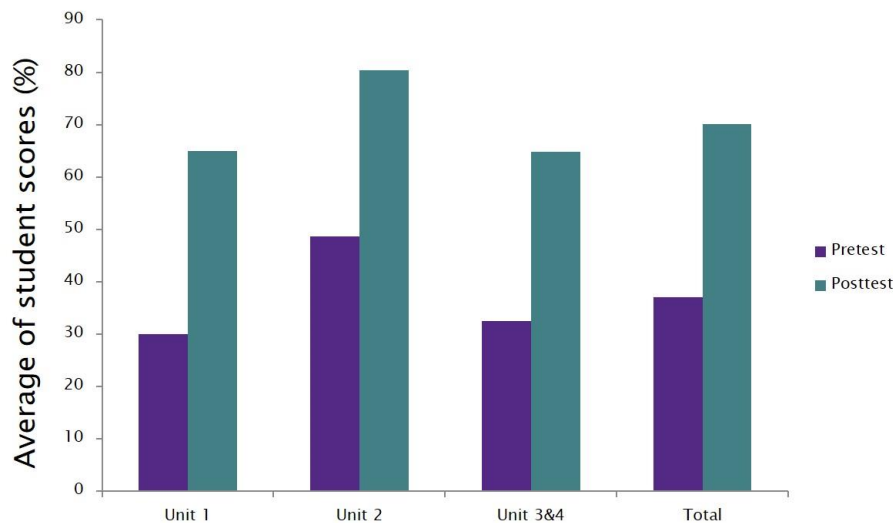


Figure 1. Pre- and post-test results for students in the online course. The assessment questions were taken from validated inventories and were conceptual questions related to quantum physics.

2.2. The development, implementation and assessment of research-based learning materials to improve students' understanding of vector calculus in electrodynamics

The use of mathematics in physics is an important topic in physics education research. Various studies report that students struggle to incorporate their mathematical knowledge in physics, because they focus on equations and calculations rather than on the underlying concepts [8-10]. Such difficulties are also experienced by students who try to make sense of Maxwell's equations in differential form, in which they have to integrate their mathematical knowledge of vector calculus in an electromagnetism context. In this section, we briefly discuss how we designed, implemented, and assessed research-based learning materials to improve students' understanding of vector calculus in electrodynamics.

Research design

At an earlier stage of our research project, we identified student difficulties with vector calculus in mathematical and electromagnetic contexts. We administered a pretest and post-test regarding the use of divergence and curl in an intermediate electrodynamics course at three universities [11,12], conducted individual semi-structured interviews with students who successfully finished the course at KU Leuven [13], and investigated students' abilities to interpret, construct, and switch between representations of vector fields at four universities [14]. Our studies confirmed that most students are fairly well trained in performing calculations with divergence and curl, but lack a thorough understanding of the vector operators. In addition, students seem to struggle with switching between field line diagrams, field vector plots, and symbolical expressions of vector fields, and experience difficulties when trying to interpret visualizations of vector fields in terms of divergence and curl. Moreover, students often fail to correctly apply Maxwell's equations in differential form in situations involving electromagnetic fields. Consequently, we have developed, implemented, and assessed specific learning materials that can help students with the use of divergence and curl in electrodynamics. In contrast to the original instruction at KU Leuven, which consisted of mainly traditional teaching approaches, the intervention uses a tutorial approach that aims to actively engage students. The research aims of this study were:

- to develop research-based learning materials regarding divergence and curl in mathematics and physics contexts;
- to implement tutorials in an intermediate electrodynamics course at KU Leuven that use the designed worksheets, engage students, and evoke student discussions;
- to assess the intervention in both a semi-quantitative and qualitative way:

- to evaluate the effectiveness of the intervention by comparing post-test results with pretest results and findings after the original instruction;
- to determine student opinions about the implemented tutorials.

Design of the worksheets

Based on the difficulties that were identified in our earlier studies, we designed specific learning materials that aim to help students with the use of vector calculus in electrodynamics. In summary, the contents of the worksheets focus on:

- students obtaining a structural understanding of the mathematical entities “divergence” and “curl”;
- interpreting visualizations of vector fields in terms of divergence and curl using conceptual approaches: for example a box-mechanism to decide where the divergence is nonzero¹ or a paddle wheel approach to determine where the curl is nonzero²;
- interpreting, constructing, and switching between field vector plots, field line diagrams, and algebraic expressions of vector fields;
- fields with $1/r^2$ (spherical) and $1/s$ (cylindrical) symmetry, which are exceptional from a mathematical point of view, but very common in electromagnetism;
- a conceptual understanding of Maxwell's equations in differential form, with a focus on the local character of the equations;
- an understanding of the link between different strategies to determine the divergence and curl, in both mathematics and physics contexts:
 - interpreting graphical representations of vector fields in terms of divergence and curl;
 - calculating and interpreting mathematical expressions involving vector operators;
 - applying Maxwell's equations in differential form.

While there are various teaching approaches that could be used when intervening in a physics course, we opted for an approach based on guided-inquiry worksheets. This means that the five sets of worksheets (divergence, curl, Gauss's law, Faraday's law, and Maxwell-Ampère's law) are structured in a way that they guide students through a set of questions that intend to help them with reconstructing their concept images [15], learning various solution strategies, learning to switch between different representations, and linking mathematical entities to physical phenomena. The worksheets can be found online [16] and an instructors' guide is available upon request.

Implementation of tutorials

There are several possibilities to implement the worksheets, but for practical reasons we opted for a tutorial approach in which students discuss the questions in small groups. The intervention took place in an intermediate electrodynamics course during three consecutive years at KU Leuven (2015-2017). In each of these years 20 to 30 physics and mathematics majors were enrolled in the second-year undergraduate electrodynamics course at KU Leuven. All of them have finished an introductory electricity and magnetism course using the textbook by Giancoli [17] leading up to Maxwell's equations in integral form, and at least one calculus course with a chapter on vector calculus, following the textbook by Adams and Essex [18]. The thirteen week electrodynamics course is comprised of one two-hour lecture and 1.5 hours of problem-solving sessions per week, and the contents of the course are based on Griffiths' textbook [19]. While no solutions were given to the students, teaching assistants were present to help students and check their responses for correctness.

¹ An approach based on the divergence theorem: when drawing a three dimensional box in a field vector plot, one can check whether the divergence inside the box vanishes or not by determining the net flux through the box. If the net flux is nonzero, the divergence will be nonzero in at least one location inside the box.

² If a paddle wheel is placed at a certain location in a field vector plot, the curl in that location will be nonzero if and only if the paddle wheel rotates about its own axis.

Assessment of the intervention

To evaluate the effectiveness of the tutorials, we used the same pretest post-test design that was adopted to evaluate learning after the original instruction. The results show that KU Leuven students gained insight in the mathematical concepts divergence and curl, were more successful when interpreting field vector plots in terms of divergence and curl, and generally improved their understanding of Maxwell's equations in differential form. Nevertheless, we do not wish to make the statement that our developed tutorials are the single best way to teach about divergence and curl in an electromagnetic context. However, our results do indicate that most students benefit from a stronger focus on conceptual understanding and the ability to interpret graphical representations. The responses on an informal evaluation document revealed that students generally enjoyed working through the worksheets. In addition, the majority also felt they were challenged, indicated they learned something, and seemed fairly interested to take additional tutorials. While such statements were not always reflected in the results, it shows that our approach engaged and motivated students. Therefore, we encourage instructors to either use the worksheets that we discussed or design their own learning materials based on the information we presented.

3. Teaching and Learning In Physics Laboratory at University

At the two universities in Amsterdam students are expected to participate in a research group as a junior researcher from the end of the second Bachelor year. Therefore students need to start to develop their experimental, academic and communication skills in the preceding years. These skills are trained in multiple laboratory courses offered in the first and second year of the Bachelor's programme. Students learn to mobilize existing knowledge, define a research question, set up an experiment based on a work plan, execute the experiment, keep a lab journal, perform data analysis, develop a critical attitude towards acquired results, formulate a conclusion, and share findings in reports and presentations. Students perform open inquiry experiments in which they need to combine their skills, concepts and cognitive processes to solve problems and become better (junior) researcher.³

In the talk *From student to researcher: developing students' experimental skills under the supervision of a lab assistant in a process lab* we focused on the role of the teaching assistant in the open inquiry laboratory courses. In the first place because the guidance of open inquiry experiments is intensive, but also because we train a total of approximately 850 students a year in ten different laboratory courses at both universities. Therefore teaching assistants, who are themselves students at the end of a Bachelor's degree or in the Master's programme of Physics and Astronomy, play an important role in the guidance of the students throughout a laboratory course. In the talk we shared our experiences with hiring suitable teaching assistants, and we focused on the training and coaching teaching assistants receive beforehand and during the laboratory course.

Profile Teaching Assistant

Running a laboratory course has to be done in a professional way and because the role of the teaching assistant is crucial in the process of teaching and learning in the open inquiry lab, teaching assistants should be selected carefully. This is time consuming, but necessary to keep a high standard in the guidance of the students. Teaching assistants should possess the following characteristics:

- Good communication skills: teaching assistants should have the ability to connect with the students and should be accessible for students. The feedback of a teaching assistant should give students the chance to reach a higher level.
- Strong physics content: teaching assistants should have a proper foundation in physics. They need to have the ability to master the content of the experiment they will guide.

³ The set-up of the laboratory courses at the two universities in Amsterdam is not subject of this section. More information can be found in the proceedings of the GIREP 2016 [20].

- Prepared for the unexpected: teaching assistants should be flexible and not scared to improvise. An open inquiry experiment cannot be prepared exhaustively, if only because the research questions students come up with are not always known beforehand. Therefore a teaching assistant cannot be prepared for every situation that can happen and every question that can be asked.
- Critical reasoning skills: teaching assistants need to be willing to drop the ‘natural’ behaviour to tell students what to do. We want students to play an active role in the laboratory course, and we want them to work towards an answer on their research question. Teaching assistants are present to help students through this process and think along with the students in a critical manner.
- Scientific writing skills: teaching assistants should be able to guide students through the process of writing a report and to give feedback and assess the reports.

Training and Coaching

In the same way students learn how to conduct an open inquiry experiment, teaching assistants need to learn how to guide students throughout the laboratory course. Even though we search for teaching assistants with the described characteristics, training and coaching beforehand and throughout the laboratory course is needed for all teaching assistants.

In the first part of the training prior to the laboratory course, teaching assistants prepare themselves by performing the experiment they will guide during the laboratory course⁴. Most of the laboratory courses are run in parallel sessions, therefore teaching assistants can work in pairs or small groups. This is a big advantage, because they can mobilize their knowledge together and discuss the set-up of the experiment and their findings. Guidance is given by staff members and this is done in a similar way as we expect the teaching assistants to guide the students throughout the course. Four questions play an important role during the execution of the experiment and are discussed thoroughly:

- What is the meaning of ...?
- What do you expect?
- Can you explain your observations/results?
- Can you convince others?

These questions should help teaching assistants to mobilize acquired knowledge and interpret this knowledge in a meaningful way. It also forces them to relate theory to practice by relating laws, concepts, facts and ideas to the (observed) phenomena. They are asked to explain (preliminary) results, which could lead to adjustments in ideas set prior to the experiment. And they pay attention to the reliability and the validity of the research.

The second part of the training prior to the laboratory course focuses on didactics, the way teaching assistants can guide the students in an open inquiry experiment. The power of the four questions mentioned above in the guidance of students is discussed. During this part of the training teaching assistants also work on a didactic framework. In this framework they set goals for the different stages in the process of performing an open inquiry experiment. As a second step, the teaching assistants decide which activities students and assistant need to execute to reach the desired goals. Finally, the teaching assistants decide on how to evaluate these goals. In the process of setting up a didactic framework the teaching assistant plays an active role, because only then it gives them a tool to make well-founded choices and to reflect on these choices in a later stage. Also, in this part of the training guidance is given and good practices are provided by staff members.

Training and coaching of teaching assistants continues during the laboratory course in weekly meetings. In these meetings practical arrangements are made, but more important is that teaching assistants can share their experiences during these meetings and that there is time for reflection and

⁴ Examples of experiments that are offered in the first year of the Bachelor’s programme of Physics and Astronomy are biomechanics, classical mechanics, fuel cell, Michelson interferometer, particle physics, solar cell, solar cooking box, vibrations and waves, spectroscopy, thermal dynamics and wind turbine. Students perform these experiments in 20-25 hours.

feedback on their guidance. These meetings are also used to discuss the assessment of the experimental and academic skills and the written reports.

Conclusion

At the two universities in Amsterdam we show that it is possible to run open inquiry experiments for large groups, but intensive professional guidance is needed to run these experiments in a proper manner. The use of teaching assistants is effective, but they require training and coaching prior and during the laboratory course.

4. Cluster Analysis to Quantitatively Investigate Students' Lines of Reasoning: Theoretical Aspects and Applications.

Many research papers studied students' conceptual knowledge and/or understanding in various fields of physics through an analysis of students' answers to open- and closed-ended questionnaires. Some of these studies examined students' answers in a variety of situations, by using various methods to subdivide samples of students into intellectually similar subgroups to develop detailed models of students' reasoning [21-25]. The problem of separating a group of students into subgroups without any prior knowledge of what form those subgroups would take (unsupervised classification, e.g. [26]) has been studied through Cluster Analysis (*CIA*) techniques (e.g. [27]). In these studies the students of each subgroup are found to be more similar to each other than they are to students not in the subgroup. The authors conclude that *CIA* is an effective method to extract the underlying subgroups in student data and that additional insight may be gained from a further analysis of clustering results. In fact, each cluster can be characterized by means of a careful reading of the typical trends in the answers of the individuals that are part of the cluster.

The research

The research we briefly describe here aims at presenting the use of *CIA* to analyze the understanding of scientific model concept by university students (for more details see [28]). This is done through the analysis of student answers to an open-ended questionnaire investigating the definition of scientific model, its main constituents and its functions. The questionnaire is made up of four open-ended questions, which focus on the understanding of the modeling concept. The questionnaire was administered to 124 freshmen of the Information and Telecommunications Engineering Degree Course at the University of Palermo, during the first semester of the academic year 2013/2014. The students were given the questionnaire during the first lesson of general physics, before any discussion on the model concept had started. Our approach aims at highlighting clusters of students that share representations of scientific model making sense to the researcher. Here, "to make sense to the researcher" means that such representations present a logical coherence and/or have been already described in the literature.

Data analysis

The first steps of data analysis (categorization and comparison of student answers by the researchers involved in the study) involve the analysis of the records representing student answers (the data), in order to reveal patterns and trends, and to find common themes emerging from them. Through comparison and discussion among researchers, these themes were developed and grouped in a number of categories whose definition take into account as much as possible the words, the phrase, the wording used by students [29]. Such categories can be considered as typical "answering strategies" deployed by the 124 students when tackling the questionnaire. Given the inevitable differences among the researchers' interpretations, the researcher lists were compared and contrasted in order to get to a single agreed list of 20 categories to be used for the cluster analysis. The complete list is reported in Battaglia et al [28], where more detail of the procedure and examples of specific student answers are also supplied. Once the categories have been shared and agreed among the researchers, as a second step of the process each researcher read again the student records and assigned to a specific category each student answer

to a given question. So, each student, i , was identified by an array, a_i , composed of 20 components 1 and 0, where 1 means that the student used a given answering strategy to respond to a question and 0 means that he/she did not use it. A 20 x 124 binary matrix (the "matrix of answering strategies"), was produced and further elaborated in terms of the calculation of correlation coefficients and "distances" among students in order to apply the *CIA* techniques, as extensively described in Battaglia et al. [26]

The k-means clustering method [30] was used to study the clusters that can be originated from the data. Besides providing an optimal partition of the sample in clusters, this method defines a new point for each cluster, representing the average position of the cluster elements (the students in our case). Each cluster centroid can also be represented by an array that remarkably contains the answering strategies most frequently given by students belonging to the cluster. In this sense, the centroid can be used to characterize the most "prominent" behaviour of students in the cluster [28].

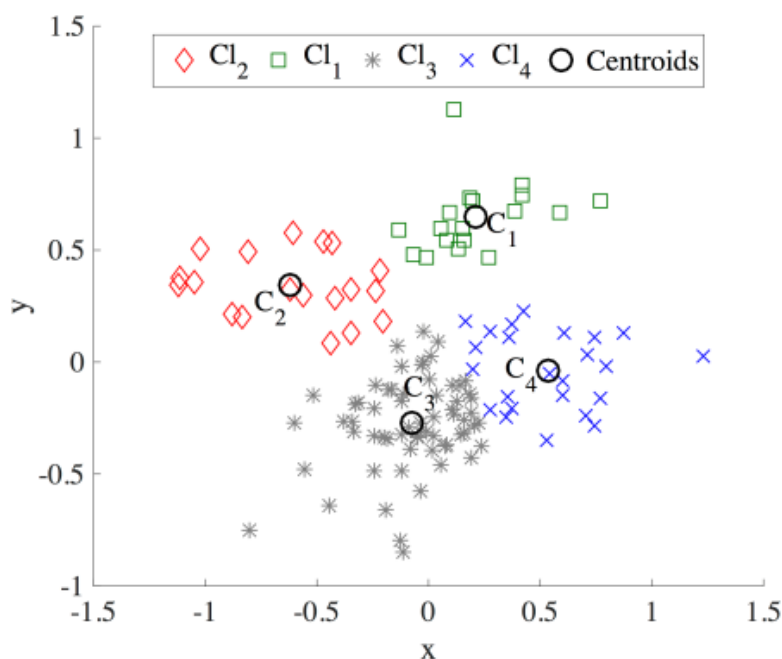


Figure 2. K-means graph. Each point in this Cartesian plane represents a student. Points labeled C_1 , C_2 , C_3 , C_4 are the centroids. Values on the axis are only representative of mutual distances among students.

Results

Looking at the *CIA* results, four clusters have been identified (See figure 2). They are characterized by the related centroids (C_1 , C_2 , C_3 , C_4) as explained above.

In particular, cluster Cl_4 is mainly composed of students that use answering strategies in many aspects similar to those shared by scientific community. Such students show a conception of model similar to that defined by [31] as "General Level 3", i. e. models as multiple representations, models as construction to test ideas or models as explanatory tools. Such ideas are also described by [32] as student relevant ideas in order to understand the role of scientific models in learning science.

Students in cluster Cl_2 show a more naive conception of scientific model. They can be matched to the Level 2 modelers of the classification scheme developed by [33]. Level 2 modelers see models as representations of real-world objects or events and not as representations of ideas about real-world objects or events, but they realize that there is a specific purpose that guides the way the model is constructed.

Students in clusters Cl_1 and Cl_3 do not show a full coherence in their answers, although in different ways. Cl_1 students seem to share with Cl_2 students the ideas concerning the definition of physics models and the modeling process, but they also share their beliefs about the function as well as the characteristics

of physics models with the students from cluster Cl_4 . According to the literature that analyzes student conceptions on modeling in different physics fields we can infer that students belonging to this cluster share a “hybrid” [33] or “synthetic” [34] conception of scientific model by referring to composite conceptions that unify different features of naïve conceptions and scientifically accepted ones.

Students in cluster Cl_3 share the ideas that are not completely consistent with the characteristics typically assigned to the model by an expert or with their same ideas about the modeling process. In fact they declare that a model must contain all the rules or all the laws for a simplified description of reality and/or it must account for all the features of reality and that every natural phenomenon can be simplified in order to be referred to a given model. Their focus on the process of “*simplification*” is also made explicit in the examples they report in order to explain their sentences. For example, many of such students agree that motion without friction is a model, as well as the ideal gas, but do not consider motion with friction or the real gases as models, and explicitly mark them only as really existing situations.

5. Discussion and Final Remarks

Although the teaching approaches presented here are different relating to the teaching strategies that they use, they have similarities. All the teaching materials presented are grounded on the research. They are research informed about students’ difficulties, implementation methodologies, etc. In particular, the research-based materials are proposing Active Learning Strategies as reflective learning (How we know that we know), tutorials or activities to promote scientific skills. The presented teaching approaches develop interactive engagement activities through physics education research that have been embraced by the physics teaching community [35]. The often used term ‘Active Learning’ covers a range of different types of activities from working in groups, individual problem solving and interactions with the teachers and/or their assistants. Interesting differences in the teaching strategies are observed between the proposals. We found that first study uses online materials and simulations for modeling explanations. The second one uses the well known teaching strategy term ‘tutorials’. The laboratory teaching proposal uses the interactions with teaching assistants for giving to students an opportunity to apply concepts, cognitive process and lab skills to set up an experimental investigation to answer questions and solve problems. In conclusion, in all proposals the students have to mobilize acquired knowledge, relate theory to practice and develop scientific communication skills. Moreover, the approaches presented here show evidences that, with the limit of the particular sample, they lead to a better students’ conceptual understanding and an improvement of using scientific skills.

If we put the attention on the evaluation and research tools presented, we can see that they are quantitative or semi-quantitative (pre-test and post-test) and qualitative (semi-structured interviews and teaching/learning interviews). It is a fact that the teaching proposals have to demonstrate that the results presented have the necessary validation and reliability. At this point it is necessary to mention the importance of having methodologies of analysis that allow presenting well-contrasted results. Thus, it is important to investigate new proposals that clarify the analysis of results. This is the fourth project presented. In this study, an inquiry about the significance of model for the students of freshmen of the Information and Telecommunication Engineering Degree was presented. The main objective is to conduct research on the effectiveness and consistency of two quantitative methods of analysis to group students in clusters. This kind of research helps us to use rigorous methodology of analysis when we present the results and, in this way, it is a necessary line of research.

The traditional curriculum approach to physics education often has been focused on the question “What do we want students to know and what do they need to do to know it? The overall goal is acquisition of what scientists know. Very little time is typically given over to examining and discussing the nature of the problem being investigated, to developing higher-level scientific skills, or to exploring the assumptions and beliefs held by the scientist. In this Symposium, different projects have been presented that investigate not only students’ difficulties in understanding concepts and theories, but also in practicing scientific work skills that are necessary for the understanding of scientific models. The

presented projects show the need of physics programs that focus on how scientists work and generate explanations, scientific reasoning skills and the ability to make explanations based on evidence.

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