Research skills development in physics laboratories located in regional headquarters of the Universidad Industrial de Santander, Colombia

E L Castellanos-Leal1, D A Miranda Mercado1, R F Valdivieso Bohórquez1, J H Martínez Téllez1, M J Sánchez Soledad1, A R Lizcano Dallos1, R Ospina Ospina1 and G A Patiño Benavides2

1 Escuela de Física, Universidad Industrial de Santander, Bucaramanga, Colombia
2 Vicerrectoría Académica, Universidad Industrial de Santander, Bucaramanga, Colombia

E-mail: elecasle@uis.edu.co, dalemir@uis.edu.co

Abstract. The Universidad Industrial de Santander developed in 2015 a novel methodology adopting Just-In-Time Teaching, active learning and mediated learning strategies for classical mechanics (Physics 1), electromagnetism (Physics 2) and, waves and particles (Physics 3) laboratories, with a focus on competencies for research formation, aimed at basic cycle engineering students. In 2017, the same methodology was implemented in three Universidad Industrial de Santander regional headquarters located in Malaga, Barbosa and Socorro cities. Initially, a first visit was made to recognize materials and equipment available in each regional headquarters, for the creation of virtual learning classrooms in Moodle platform. Then, in 2018 during a second visit, students and teachers who participated in the process were interviewed and the main difficulties and opportunities that they detected in the implementation were collected, thus allowing the action plan creation that contributes to the continuous improvement in the laboratory experiences.

1. Introduction

In the natural sciences teaching, "laboratory" is the general name that is given to an activity based on observation, tests and experiments done by students, it is difficult to learn to do science or understand science, without laboratories [1]. According to Hurd [2], laboratories’ purpose is to involve learners in logical use of procedures and strategies to demonstrate the scientific theories and laws implications, to provide experience to solve natural questions. Vygotsky explained the relationship meaning between language and action and how students learn in different social conditions [3]. With respect to science learning, Vygotsky's theory suggests that social interaction is crucial for learners to internalize new and/or complex knowledge. The laboratory is the place for a social exchange and ideas exploration; It is in fact a place for personal maturation and cognitive growth. Klopfer [4] emphasized that science teachers have a responsibility to help students understand scientific research nature. However, for most students, and particularly the younger ones, teachers must make a special effort to help them achieve the goal of understanding scientific research. In the past, limitations such as the shortlife equipment, the limited time of the classes for experiments and aspects related to safety and cost decreased the practical experiments effect [5]. Currently, advances in information technology have caused than computers to become a powerful cognitive tool, which extends students' investigative
skills and supports the science learning [6]. Functions provided by learning materials, shared ideas, and online simulations allow the internet to be an effective way to support scientific experiments [7].

At Universidad Industrial de Santander regional headquarters (UIS-RHQs) have recently incorporated a series of teaching-learning strategies for Physics laboratories aimed at training for research competences in students of engineering basic cycle [8]. Basic processes in science such as observation, deduction, measurement, communication, classification and prediction are integrated, with scientific competences processes (identification of variables, construction of graphs, description of relationships between variables, data acquisition and processing, design and analysis of research, and experimentation) to carry out each stage in the problems resolution [13].

2. Methodology
The same pedagogical strategy developed by Miranda and collaborators [4] focused on active learning [14], was used for the development of research competences in students of Physics laboratory belonging to the UIS-RHQs. To carry out this implementation for the first time in Malaga, Socorro, Barbosa and Barrancabermeja, the following methodological phases were established:

2.1. Review of equipment and materials available in the UIS-RHQs’ laboratories
Initially, a series of visits was made in 2017 with the purpose of doing the practices verification and assemblies used in the laboratories of Physics 1, Physics 2 and Physics 3. The material collected was selected and edited to later adapt in the virtual platform.

2.2. Adaptation of digital resources for each UIS-RHQs in the Moodle platform
In the Moodle platform, the digital content (photos and videos) compiled in the previous visits was added. In addition, research projects and worksheets that are necessary for the development of laboratory practices were created. Finally, a laboratories’ agenda was proposed by RHQs, where the work schedule of the laboratory groups is established during the semester. These students carry out the laboratory preparation questionnaires (CPL), reports and final projects [4].

2.3. Analysis of the satisfaction level
Two perception surveys were designed on the project, one aimed at teachers and the other at students who participated in this implementation. The first, focused on evaluating aspects of quality and usefulness of digital resources available on the platform, for the development of laboratory practices focused on research training of Physics students. The second survey for students was also designed with the intention of knowing the degree of satisfaction of the process developed in the first academic semester of 2018, in which the description of the experience in the use of virtual resources adapted to the Moodle platform is requested and its use throughout the course. Additionally, a series of visits were scheduled in each UIS-RHQs during 2018, to support teachers and students on the methodology proposed in the project and the digital resources management. The results of this initial work are detailed below.

3. Results and discussion
3.1. Perception surveys of teachers
The perception survey 2018-1 carried out with 16 physics teachers in whole university, considering that some teachers have groups in Universidad Industrial de Santander (UIS) also have in UIS-RHQs. Results are shown below.

3.1.1. Structure of support videos for research projects. Quality of videos presented in the platform to support the laboratories was associated to several parameters, that must be included in the development practice and that were previously defined. These factors are: presentation of project
objective, a methodology description, image and sound clarity, and usefulness that it represents for students. Perception that teachers have about this didactic resource is shown in Figure 1.

Results reveal approximately 4 points for all parameters associated with quality. Taking into account an evaluation scale between 0 and 5, it can be inferred that teachers consider that some aspects should be improved. Within the suggestions presented are: (i) improve sound quality in some videos, (ii) add support subtitles to identify names of the elements in the laboratory, (iii) give recommendations in the experiences, and (iv) make videos in group to promote teamwork among students. During first semester of 2018, new research projects were made with improved videos, where precisely the changes highlighted by the teachers were required.

3.1.2. Quality and usefulness of laboratory preparation questionnaires (LPQ). In respect of questions quality (see Figure 2), teachers recommended carrying out a review and update process, because they have found with questions that are a little confusing, that generate frustration in students and that are not oriented to demonstrate the basic knowledge of concepts that have been addressed in the theory. For this reason, some corrective actions have been taken to improve questions for second academic semester, collecting each questionnaire from questions banks created in Moodle platform, and supplying them to a teacher group trained in each physics areas, who modified some questions and proposed new ones. Regarding the LPQ usefulness, teachers surveyed mentioned that open questions allowed identifying the students' shortcomings.

3.1.3. Relationship laboratory-theory and development of research skills. Relationship between laboratory and theory should be considered important in physics study and any theoretical and practical subject that involves the research skills development [8,9,10], for this reason teachers were consulted about what so related are these. Although 62.5% of teachers surveyed say that theory with laboratory are complemented very well. They mentioned that theoretical content prior to laboratory has not been seen sometimes, and students attend class very dispersed. But in other cases, where the practice is related to the topics seen in the theory, just by explaining some basic concepts, student reinforces what he has already seen and responds very well during the development and analysis of the experience [11,12].

With regard to training for research, almost 70% say that the methodology is aimed at strengthening the research skills of students. A 18% indicated that in part it does contribute, but many research competencies still need to be stimulated, only 6% affirm that there are competences that can be stimulated and are not treated, and, the remaining 6% consider that the strategies applied are not oriented towards improve this field. Additionally, many teachers said that this strategy allows
generating greater discipline in students and they follow a protocol for reporting results and strengthening group work. In the laboratory, students also learn to write a research report, to study a specific topic using several references, to perform a statistical analysis of experimental results, and to propose a research project in the one that set objectives and a methodology to achieve those objectives.

![Figure 2. Evaluation of LPQ’s quality.](image)

3.2. Perception surveys of RHQs’ students

In Figure 3, results of the question: Do you consider the bases offered by the project sufficient or insufficient to achieve experimental verification of theoretical concepts? carried out to 217 students (in Bucaramanga) (102 of Physics 1, 88 of Physics 2 and 27 of Physics 3) are presented. These reveal that more than 80% of Physics 1 students consider sufficient the bases given in the laboratory to verify the theoretical concepts that the subject involves, equally it happened in Physics 3 with a value close to 80%. Furthermore, in Physics 2, students didn’t consider the verification of physical phenomena with the theory to be as relevant, almost 10% less than in the case of Physics 1.

Approximately 20% of surveyed in Physics 1, mentioned that they don’t have problems with the laboratory practices execution. However, some difficulties were encountered with assembly and data collection, often related to the short time for practice execution. On the other hand, another group said that the greatest difficulties are in data analysis and error calculation, due to the great uncertainty generated by the laboratory elements and equipment.

Figure 4 shows the response of: Which of the following parameters caused difficulties in making the laboratory report? in the group of 102 Physics 1 students, it is mainly stated that more than 50% experienced difficulties in the handling of error obtained from experimental data compared with theoretical data and in subsequent results analysis, in addition 50% consider that graphs elaboration is also a critical factor that must be explained a bit more by teacher or within material provided on the platform. Physical principles understanding and reports writing present the lowest percentage of difficulty, 9 and 22% respectively, while conclusions construction and presentation of results are at an intermediate difficulty level (28 and 32% respectively).

As in Physics 1, a percentage close to 22% of Physics 2 students mentioned not having difficulties in performing laboratory practices, the rest of students indicate that they have presented problems in the assemblies’ preparation, data acquisition and analysis of results. Physics 2 students stated that the greatest difficulty was presented in error management, data analysis and graphs elaboration. On the other hand, in the case of Physics 3, students affirm that the most common mistakes are made in the assembly and data acquisition, some assemblies are very complex and results obtained are difficult to interpret, so it is necessary to spend more time explaining methodology and equipment calibration.

In general, students recommend improve the videos quality presented on the platform for a better understanding of what should be developed in the laboratory, including programs to graph the results along with some tips to avoid making mistakes when making laboratory reports. Students consider that resources offered are good, however, in some cases the videos don’t explain the process very well, and they would like to include videos or instructions on the operation of each element that will be used in the laboratory.
3.3. **Implementation of the methodology in the UIS-RHQs**

There are some factors that made it difficult to start the implementation of consolidated methodology. In the first place, the same laboratory equipment was not available and, the number of elements required aren’t enough. In this year, two of the four regional headquarters (Malaga and Barrancabermeja) already have the same laboratory equipment as in the central headquarters, which makes it easier to articulate the research projects carried out by the students.

However, Socorro and Barbosa still don’t have the same elements or assemblies. An “in situ” visit was made, and laboratory practices were verified with the intention of adapting the didactic contents (laboratory guides, videos and photographs) on the platform and thus starting with the implementation of the methodology in the proposed work schedule for the subjects. During the visit to Malaga, some inconveniences were identified in the laboratories logistics, in spite of having new equipment identical to those used at the headquarters. Table 1 summarizes the problems encountered with the group of teachers and the possible solutions proposed to each one.
Table 1. Problems and solutions identified in the Physics laboratories in Malaga.

| Problems                                                                 | Solutions                                                                 |
|--------------------------------------------------------------------------|---------------------------------------------------------------------------|
| a. The practices are not established by elements.                        | a. Hire 2 or 3 assistants to help with the assemblies.                     |
| b. There are assemblies that are made in the same laboratory and require a lot of care and logistics to carry them out. | b. Define mounts and responsible teacher.                                  |
| c. Laboratory sessions very close that don’t allow enough time to put together some complex assemblies. | c. Define class times before the start of the semester that consider the preparation of each session. |
| d. Lack of better organization and storage of equipment.                 | d. Define a storage strategy by headquarters, before and after each part of the assembly (reference and photo) and create a laboratory role for the training in "School of Trainers". |
| e. Missing recommendations on the use of equipment.                      | e. Include recommendations, limits restrictions on the use of laboratory elements in the worksheets. |

Problems identified in UIS-RHQs, were addressed one by one, from the logistics of laboratories until digital resources improvement (videos and assemblies’ photographs), with the purpose of being passed and delivering an improved version in the following semester.

3.4. Perception of the implementation by students of the Regional headquarters

Although the number of students surveyed in the UIS-RHQs were lower than Bucaramanga, many similarities could be found in the project perception. The students also suggest that more videos with higher quality should be added for the laboratory development, where objectives and methodology of the research project were more explained clearly, they also insist that more laboratory elements are required.

4. Conclusions

To improve the coordination of each practice developed in the laboratory, we have been working together with the theory and laboratory teachers in a teacher improvement program called "School of trainers", focused on providing teachers with the aspects pedagogical, didactic and practical in the development of the subjects intervened with the proposed methodology. In this space, the pedagogical concepts application linked with the development of the laboratories is analyzed critically: active learning, Just-in-Time Teaching (JiTT) and the mediated learning. It has also been possible to recognize quality parameters for audiovisual resources development and identify the processes necessary for the organization of evaluation instruments, in the context of the proposal.

In the physics laboratories, some research training activities are carried that include the projects execution. These research projects extend the students’ perspective because allow them to strengthen research competences based on active and mediated learning strategies. An increase of students’ autonomy, greater command of concepts, tools and methodologies required to carry out the experiences, and reports of the executed projects preparation were observed; the reports are made in scientific journal formats.

Acknowledgments

We are grateful to Academic Vice-rector and Physics School UIS for support the ExperTIC project, teachers and students of the laboratories that participate in this wonderful experience.

References

[1] Trumper R 2003 Science and Education 12 645
[2] Hurd P D 1969 New Directions in Teaching Secondary School Science (Chicago: Rand McNally)
[3] Vygotsky L S 1978 Mind in Society (Cambridge: Harvard University Press)
[4] Klopfer E L 1990 Learning Scientific Enquiry in the Student Laboratory Hegarty-Hazel E(ed) (London: Routledge)
[5] Kun Yuan and Jian Sheng 2007 J Sci Educ Technol 16 451
[6] Chia-Yu Liu et al 2017 Computers and education 105 44
[7] Sufen Chen et al 2012 Physical review special topics Physics education research 8 020113
[8] Miranda D A, Sanchez M J and Forero O M 2017 J. Phys Conf. Ser. 850 012015
[9] Hodosyova M, Ubra J, Vanyova M, Vnukova P and Lapitkova V 2015 Procedia - Social and Behavioral Sciences 186 982
[10] Murat A, Gokce A, Huseyn M P and Mehmet A O 2016 Computers in Human Behavior 57 334
[11] Jingyin W, Donghui G and Min J 2015 Computers in Human Behavior 49 658
[12] Wilcox B R and Lewandowski H J 2017 Physical review special topics. Physics education research 13 010108
[13] Tristancho J A, Contreras L E and Vargas L F 2014 Educación y desarrollo social 8 28
[14] Novak G M, Patterson E T, Gavrin D and Christian W 1999 Just-in-Time Teaching: Blending Active Learning with Web Technology (New Jersey: Prentice Hall)