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ASSESSMENT OF ELECTRONICS LABORATORY COMPETENCIES USING VIRTUAL OBSERVATION

Antonio-Torres D[1*], Medina-Pozos JM[2], Aguilar-Mejía JR[3], Zamora-Hernández I[2], Torres-Ríos E[1] and Moreno-Moreno J[2]

[1]*Computer Science Department, Tecnológico de Monterrey in Puebla,*
[2]*Mechatronics Engineering Department, Tecnológico de Monterrey in Puebla,*
[3]*Basic Sciences Department, Tecnológico de Monterrey in Puebla,*

Abstract: One of the graduate competencies in electronics engineering degree programmes under scrutiny in recent years, and much appreciated by the industry, is the proficient use of electronics laboratory equipment. Some academic institutions conduct their assessment using the observation of student performance while they develop laboratory experiments, whereas other institutions base their assessment on simulators and environments that allow capturing the interaction of students with traditional electronic circuits running on a computer. In contrast, this paper presents a novel approach on assessing electronics laboratory competencies using a remote laboratory, virtual observation and faulty prototyped electronic circuits. The selection of faulty electronic circuits as the instrument for the assessment resulted from coincidences of the graduate competencies declared by the university the authors work for and a survey among company leaders and professionals. Virtual observation consists in gathering information as to how a student uses some software to solve a challenge in order to produce an assessment. Virtual observation has been reported to be successful in substituting physical observation, thus reducing the tedious and error-prone revision of laboratory reports. The use of a remote laboratory allows students to interact with a traditional laboratory at home, while facilitating virtual observation to take place. The paper discusses the competency selected to be assessed and the levels of competency a student can attain based on the performance results. The different candidate faulty circuits as well as the faults to be found by the students are reviewed. Finally, the characteristics, configuration and expected outcomes of the assessment are outlined, as the competency assessment is scheduled to take place during the spring term.

Keywords: Higher education, educational innovation, graduate competencies, laboratory, virtual observation

Introduction

In the last decade, professional competencies have gradually changed and in the last year they have done so drastically, it was surprising to observe how companies, institutions, and organizations were taken by surprise by this situation as they were not prepared in their operation, production or care to their markets. The first studies find that the changes are focused on the development of not only academic skills but also soft skills of professionals (Azami and Ibrahim, 2012).

*Corresponding Authors' Email: *davidant@tec.mx*

These companies and institutions considered professionals a plus to have developed soft skills, however, at this time they consider it necessary and indispensable, Industry 4.0 is the next step, for which professionals must be trained and prepared with more and different competencies, the needs have been observed exponentially from 2010 to 2018 (Liane and Kipper 2021). Making disciplinary skills and soft skills even more necessary, such as sensor, embedded systems, Pro-activity, Problem Solving, Communication and Flexibility (Liane and Kipper, 2021).

As mentioned, 10 years ago, companies did not seek competencies, few were evaluating or requesting them as requirements (Liane and Kiper, 2021). However, at Tecnologico de Monterrey, the proximity with these companies or with the different organizations (Training Partners) made it easier to observe the evolution of their needs over time, therefore, for 8 years the surveys and interviews with the training partners gave the guideline to start with the evolution of the educational model at Tecnologico de Monterrey, which would focus on the development of competencies within its training units (subjects).

This new educational model is based on solving challenges within an academic learning environment, in which different academic competencies can be developed, but extra-academic ones (known as skill) are also addressed. The student in the process of his formation is involved in different real problems, in which she/he learns to learn and make use of his knowledge, also to carry out research that allows her/him to develop them from a basic level of mastery to the highest level. For Tecnologico de Monterrey, the TEC21 educational model is the pillar for the training of future professionals, due to the early involvement with training partners by employing real challenges applicable to its operation or functioning.

This means a change not only in the teaching mode or in the tools used to achieve the training, but there is also a drastic change in the evaluation model of the training units, this is because it is no longer enough to know (qualification for knowing), it is now necessary to know how to apply knowledge to solve real situations that arise in defined times since the challenges can be of a company, an organization or daily life (evaluation of knowledge and its application).

Currently, to be able to evaluate the competencies acquired by the students, two pieces of evidence are requested, a written argumentative exam and oral argumentative exam, these pieces of evidence are evaluated using an instrument that consists of tables of criteria, where the observables are described to decide whether the student demonstrates or does not demonstrate these skills, it is worth mentioning that it is at the discretion of each teacher.

Reason for which the question arises of how to ensure a correct evaluation in the application of knowledge and above all, how you manage to reduce response times with the aim that this evaluation is not only to decide if the subject passes or has the competence at the end of the course, but also ideally expected to be able to provide feedback to the student in real-time and in this way to ensure the obtaining of said competencies as they pass through the training unit.

It should be noted that, for this study, the competencies to be evaluated are practical, the training units are within the technology careers, specifically in the electronics disciplines, this we had the approach with employers of the branch, to land the current needs and develop the most appropriate mechanism that measures all the dimensions considered within this document.

Competencies evaluation

The emergence of competency-based education stems from the current needs of society and business. Professionals not only require knowledge, but also the development of skills, attitudes, and values. The integration of these four elements makes professionals have the necessary tools to solve problems within their discipline. The development of competencies must be done from an integral perspective (López, 2016), so higher education schools are changing from traditional educational models to models based on competencies.

Competencies can be classified into two types, transversal and disciplinary. The first ones refer to knowledge, skills, attitudes, and values that every professional should have regardless of the discipline in which they are developing. The disciplinary competencies are necessary to solve problems in a specific area (Barbera and Gunawardena, 2014). Students need to develop both during their professional training, so institutions must implement methodologies to ensure their development.

One of the main activities for competency development is evaluation. This process has the aim of knowing the level of competency development. Evaluation can be implemented before, during, and at the end of the learning process. It allows students to provide feedback and customize the learning process according to the needs of each student (Vilarinho, *et al*., 2020). For this reason, in the literature there is research that talks about the creation and implementation of instruments that allow testing the level of performance of particular competencies (Vilarinho, *et al*., 2020, Tinoco, *et al*., 2020).

For the assessment of competency-oriented learning, it must be clear the observables that the student has to show to generate appropriate measurement tools. For this purpose, it is possible to rely on the taxonomies of learning processes such as the one developed by Kendall and Marzano (2007). This taxonomy has the following characteristics: it is based on a theory of human thought; it takes into account the difficulty involved in carrying out the mental process (processing levels) and the familiarity that the student has with the process (domains of knowledge) (Gallardo, 2009). This taxonomy allows the definition of the criteria to know the development of the competency.

Definition of the competency

Competencies and skills in a laboratory are of great importance in the formation of students. From the academic perspective, the laboratory experiments contribute to complementing the concepts and fundamentals exposed in the classroom. It has been reported in the literature that laboratory experiments are instrumental for students to evaluate the quality of their knowledge and see those concepts in action (Salgueiro and Seixas, 2011, Chen, *et al*., 2018). From the employer perspective, research and design departments demand skillful performance in a practical setting and a prospective employee with such skills is considered to be an asset. However, in order to clarify and contrast the different conceptions of a skillful graduate, the authors decided to consult a number of sources of information related to the definition of graduate competencies.

The selection of the sources of information consulted by the authors was heavily influenced by the international professional certifying agencies Tecnologico de Monterrey collaborates with to certify their academic programs and by the graduate competencies defined by the institution itself. Considering students that make intensive use of the laboratory of Electronics, only two academic programs were considered for this consultation: Mechatronics Engineering (IMT for its initials in Spanish) and Digital Systems and Robotics Engineering (IRS for its initials in Spanish). The consulted sources are: the Accreditation Board for Engineering and Technology (ABET) (ABET, 2021), Accreditation Board for Engineering Teaching (CACEI for its initials in Spanish) (CACEI, 2021), the institutional department for competencies accreditation, SAEP, and the graduate competencies declared by the institution in light of the new educational model, Tec21 (ITESM, 2021).

ABET is a nonprofit, non-governmental agency that accredits programs in applied and natural science, computing, engineering and engineering technology. ABET accreditation provides assurance that a college or university program meets the quality standards of the profession for which that program prepares graduates. The selected category is Electrical, Computer, Communications, Telecommunication(s) and Similarly Named Engineering Programs and one relevant competency is: an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

CACEI is a non-profit civil association. Its primary objective is, through the accreditation of educational programs in the area of engineering, to promote higher education institutions to offer quality education to future graduates. CACEI conceptualizes the performance and skills of engineering students in seven competencies, spanning from effective oral expression to synthesizing design processes of engineering. It is the authors' opinion that one of the selected competencies remarkably matches the expected overall performance of a student in the laboratory: to develop and conduct an adequate experimentation; to analyze and interpret data and utilize the engineering judgement to draw conclusions.

As of 2009 and as a mechanism to nurture graduate competencies as early as the first academic periods, Tecnologico de Monterrey launched SAEP. SAEP is a computational platform in which evidence of the performance of students in several courses are registered and evaluated. In order to guarantee the successful accomplishment of the declared graduate competencies, several stepping competencies were attached to a certain group of courses and adequate evaluation instruments were designed. Along the way, the evaluation instruments were expressed in terms of criteria and degree of achievement, that is, in the form of a rubric. At the end of the academic period, professors are required to publish the evidence of each student and report the results of the evaluation. The stepping competencies were defined by consensus of the faculty and the evaluation instruments were designed according to the nature of each course.

SAEP identifies two types of competencies: disciplinary and personal and each type is supported by a group of sub-competencies. The IMT academic program consists of seven disciplinary competencies and one personal competency. One of the selected competencies is translated as: the student will design and conduct experiments, extrapolating her/his results towards the development of a product or a process of Mechatronics Engineering. Two associated sub-competencies can be translated as: 1) the student builds and evaluates prototypes of products and mechatronic systems and 2) the student designs and conducts experiments and analyzes and interprets data to evaluate and characterize the fulfillment of the specifications of the product or the mechatronic system. The IRS academic program consists of eight disciplinary competencies and one personal competency. The selected competency can be translated as: the student will design and conduct experiments, extrapolating the results towards the development of a new product or process of electronics engineering, working individually or as a team. Two associated sub-competencies can be translated as: 1) the student implements prototypes of electronic systems (hardware/software) and determines experimentally aspects such as: power consumption, response time, functionality and reliability and 2) the student detects failures in electronic systems (hardware/software) using testbenches. It is worth noting the presence of words such as prototype, experiments, electronic/mechatronic system. Also, another word that caught the authors' attention is failures.

In 2019, Tecnologico de Monterrey launched a new educational model, Tec21, with input from academic and education experts. Tec21 is centered on four pillars: challenge-based learning; flexibility in how, when and where students learn; inspirational faculty; and an engaging university experience (Garza, 2019). It is believed that Challenge-based learning (CBL) is the element that most differentiates Tec21 from traditional educational models. CBL is a pedagogical approach in which students play an active role in the solution to a relevant problem within a real-world context. CBL implies the definition of a challenge and the implementation of a solution. Students collaborate with professors and national/international experts to solve real-world problems to develop a deeper knowledge of the subjects and topics they are studying. It is the challenge itself which prompts the obtention of new knowledge and the necessary resources and tools. Traditional subjects have now migrated to units of formation (UF). An UF is composed of contributions from a few traditional subjects, only those topics that contribute to the completion of the challenge are to be part of the UF. The topics are now organized as modules and a module is delivered by a professor of the respective discipline, thus giving rise to a multidisciplinary group of professors. A module provides students with the necessary knowledge to tackle the challenge.

Tec21 defines and groups competencies according to a certain number of areas of each academic program. For example, IRS considers three groups of competencies: Embedded Systems, Intelligent Components and Intelligent Interfaces. Each competency is decomposed into sub-competencies, which run along three dimensions: complexity of the doing, depth of the knowing and autonomy. Sub-competencies can have one of three levels A, B and C. It is desired that students start from A-level sub-competencies during the first academic periods and reach C-level ones by the end of the academic program.

Once all the information from the sources mentioned above had been collected, the authors conducted an exercise to contrast the competencies and find coincidences between them. Among the common actions found are validate the functioning, conduct experiments, build prototypes, detect failures, and apply methodologies of design. These findings led the authors to propose a competency that reflects the expected performance of a student in the electronics laboratory: the student designs and conducts experiments that allow her/him to detect failures using testbenches and equipment of the electronics laboratory. The next step was to validate that this competency was relevant to academia and the industry.

Validation of the competency

After the definition of the competency, a validation is necessary, in order to ensure that the actors in the work environment share the importance of this competency. The search and choice of the people surveyed is focused on people with an area of experience in electronic and mechatronic development areas, with tasks ranging from the most technical to managerial levels. This validation is carried out in the form of a survey, through which the following information is collected for subsequent analysis.

1. Nationality and years of professional experience
2. Personal opinion to the question: Is the sub-competency described above one of the main ones that a graduate needs to work within the area or company where you work?
3. Personal opinion to the question: What KNOWLEDGE (know) should have a graduate of the careers related to electronics within the context of the use of measuring equipment? (Example: know Ohm's law)
4. Personal opinion on the question: What SKILLS (know-how) should a graduate of electronics-related careers have within the context of the use of measurement equipment? (Example: knowing how to measure the current in a resistance)
5. Personal opinion on the question: What ATTITUDES (knowing how to be) should have a graduate of careers related to electronics within the context of the use of measurement equipment? (Example: having initiative to propose different experiments of the validation of Ohm's law)
6. Personal opinion on the question: Is the sub-competency adequate to identify in students the attitudes typical of an engineer with training in the area of Electronics for IMT and IRS careers?
7. Personal opinion on the question: If you consider that this sub-competency is not the most appropriate to evaluate the knowledge, skills and attitudes of IMT and IRS students, which one would you recommend?

Due to the structure of the competency assessment model, these questions also seek to gather valuable information from experts, so that the choice of assessment instruments is the most appropriate. The survey was conducted with a total of 79 professionals, of which approximately 12% are of non-Mexican nationality and the rest are of Mexican nationality. Figure 1 shows a balanced distribution in terms of years of experience, which is considered beneficial to obtain a broader picture.

In response to the question, is the sub-competency described above one of the main ones that a graduate needs to work within the area or company where you work? We can observe that, for the most part (75.32%), professionals think which is a primary competency, and only 6.49% believe that it is not, see Figure 2.

As mentioned above, this survey also allowed the collection of additional information, which consisted of having an opinion from professionals about the 3 dimensions of a competency: knowledge, skills and attitudes. Figures 3, 4 and 5 show the knowledge, skills and attitudes, respectively, that professionals consider to be required within the context of the use of measurement equipment. This information will help to better define the competency evaluation criteria, as well as the evaluation instruments to be used.

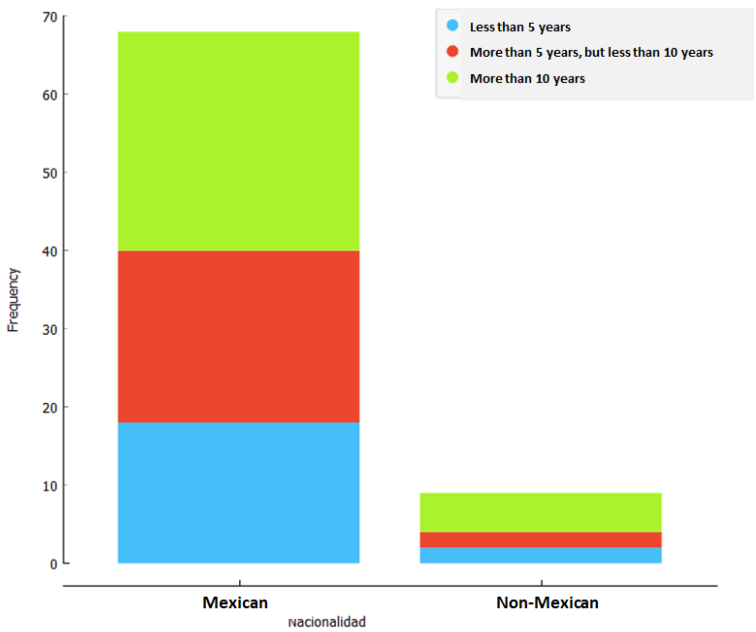

Figure 1: Distribution of the nationality of the professionals surveyed. Years of experience for each group are also shown.

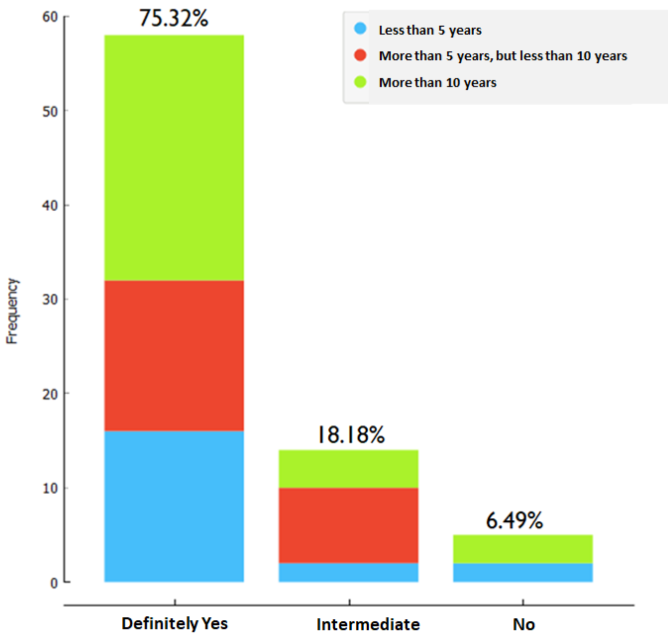

Figure 2: The distribution of the respondents who consider that the competency is one of the main ones is shown.

Figure 3 shows the result of the analysis of the responses given by the respondents to the question: What KNOWLEDGE (know) should a graduate of the careers related to electronics have within the context of the use of measurement equipment? (Example: know Ohm's law). Table 1 shows the table version of Figure 3 with translation between Spanish and English. Figure 4 shows the result of the analysis of the responses given by the respondents to the question: What SKILLS (know-how) should a graduate of electronics-related careers have within the context of the use of measuring equipment? (Example: knowing how to measure current in a resistance). Table 2 shows the table version of Figure

4 with translation between Spanish and English. Figure 5 shows the result of the analysis of the responses given by the respondents to the question: What ATTITUDES (knowing how to be) should a graduate of careers related to electronics have within the context of the use of measurement equipment? (Example: having initiative to propose different experiments of the validation of Ohm's law). Table 3 shows the table version of Figure 5 with translation between Spanish and English.

Figure 3: Word cloud resulting of the analysis of the responses given by the respondents to the question: What KNOWLEDGE

Table 1: Table format version of Figure 3.

Weight	Word - ES	Word - EN
10	Kirchhoff	Kirchhoff
8	Circuito	Circuit
7	Ohm	Ohm
7	Transistor	Transistor
5	Potencia	Power
5	Corriente	Current
4	Impedancia	Impedance
4	Diodo	Diode
4	Diseño	Design
4	Digital	Digital
4	Medición	Measurement

Figure 4: Word cloud resulting of the analysis of the responses given by the respondents to the question: What SKILLS

Table 2: Table format version of Figure 4.

Weight	Word - ES	Word - EN
13	Voltaje	Voltage
12	Medir	Measure
11	Corriente	Current
10	Medición	Measurement
9	Resistencia	Resistance
9	Osciloscopio	Oscilloscope
9	Frecuencia	Frequency
6	Circuito	Circuit
5	Capacitancia	Capacitance
4	Potencia	Power
4	Multímetro	Multimeter

Competency Assessment and methodology

A great effort has been put to define the core competencies of technological academic programs around the world (Chang and Shih, 2020, ABET, 2021). It has been found that among those should be the ability to measure, conduct, analyze and explain experiments and those to be cultivated are competency in experiment design and execution and competency in techniques, skills and tools required for executing engineering practices. It can be arguably stated that laboratory competencies play a critical role in that cultivation.

Figure 5: Word cloud resulting of the analysis of the responses given by the respondents to the question: What ATTITUDES

Table 3: Table format version of Figure 5.

Weight	Word - ES	Word - EN
3	Error	Error
3	Proactivo	Proactive
3	Capacidad	Capacity
3	Cambio	Change
2	Escuchar	Listen
2	Idea	Idea
2	Búsqueda	Search
2	Buscar	Look for
2	Aprender	Learn
2	Mejorar	Improve
2	Identificar	Identify

Universities have traditionally relied on rubrics, logbooks, projects, questionnaires and reports, among others, to assess the performance of students in the electronics laboratory (Naim, *et al*., 2010, Chen, *et al*., 2017, Na, *et al*., 2019, Lopez-Reyes, 2018), where physical observation is also considered in the assessment and grading of the students. It has been reported and analysed extensively that physical observation is “deficient and subjective with possibilities of bias and unfairness” (Achumba, *et al*., 2013) and that assessment with rubrics may lead to inconsistencies mainly due to three factors “misconception of the facilitators’ perception towards rubric ranking, halo effect issues in the assessment and the objective of the rubrics” (Barhi, *et al*. 2012). Different approaches, such as virtual laboratories (Gil, *et al*., 2013, Achumba, *et al*., 2013), remote laboratories (Dinesh and Vishal, 2010) and formative assessment (Barhi, *et al*., 2012) have reported improvements in the students’ and evaluators’ perception and assessment results. In particular, the authors believe that virtual behavioral observation is an assessment tool that may eliminate the assessment pitfalls discussed above. Virtual behavioral observation is defined as “the collection and recording of behavioral data while subjects are engaged in activities in an interactive virtual environment" (Achumba, *et al*., 2013). As reported, virtual observation relies on virtual laboratories and can generate very precise assessment when collected data is related to the expected performance of the students.

Considering the arguments and findings discussed above and, in order to comply with the current conditions of social distancing and lockdown, the authors have decided to incorporate technologies and techniques that have proven successful. The first step taken in this direction is the use of remote laboratories. Remote laboratories have allowed universities around the world to offer access to equipment 24/7, while keeping the investment budget more manageable (Aajli and Afdel, 2013, Gil, *et al*., 2014). However, due to the current restrictions of access to universities, the control and preparation of the equipment within the premises have also been affected. One solution is to build a remote laboratory using low-cost pocket-sized equipment connected to a personal computer (PC) (Digilent, 2021). Oscilloscopes, waveform generators, digital analyzers and voltmeters can nowadays be found integrated together in a single equipment and configured via software. This same software also collects and presents the information reported by the instruments in a similar way as that found in traditional equipment in an electronics equipment. The preparation of the electronic circuits as well as the configuration of the instruments can now take place in the instructors' PCs and made available through the Internet to the students via a specialized software (RealVNC, 2021). Figure 6 shows a pocket-sized device with the three major laboratory devices: oscilloscope, waveform generator and voltmeter, connected to a development board for digital system prototypes.

Figure 6: Pocket-sized laboratory equipment testing a development board.

A second step taken is the use of virtual observation (Dinesh and Vishal, 2010, Achumba, *et al*., 2013). This implies the use of software to offer the student the use of traditional laboratory equipment and validate the correct functioning of electronic circuits. Both equipment and circuits are simulated by the software itself. The benefit of virtual observation is that the software can be extended to allow the capture of the interaction of the student with the equipment and the circuit and, from this, assess the performance of the student. The authors have developed an in-house application in which to embed the configuration software of the remote laboratory station using LabVIEW, a proprietary programming language for industrial testing and instrumentation (LabVIEW, 2021). A benefit of this in-house application is that virtual observation can take place in a pretty straightforward manner and the recollected information can then be fed into a data analysis engine. This data analysis engine is going to organize the recollected information and help in the application of an evaluation instrument with which professors can assess the performance of the students. Figure 7 shows an example of a user interface that a student will use to test a circuit and configure and use laboratory equipment.

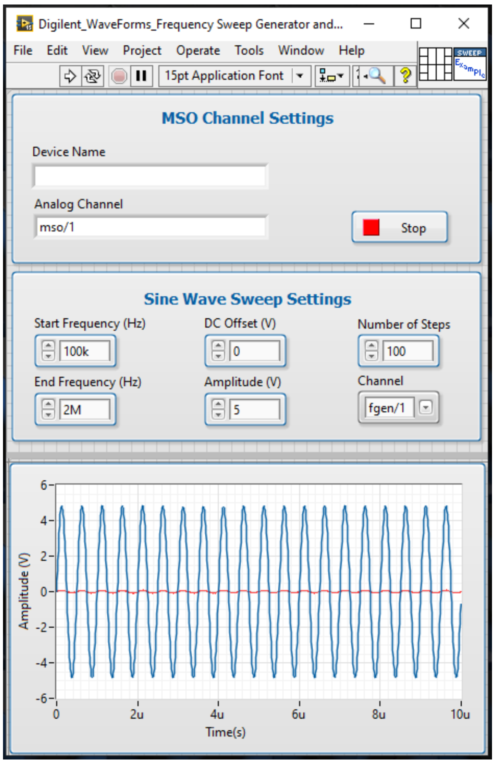

Figure 7: User interface of a software environment to implement competency assessment

As a third step and following the results and recommendations collected from the survey discussed in a previous section, the authors considered a number of electronic systems as candidates to be used as the instrument to assess the competency. The criteria used for the selection of these circuits are: how easy the circuits are to evaluate; how close the circuits are to the proposed competency and how easy the failure is to identify. Given its widespread study, development and use in the laboratory, the assessment is to be conducted using an electronic circuit that is described as: a DC power source is implemented as a collection of subsystems: transformer, full-wave rectifier, voltage regulator and resistor-capacitor circuits, and the student is indicated that one of the subsystems is faulty. The student is asked to identify the faulty subsystem by using laboratory equipment and analyze the respective measurement readings and waveforms. It is expected that the student first identifies the faulty subsystem and then pinpoints the failure in the subsystem.

The proposed methodology to assess the proposed competency can be summarized in Figure 8. The student proposes a hypothesis to pinpoint the failure and breaks down the hypothesis in steps. These steps involve the use of laboratory equipment and running tests on some specific components or subsystems of the electronic circuit. These steps also require the student to analyze the readings and waveforms generated by the tests and measurements. Along the way, the student provides feedback as to why she/he decided to run some specific tests and the chosen order and on the selection of laboratory equipment. As laboratory equipment requires configuration before testing and adjustment during testing, these actions are also collected by the software environment to be part of the assessment.

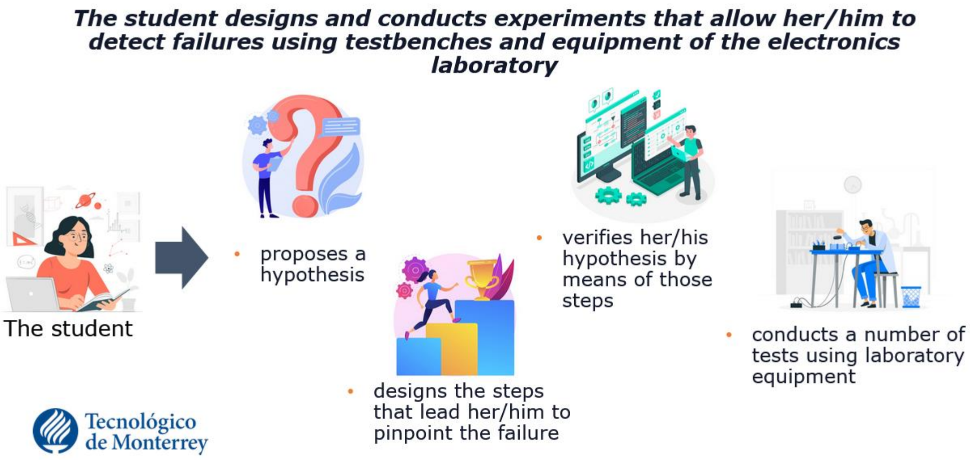

Figure 8: Proposed methodology for the assessment of the proposed competency

Expected results and future work

The authors are currently applying the proposed assessment and methodology to three communities of students with different levels of skills in the operation of laboratory equipment: 1) students in their second year with an introductory formation in electric and electronic circuits and with a modest use of laboratory equipment; 2) students in their third year with a solid exposition to the analysis of electric and electronic circuits and with a regular attendance to the laboratory and 3) graduating students with a solid formation in the analysis and design of electric and electronic circuits and with an intensive use of laboratory equipment. The selection of these communities was based on the necessity to validate and calibrate the assessment approach and the evaluation instrument. The number of students considered in this stage of experimentation is around 50. These students are invited to participate in the experiment. Some of the expected outcomes are that the proposed assessment helps identify different levels of performance of the three selected student communities and contributes to the feedback delivered to the students as to what theoretical and practical backgrounds were either key to the result or need to be reinforced for an improved performance.

As discussed in the previous section and shown by Figure 8, the methodology to analyze the collected data and return an assessment is going to follow a concurrent mixed method, as the students deal with both open and closed questions in the form of drop-down menus and brief essay-type answers. Closed questions are categorized and analyzed by the software environment, whereas open questions call upon the intervention of evaluators and professors. Depending on the results, the proposed methodology, the proposed electronic circuit and or the proposed competency might be revised and or improved. This might also involve reprogramming of the software environment. Particular attention is going to be paid to the definition of the levels of competency and that these levels be assessed correctly.

The current scope of the application of this competency assessment and methodology is local to a single Campus of the university and targets a couple of academic programs: Robotics Engineering and Mechatronics Engineering. However, the authors believe that this assessment can also be applied to the students of the same academic programs of the other campuses of the university, considering that all the campuses share the same guidelines and contents of these two academic programs. Furthermore, the authors have found that some aspects of the proposed methodology are currently being applied to the School of Medicine of the university, indicating that the proposed methodology and competency assessment could be extended to incorporate some other disciplines and academic programs. Further research is required.

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