Innovation Strategies to Develop Specific Professional Skills on Photovoltaic Systems using Laboratory experience guides: Technologies and Sustainability Education

Estrategias innovativas para el desarrollo de habilidades específicas en sistemas fotovoltáicos usando guias de experiencias de laboratorios: Tecnologías y educación sustentable

Adalberto OSPINO-CASTRO 1; Jorge Iván SILVA-ORTEGA 2; Yecid MUÑOZ-MALDONADO 3; John Edwin CANDELO Becerra 4; Mario MEJIA-TABOADA 5; Guillermo VALENCIA-OCHOA 6; Samir UMAÑA-IBAÑEZ 7

Recibido: 30/05/16 • Aprobado: 15/06/2016

Contents

ABSTRACT:
The use of new strategies for develop professional skills on photovoltaic systems was designed as result of integrated cooperation between universities and research groups that work in the development of tools to implement an academic program for using solar energy. This paper covers the proposed outcomes that will be achieved during the application of activities, an introduction to the concepts that are considered, the methodological process that is applied, and activities that promote independent work by the students using experiences guide applying photovoltaic systems. There are used during the teaching process preliminary questions to assess the understanding of the concepts and objectives considered. As a result, students will design a final report to validate the outcomes completion. These strategies search the development of skill through courses, gaining as result a solid experience in research aimed to develop photovoltaic technologies as classroom activities in order to keep a sustainability of the program. This paper presents an example of a practice guide called "Characterization of Photovoltaic Cell with Artificial Lighting and Natural Lighting" in order to present the structure and explain the cognitive process, allowing the assimilation of knowledge. The strategies were designed to stimulate interaction with a real environment, with a focus on validating theories and models focusing on the application of photovoltaic systems including developmental educational model; for this reason, there

RESUMEN:
El uso de nuevas estrategias para desarrollar competencias profesionales en el manejo de sistemas fotovoltaicos fue generado como resultado de una cooperación integrada de universidades y grupos de investigación que trabajan en el desarrollo de herramientas para implementar un curso que promueva el uso de energía solar fotovoltaica. Este artículo realiza la descripción desde las competencias a desarrollar durante el desarrollo de las actividades, la introducción a los conceptos considerados, el proceso metodológico aplicado y las actividades que promueven el trabajo independiente por parte de los estudiantes. Las preguntas iniciales buscan identificar conceptos y objetivos de las actividades a desarrollar, como resultado el estudiante desarrollará un reporte final que valide el cumplimiento de los logros obtenidos. Estas estrategias buscan el desarrollo de competencias, permitiendo la obtención de una experiencia inicial en investigación en el área de tecnologías para sistemas fotovoltaicos, generando así una actualización de los contenidos para los siguientes cursos, propiciando el concepto de educación sostenible. Este articulo presenta un ejemplo de una de las guías como estructura para explicar el proceso cognitivo descrito en donde se evidencia como se logra la asimilación del conocimiento por parte del estudiante. Las estrategias fueron diseñadas para estimular la interacción con el medio real y generar un enfoque en la validación de modelos y teorías aplicados a sistemas fotovoltaicos involucrando el modelo desarrollista bajo el cual concibe

are promoted new ideas for education in the area of photovoltaic systems considering the implementation of sustainable energy and increasing the scope of engineering education.
Keywords: Photovoltaic systems; sustainability; outcomes; independent work; sustainable energy

el desarrollo de la guía. Finalmente el objeto de las guías busca generar nuevas desde la educación alrededor del tema de sistemas fotovoltaicos, considerando la implementación del concepto de energía sostenible, lo cual incrementa el campo de acción de la educación en las áreas de ingeniería.
Palavras-chave: Sistemas fotovoltáicos; sostenibilidad; productos; trabajo independiente; energía sustentable

1. Introduction

Laboratory experience guides have been useful tools in engineering education since the earliest days of engineering education, and instructional laboratories are an important aspect of undergraduate programs. Also, many applied cases from graduate students are covered in laboratory cases. These experience guides help students reinforce the theoretical process, and they include discussions and strategies for solving applied problems (Huntzinger, Hutchins, Gierke, & Sutherland, 2007). Many experience guides require a structured process in order to meet all the requirements for the students, because in many cases they are based on the principle of self-education (Vivas & Allada, 2006). The aims of practical activities fall into four broad groups (Edward, 2015):

1. *Cognitive learning*: Integrate theory with practice.
2. *Inquiry methodology*: Include initial questions, hypothesis, experimental design, and methodological process developed during practice and the evaluation process.
3. *Vocational aims*: Include awareness of current practices.
4. *Professional skills*: Evaluate the development of students in communication, report writing, and working in groups.

It is useful to identify three types of engineering laboratory practices: developmental, research-oriented, and educational. The classification is based on the expected achieved objective. Engineering laboratories are useful because students require experimental data to be analyzed, and the laboratories will guide them in the design and development of a product or process. Developmental laboratories are used when it is required that students understand a cyclical process, as is the case of electrical engineers; for example, to understand the process of electrical energy generation (Diantong, Weiping, & Liping, 2010). However, students do not only need to know the process, they also need to understand broader knowledge that can be generalized and applied. In these cases, a research-oriented laboratory is required. An example is mentioned in the application case of the power-flow algorithm (Blanco Solsona, 2012). Finally, there is also an educational process in undergraduate programs, as is the case in the accreditation process in universities. It requires academic support to provide tools to students in order for them to achieve their desired professional outcomes (Speich, McLeskey, Richardson, & Gad-El-Hak, 2004). An educational laboratory can be a guide to understanding processes and pedagogical tools to be considered during the processes (Feisel & Rosa, 2005).

In Colombia, renewable energy applications have become a priority and a new policy since the establishment of Law 1715 in 2014 that promotes the development and use of renewable energy sources integrated into the Colombian power market. According to (Mantilla Gonzalez, Duque Daza, & Galeano Ureña, 2008), 78.5% of the energy generation process in Colombia is derived from conventional renewable energy based on hydroelectricity. According to (Congreso de Colombia, 2014), the use of unconventional renewable energy that aims toward the development and use of renewable energy-oriented public policies has the purpose of establishing a legal framework, giving the instruments for increasing the use of clean energy sources, and promoting investment, research, and technological development.

The undergraduate program of electrical engineering at Universidad de la Costa - Colombia, has been developing a survey process with a group of researchers from the Research Group on Energy Optimization (GIOPEN), supported by integrated cooperation between universities that work on the development of tolls to implement an evaluation program to use wind and solar energy. This educational process seeks methods of sustainable development that are focused on the benefits of using renewable energy in order to prepare professionals with skills aimed at solving technical, regulatory, economic, financial, and social problems that involve the use of renewable and unconventional energy (Healy, Smestad, & Gonzalez, 2013). It is expected that the students will gain the professional skills to develop elements, guide research, produce systems, and implement processes based on renewable energy (Balbis Morejon, 2010).

In Colombia, this guide is a novel tool because, according to the bibliography search and state-of-the-art literature reviewed, there are no developed methodological guides based on photovoltaic systems considering the strategies of a developmental educational model.

2. Method

Laboratory experience development takes into account the use of conventional and modern learning theories. John Locke proposed that students must complete applied assignments during undergraduate courses, and at the end of XIX century, these were included as an integral part of science curriculums in England and the United States (GEE & Clackson, 1992); (Layton, 1990); (Lock, 1988). Since then, laboratory experiences have been maintained as a tradition in the practical work of science teaching and applied courses (Barberá & Valdés, 1996).

Different types of models have been used to structure laboratory experiences. In schools of engineering, the laboratory experiences have produced an evolutionary process based on the pedagogical model used and the perspective considered during the undergraduate students' learning process (Ruiz & Francisco, 2008). The design of laboratory experiences considers four models: transmission and reception, process-focused, autonomy, and constructivist. These models have been used for years to support case studies and practical experiences such as those presented in (Crespo & Vizoso, 2001), (Korzenowski, Dall'Angol, & Silva, 2016).

The transmission and reception modelconsiders applied cases during the development of a laboratory experience to support the theory learned in classes. Instruments and elements are used to acquire skills in their use. The model always includes a step-by-step process suggested by the professor in order to support the theory.

However, the transmission and reception model does not provide the student a chance to analyze or reject the process. This is in contrast to the autonomy model, where students must arrive at their own discoveries of laws and facts. The autonomy model is explorative and focused on theoretical principles, but it does not include an organized structure to overcome problems. For that reason, it can be considered flexible. This model does not consider important to acquire specific knowledge (Silva de Oliveira & Dirceu , 2016).

The process-focused model is centered on the scientific method and its elements, such as observation, classification, hypothesis, and results. On the other hand, the constructivist model integrates the application of experiences in applied cases, and its use creates a link between the student and the professor in order to support criteria required for a quality process and specific knowledge.

In contrast, (Vivas & Allada, 2006) describes the levels of the learning identification process in engineering using thematic case-based learning as proposed by Benjamin Bloom in 1956. The levels of learning identification are: knowledge, comprehension, application, analysis, synthesis, and evaluation. In this experience manual, we also use Bloom's learning taxonomy to develop experiences, and it will be considered in the application cases of renewable energy and their interaction with elements and systems used in real situations. The laboratory includes elements such as those shown in Figure 1 and Figure 2.

Figure 1 . Renewable energy laboratory.

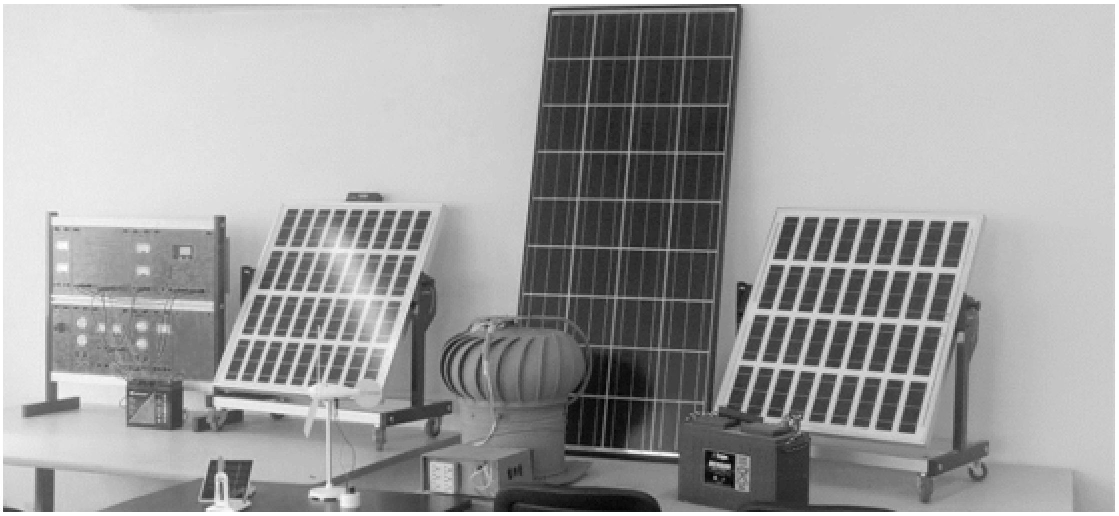


Figure 2 . Typical elements used during laboratory experiences.

The models structure the contents of the laboratory experiences based on the process-focused model and the constructivist model, seeking to strengthen the scientific method and applied research to enable students to acquire the tools that will allow them to provide solutions using photovoltaic systems and to achieve their desired professional outcomes as engineers (Amante, Martinez-Martinez, Cadenato, Gallego, & Salan, 2011).

Title:The title focuses the students on the topic reviewed during the experience.

Introduction:A general review of the concepts is given, and the objective of the experience is stated in order to give the student reasons to complete the activities and introduce the knowledge that will be learned during the process.

1.1 ELECTRICAL MEASUREMENTS IN PHOTOVOLTAIC SYSTEMS
1.1.1 Introduction
Photovoltaic technology has been applied since the aerospace industry through the implementation of photovoltaic panels. Since then, their evolution has become an alternative to supplying electrical energy. Taking as reference, sunlight, without the impediment of the atmosphere and its high relation between powers versus weight, enable the optimal functioning of these devices. The increasing demand for renewable energy led to the manufacture of solar cells and photovoltaic installations and technology. Since then, the technology has advanced considerably during the last few decades. Panels are composed of interconnected cells (Figure 1) and they are used in order to power electrical equipment such as houses located in remote areas.

Figure 3. Introduction to concepts and objectives developed in the experience.

Previous knowledge:Lists the concepts that the students should already know in order to achieve all the objectives of the experience. This previous knowledge can be based on previous experiences, possible concepts, and initial questions that guided the students to make a previous survey of the topic.

Outcomes and objectives: Outlines the skills that the students will acquire and the knowledge that they will gain focused on the use of photovoltaic systems (McCowan & Knapper, 2002).

Concepts and theories: Introduces the terms, elements, systems, and procedures used, and mentions applications in the development of theory in photovoltaic systems. This is not a brief summary, and it is focused on supporting the students during the experience. If the students require more information, bibliographical references that the students could use to gather more information or complement the theory are also provided.

1.1.2 Theories
1.1.2.1 Photovoltaic systems
Solar panels based on photovoltaic technology are a set of elements with an electrical connection of photovoltaic cells in an aluminum framework with polymers sheets and a front cover made of tempered glass [1], [2]. The tempered glass protects the disposal of the collecting cells from external agents. They are easy to transport and install [2]. The absence of moving parts indicates a minimal maintenance, durability, and high reliability during operation [3]. These qualities allow manufacturers to provide an extensive guarantee on devices and improve efficiency over a period of up to 25 years [4],[5].

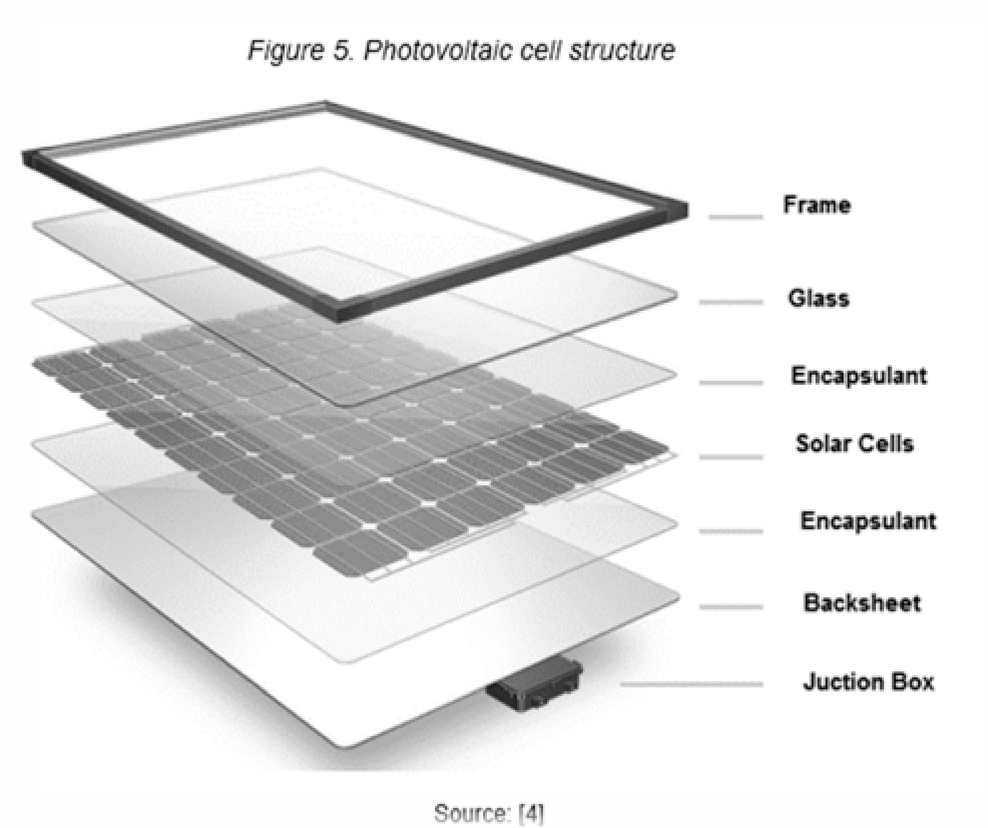


Figure 4. Example of concepts and theories required in the experience guide.

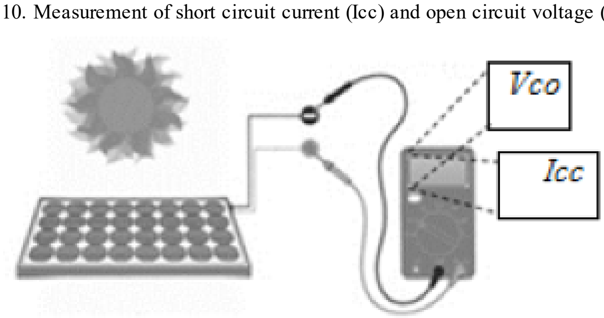
Experience description: The procedure to complete the laboratory experience using the required elements is described. This explains the process to gather information and use the graphs and tables suggested, and it is condensed into a guide that allows students to finish the practice (McCowan J. D., 2002). During the process, it is suggested that the students record observations in order to provide feedback to improve the experience, including the use of new tools and processes.

1.1.3 Experience description

1.1.3.1 Measurement of variable

Determine the operation of a photovoltaic cell through the measurement of short circuit current (Icc) and open circuit voltage (Vco).0

Figure 10. Measurement of short circuit current (Icc) and open circuit voltage (Vco).



1.1.3.2 Guide to measuring variables

Figure 5. Example describing the experience.

Results and tables:Tables are included in this section and their use is required during the information-gathering process. Using analysis similar to that explained in concepts and theories is suggested.

1.1.5 Results

Fill in the following table with the gathered information. Based on variables, the operational parameters of photovoltaics in the different inclination angles can be determined. Use this information in order to estimate draft angles. After that, calculate the efficiency and the form factor in all cases. Use the information to plot current vs. voltage and power vs. voltage, and describe the relation between them.

1.1.5.1 Measurements of the fundamental parameters:

Table 5. Test data from PV panel.

Time	Cell measurement	Radiation [W/m²]	Temperature [°C]	Voltage [V]	Current [A]	Draft angle [°]	Power [W]	Efficiency [%]
:	Open circuit voltage [Vco]					0		
:						30		
:						60		
:						90		
:	Short circuit current [Icc]					0		
:						30		
:						60		
:						90		

Figure 6. Results and tables.

Applied research:In this section, the students are asked to develop a survey using the scientific method with the aim of developing new projects based on photovoltaic systems. This will promote the growth of this line of investigation and the origination of theses for graduate and undergraduate students.

Conclusion and recommendations:The section is divided into two parts. The first part considers the conclusions of the guide. Students describe the outcomes reached in conducting analyses and comment based on the results they obtained during the process. The second part describes the results achieved by asking students if the outcomes proposed were achieved and the required skills were gained. Finally, it is suggested that they give feedback on the guide in which they explain any problems noticed during their experience and how they achieved the solution, in order to improve the guide’s practices for future students (Huntzinger, Hutchins, Gierke, & Sutherland, 2007).

1.1.6 Results and conclusions

Based on the experience, very briefly revisit the most important findings, giving suggestions for improvements and recommendations for future works, including for the experience book, and express a final judgment on the importance and significance of the information."

Figure 7. Analysis and evaluation of results.

References: Includes all the references used to gather the previous knowledge, concepts, and theories, and the description of the experience.

3. Structure and Outcomes

The laboratory experience manuals are organized into four chapters based on assessment tools to evaluate outcomes (Martinez, Olmedo, Amante, Farrerons, & Cadenato, 2014). The first chapter is an introduction to working with renewable energy using photovoltaic technologies; basic concepts are given that will be developed in the following chapters and sections of the book. The second chapter describes the structure of photovoltaic technologies and is aimed at measuring the characteristics of the system and the scheme of the electrical connections required. The third chapter introduces photovoltaic systems and focuses on the design of schemes of solar panels, batteries, and invertors. The last chapter explains mathematical models applied to photovoltaic technologies and is centered on panel modeling, DC–AC inverters, and DC–DC converters. Table 1 describes the structure of the book, including chapters and sections.

Table 1 . Structure of the laboratory experiences book.

Chapter 1. Introduction to solar energy

Characterization of photovoltaic cells with artificial and natural lighting. Parameters of photovoltaic cells. Serial, parallel, and mixed connections of photovoltaic cells.
Chapter 2. Photovoltaic traits
Electric measures in photovoltaic systems. Electrical characteristics. Electric connections.
Chapter 3. Photovoltaic systems
Design of photovoltaic solar arrays. Battery design. Application of photovoltaic technology in pumping systems. Application of photovoltaic systems in lighting.
Chapter 4. Mathematical models in photovoltaic systems
Solar panels. Invertors: DC–AC. Converters: DC–DC.

As is expressed in (Ponza, y otros, 2009), the laboratory experiences book focuses on strengthening skills to manipulate and operate photovoltaic systems in order to provide students with the following learning outcomes:

1. Ability to understand concepts, theories, and operation.
2. Identify types of photovoltaic systems implemented and the elements required during their operation.
3. Recognize characteristics, properties, and their impact on energy conversion processes.
4. Propose applications and projects using renewable energy.
5. Acquire theoretical and practical tools.
6. Design and propose renewable energy systems, including photovoltaic systems and their elements.
7. Ability to develop mathematical models.

4. Evaluation process

The evaluation process must consider methodological strategies and the learning process developed with the objective of demonstrating student improvement, taking into consideration that the evaluation process must demonstrate the use of applied tools that show the application of the developed topics (Castiblanco & Vizcaino, 2008).

Students evaluated the experience guide on photovoltaic systems to determine if the book could achieve the learning objectives, focusing on the subject of renewable energy outcomes. Based on (Osorio Garcia, 2014) and the successful experiences described in (Zamora Musa, 2011), the evaluation format includes ten structured components: 1) clarity in objectives, 2) coherence in objectives, 3) methodical process, 4) use of applied tools, 5) coherence with renewable energy courses, 6) clarity of experience, 7) experience level, 8) contents of the guide, 9) bibliography and references, and 10) evaluation process.

The components to evaluate were designed for students based on (Hung, Choi, & Chan, 2003), and the procedure and evaluation process were applied when students finished the course on renewable energy. The range of the responses for each component ranged from “1” (very negative) to “5” (very positive). Sixty-seven students evaluated the guides during the first year of the renewable energy course. Table 2 shows the descriptive statistics for the evaluation process applied.

Table 2 . Descriptive statistics of evaluation.

No.	Component	Mean	Std. Deviation
1	Clarity in objectives	4.81	0.88
2	Coherence in objectives	4.03	1.78
3	Methodical process	4.20	1.70
4	Use of applied tools	4.05	1.61
5	Coherence with renewable energy course	4.90	0.10
6	Clarity of experience	4.90	0.10
7	Level of the experience	4.15	0.50
8	Contents of the guide	4.60	0.72
9	Bibliography and references	4.50	1.60
10	Evaluation process	4.70	0.92

The mean value of the experience book evaluation by students gave a total grade of 4.48, taking into account that the maximum grade is 5.0. Results show an acceptable grade to the university and the group of researchers in the renewable energy area. They will be used to improve the experience with other courses to be in keeping with the continuous improvement process and to respond to professional skills in multidisciplinary scenarios (Ponsa, Román, Arnó, & Peréz, 2015).

It is important to note the role of the professor in the evaluation because of the application of real-life measurements and cases that allow the students to achieve the outcomes of the course (McGourty, et al., 2002), (Molina Freitas, 2015). The objective of the evaluation sought to assess what students learned from the practice. In the conclusion of each guide and in the final report provided by the students, there must be evidence of what they learned and an explanation of how they found the experience (Huntzinger, Hutchins, Gierke, & Sutherland, 2007).

---

5. Conclusions

Results show that the Photovoltaic Systems Laboratory Experience Manual is designed to be a helpful tool that allows students to identify the application of theoretical concepts with practice, providing a better result in student grades and outcome achievement. Results show that students can learn the procedures and use elements described in the experiences easily. They are also guided to identify advantages and applications in real cases giving them the skills to design and develop system in order to promote sustainability in their communities.

To improve the experience laboratory with every course, we are working on the aspects of the test that are under 4.5 (mean grade), such as objective coherence, methodical process, use of applied tools, and experience level.

The aim to develop new strategies were based in the requirement of the industry and communities to have engineers formed in applied areas and able to design novel and new systems and business (Moreno Gomez, Gomez Betancourt, & Betancourt Ramirez, 2016), making a change in the traditional education. For this reason, there are promoted new ideas for education in the area of photovoltaic systems considering the implementation of sustainable energy and increasing the scope of engineering education.

Finally, as a successful result of the experience guide, the group is focused on designing a specific course to teach photovoltaic systems and promote the newest area of research called Strategies to Teach Renewable Energies.

References

Amante, B., Martinez-Martinez, M., Cadenato, A., Gallego, I., & Salan, N. (2011). Applied Scientific Method' in the Laboratory. *International Journal of Engineering Education, 27*(3), 559–570.

Balbis Morejon, M. (2010). *Caracterización Energética y Ahorro de Energía en Instituciones Educativas.* Barranquilla: Educosta.

Barberá, O., & Valdés, P. (1996). El Trabajo Práctico en la Enseñanza de las Ciencias: Una Revisión. *Revista Enseñanza de las ciencias*, 365-379.

Blanco Solsona, A. (2012). CIPFP Remote Laboratories in Valencia Vicente Blasco Ibáñez. *International Symposium on computers in Education (SIIE)*, 29 - 31.

Castiblanco, O. L., & Vizcaino, D. F. (2008). La Experiencia de Laboratorio en la Enseñanza de la Física. *Revista Educación en Ingeniería*, 68 - 74.

Congreso de Colombia. (2014). *Ley 1715 de 2014.* Bogotá.

Crespo , E. J., & Vizoso, T. A. (2001). Clasificación de las Prácticas de Laboratorio de Física. *Pedagogía Universitaria*, 2-8.

Diantong, L., Weiping, G., & Liping, X. (2010). Exploration and Practice of Specialized Laboratory Construction and Innovative Talents Cultivation. *2nd International Conforence on Education Technology and Computer (ICETC)*, 244 - 247.

Edward, N. S. (2015). The role of laboratory work in engineering education: student and staff perceptions. *International Journal of Electrical Engineering Education*, 11- 19.

Feisel, L. D., & Rosa, A. J. (2005). The Role of the Laboratory in Undergraduate Engineering Education. *Journal of Engineering Education*, 121 - 130.

GEE, B., & Clackson, S. G. (1992). The Origen of Practical Work in the English School Science Curriculum. *School Science Review*, 79-83.

Healy, T., Smestad, G. P., & Gonzalez, J. (2013). A Project-Based Interdisciplinary Program in Sustainable Energy. *Interdisciplinary Engineering Design Education Conference*, 148-152.

Hung, I., Choi, A. C., & Chan, J. (2003). An Integrated Problem-Based Learning Model for Engineering Education. *An Integrated Problem-Based Learning Model for Engineering Education, 19*(5), 734-737.

Huntzinger, D. N., Hutchins, M. T., Gierke, J. S., & Sutherland, J. W. (2007). Enabling Sustainable Thinking in Undergraduate Engineering Education. *International Journal of Engineering Education, 23*(2), 218-230.

Korzenowski, A. L., Dall'Angol, M., & Silva, G. (2016). Production engineering in northern Brazil: The teaching skills of course coordinators. *Espacios, 37*(12).

Layton, D. (1990). Student laboratory practice and the history and philosophy of science. *The student laboratory and the science curriculum*, 37-59.

Lock, R. (1988). A history of practical work in schools and universities: structures and strategies still largely unexplored. *The Australian Science teachers Journal*, 31-39.

Mantilla Gonzalez, J. M., Duque Daza, C. A., & Galeano Ureña, C. H. (2008). Distributed generation scheme analysis as an option for colombian electrical system. *Rev. Fac. Ing. Univ. Antioquia*, 97 - 110.

Martinez, M., Olmedo, N., Amante, B., Farrerons, O., & Cadenato, A. (2014). Analysis of Assessment Tools of Engineering Degrees. *International Journal of Engineering Education, 30*(6), 1689–1696.

McCowan, J. D. (2002). An Integrated and Comprehensive Approach to Engineering Curricula, Part Two: Techniques. *International Journal of Engineering Education, 18*(6), 638-643.

McCowan, J. D., & Knapper, C. K. (2002). An Integrated and Comprehensive Approach to Engineering Curricula, Part One: Objectives and General Approach. *International Journal of Engineering Education, 18*(6), 633 - 637.

McGourty, J., Shuman, L., besterfield-Sacre, M., Atman, C., Miller, R., Olds, B., . . . Wolfe, H. (2002). Preparing for ABET EC 2000: Research-Based Assessment Methods and Processes. *International Journal of Engineering Education, 18*(2), 157±167.

Molina Freitas, F. P. (2015). Educational Inclusive Policy and Formation Teachers. *Espacios, 37*(1).

Moreno Gomez, J. I., Gomez Betancourt, G., & Betancourt Ramirez, J. B. (2016). Board of director in the family business and its impact on socioemotional wealth" . En: Colombia. *Espacios, 37*(8), 6-11.

Osorio Garcia, C. (2014). Application of new monitoring tools that validates academic generic skills assesment in the faculty of engineering at Universidad de la Costa (CUC). *Revista Educación en Ingeniería*, 1-11.

Ponsa, P., Román, J. A., Arnó, E., & Peréz, J. (2015). Professional Skills in International Multidisciplinary Teams. *International journal of engineering education, 31*(4), 998-1006.

Ponza, P., Beatriz, A., Roman, J. A., Oliver, S., Diaz, M., & Vives Josep. (2009). Higher Education Challenges: Introduction of Active Methodologies in Engineering Curricula. *International journal of engineering education, 25*(4), 799-813.

Ruiz , O., & Francisco, J. (2008). Modelos Didácticos para la Enseñanza de las Ciencias Naturales. *Revista Latinoamericana de Estudios Educativos*, 41-60.

Silva de Oliveira, A., & Dirceu , D. (2016). Evaluation of the indicators of the teaching-learning process in post-graduate distance mode. *Espacios, 37*(12).

Speich, J. E., McLeskey, J., Richardson, J., & Gad-El-Hak, M. (2004). The Experiential Engineering Library. *International Journal of Engineering Education, 20*(6), 1022-1033.

Vivas, J. F., & Allada, V. (2006). Enhancing Engineering Education Using Thematic Case-Based Learning. *International Journal of Engineering Education, 22*(2), 236-246.

Zamora Musa, R. (2011). *Análisis de requerimiento para la implementación de laboratorios remotos.* Barranquilla: Educosta.

---

1. Research Group on Energy Optimization (GIOPEN), Universidad de la Costa, Colombia. Email: Email: aospino8@cuc.edu.co
2. Research Group on Energy Optimization (GIOPEN), Universidad de la Costa, Colombia. Email: Email: jsilva6@cuc.edu.co
3. Research Group on Resources-Energy-Sustainability (GIRES), Universidad Autónoma de Bucaramanga, Colombia. Email: Email: ymunoz294@unab.edu.co
4. Research Group on Applied Tecnologies (GITA), Universidad Nacional de Colombia, Sede Medellín. Email: jecandelob@unal.edu.co
5. Research Group on Energy Optimization (GIOPEN), Universidad de la Costa, Colombia. Email: mmejia6@cuc.edu.co
6. Energy management group (KAÍ), Universidad del Atlántico, Colombia. Email: guillermovalencia@mail.uniatlantico.edu.co
7. Productivity and Competitiveness (PRODUCOM), Universidad de la Costa, Colombia. Email: sumana1@cuc.edu.co

---

Revista Espacios. ISSN 0798 1015
Vol. 37 (Nº 29) Año 2016
[**Índice**]