Implementation of a remote laboratory for the identification of polymeric materials by means of physical properties analysis

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Abstract. Due to the strategies implemented to carry out the development of a correct teaching by virtual means, a methodological strategy of experimental tests was developed for the identification of polymeric materials through the identification of physical and chemical properties, with the objective of providing the engineering student a greater approach to the application of the scientific method and the activation of the capacity of reasoning and deductive thinking from the physical and chemical point of view. Therefore, the purpose of this research was to validate this strategy implemented with a group of engineering students, for this purpose, the strategy was implemented, and the results obtained by the students from the development of the experimentation were analyzed, the data were analyzed by means of nonparametric tests, in this case binomial test. Finally, it is concluded that the polymer identification test is feasible to be implemented as a remote laboratory, as a methodical strategy in teaching, since it allows the development of experimentation, in this case, the identification of polymeric materials, which present diverse physical properties.

1. Introduction
The purpose of teaching science, technology and innovation is to develop skills and knowledge that allow the learner to better understand and interact with the environment [1]; therefore, within the framework of a comprehensive approach, the area of science, technology and innovation is aimed at achieving optimal learning levels through cognitive and technological processes in a changing society [2]. The knowledge of physics, which deals with the fundamental components of the universe and is closely related to the natural sciences, is vital for the scientific training of young people today, being considered a necessary area in today's world; this knowledge is essential for students, in order to progress in the study of other aspects of experimental sciences and even more linked to laboratory practices, which play an important role in the teaching-learning process [3]. However, conducting experiments with real laboratories is usually costly in terms of time, money, and energy, since it requires the development of teaching infrastructure, equipment, materials, reagents, among others, usually expensive and difficult to maintain.

On the other hand, it is frequent that once these infrastructure resources are put into operation, they remain underutilized due to the limited time that they can be used by students and the fact that they are usually specialized equipment [4]; currently, the experimental training of engineering students is becoming the key that opens the doors to prosperity within the industrial field. For this reason, many of the technical research groups are working on the development of virtual and remote laboratories for engineering education [5]. Therefore, although the concept of physical laboratory is a traditional and clear concept for the entire teaching and research community, the concepts of simulation, virtual
instrument, remote instrument, remote laboratory, and virtual laboratory do not have clear definitions that distinguish them [6]

In the traditional laboratory, resources in terms of people and space are restricted, due to its massification and budgetary problems; the physical presence of the student and the supervision of the teacher are required. A solution to these problems is found in the application of technological advances to university teaching and research, such as the use of virtual and remote laboratories [7]. Virtual and remote laboratories, bring and facilitate the realization of experiences to a greater number of students, although student and laboratory do not coincide in space, since they allow simulating physical phenomena and models, abstract concepts, hypothetical worlds, controlling the time scale, among other advantages, hiding the mathematical model and showing the simulated phenomenon in an interactive way [8]. Halfway between traditional and virtual laboratories are remote laboratories, laboratories that offer real experiments to remote users [9]. The combination of both approaches, virtual and remote laboratory, not only allows students to take experimental conditions beyond the limits imposed by the real equipment using the virtual paradigm, but also makes it possible to compare the behavior of physical experiments with their simulations [10,11].

At present, due to the times of the Covid - 19 pandemic, virtual and distance education has gained relevance. Since during the last years due to the globalization of education and economy, virtual and distance education has taken an important space [12]. Therefore, for the development of the present research, questions arose such as: (a) How to encourage the development of skills and competences from experimentation? (b) How to implement a remote laboratory to bring the student closer to research? (c) How to develop the scientific method from a remote laboratory? (d) How to manage the appropriation of knowledge in materials science and physics concepts from experimentation without a physical laboratory? Thus, this document is structured as follows; in section 2, the methodology used for the development of the research is presented, in section 3, answers to the questions mentioned above are provided, addressing the implementation of a remote laboratory and the experiences of the same, which was subjected to validation based on the learning outcomes of the participants, determining the level of development of competencies. Finally, in section 4, conclusions and a final contribution are presented.

2. Methodology
For the development of the present research, a descriptive methodology was adopted, where an experimental practice was used in the students, given according to Figure 1, identification of polymeric materials by means of the analysis of attributes and physical properties through organoleptic tests, as a remote laboratory strategy, giving the participants of the practice an approach towards exploration, experimentation, and a deepening in the concepts of the physical and chemical properties of the polymeric materials, of the thermosetting family. For this purpose, an oriented guide with indications and steps to be followed was provided to the participants, after which the results were analyzed, with the objective of determining the degree of assertiveness in the practice that consisted in the identification of the given material.

2.1. Implementation of the remote laboratory
The indications were given to a group of 25 participants, from which a basic instrument was designed for the collection of results, where information is obtained on the identification of the material given as the object of study, and thus, to determine whether the results of the practice according to each level were correct or incorrect.

2.2. Data analysis
An exploratory quantitative analysis of the results of the practice was made according to each level, that is, according to each test, where they were catalogued in dichotomous scales, that is, they have only two options, correct or incorrect, where the result of the identification of the material given as the object of study is obtained.
3. Results and discussion

The main activity consisted of using a space and converting it according to previous indications, with elements of easy access and under a directed scheme and a designed methodology, the development of a practice of identification of polymeric materials of the thermosetting family. The experience was carried out with a small group of students enrolled in the subject of polymers, where topics of materials science, engineering materials, concepts of physics, chemistry, and mechanics, among others, are consolidated, which will be useful for future professionals and their performance in the productive sector, since these practices encourage scientific and technical thinking that serves when making decisions, based on evidence.

3.1. Implementation and development of the experimental knowledge appropriation mechanism

Thus, within the practice, three types of samples were evaluated, with a slight suspicion of the type of material, i.e., its composition. The specimens were labelled for later identification, as can be seen in Figure 2. The results presented below are only from one group of students, because to optimize the space provided in this manuscript and not to extend too much without justified purpose.

The equipment used for the development of the practice should have characteristics such as: easy access, low cost, and timely availability, therefore, some students opted for items such as scales or scales, and micrometers to measure thickness, and other elements such as burner and gas, for the combustion test. According to the above, it is evident, the presence of some uncertainty in the measurements since the equipment is not specifically laboratory equipment. The method to be followed for the development of the practice is established in Figure 1, from which both qualitative and quantitative data are obtained, as can be seen in Table 1.

Figure 1. Identification of polymeric materials by analysis of attributes and physical properties through organoleptic tests.
According to the data reported in Table 1, the participants recorded the values with significant figures, where the mass was determined for the three types of samples with the assistance of the weighting machine, due to the fact that the group presented very thin films of plastic material, they resorted to determine the thickness with the help of a micrometer, which presented different results with uncertainty according to its handling. In addition, the samples did not present uniformity in their geometry, so the thickness data will work for the calculation of the volume of the samples, based on the references provided, the participants were able to compare some test results with data found in the literature, through these tests, it was possible to observe the behavior of the material against different types of tests.

On the other hand, the analysis of attributes and physical properties was carried out through organoleptic tests, in this case, qualitative results were obtained, as shown in Table 2, where the possible materials that comply with the characteristics were identified from the qualitative and quantitative data, such as: Figure 2(a) show M1: sample N°1, high density polyethylene (HDPE), Figure 2(b) show M2: sample N°2, low density polyethylene (LDPE), and Figure 2(c) show M3: sample N°3, polystyrene (PS). As could be observed, samples M1 and M3, presented similar characteristics and attributes, however, the property that helped to differentiate them was their density, as well as expanded polystyrene (EPS), presents similarity with PS, however, according to the density of EPS is in an interval of 10 Kg/m$^3$ – (≥) 50 Kg/m$^3$, in which the test was close to this result [13].

![Figure 2. Samples under study. (a) Sample M1 (b) Sample M2 (c) Sample M3.](image)

| Table 1. Quantitative data. |
|-----------------------------|
| Sample | mass (g) | thickness (mm) | volume (cm$^3$) | Density (g/cm$^3$) |
| N°1 | 0.528 | 0.0534±0.0036 | 0.445±0.0337 | 0.910±0.1000 |
| N°2 | 1.352 | 0.0445±0.0015 | 25.000±0.0040 | 0.054±0.0023 |
| N°3 | 0.403 | 0.0534±0.0036 | 0.534±0.0674 | 0.988±0.1450 |

| Table 2. Results of the analysis of attributes and physical properties through organoleptic tests [13]. |
|-----------------------------|
| Polymer/ | Rigidity | Surface | Combusb test |
| Sample | F$^a$ | S$^b$ | R$^c$ | G$^d$ | W$^e$ | Dull | Bs$^f$ | Bc$^g$ | Se$^h$ | Drips | Nd$^i$ | Yf$^j$ | Bf$^k$ | Gf$^l$ |
| HDPE | M1 | | | | | | | | | | | | | |
| LDPE | M3 | | | | | | | | | | | | | |
| PS | M2 | | | | | | | | | | | | | |

$^a$Flexible (elastic), $^b$Semirigid, $^c$Rigid (brittle), $^d$Glassy, $^e$Waxy, $^f$Black soot, $^g$Burns clean,

$b$Self-extinguishing, $^i$No drip, $^j$Yellow flame, $^k$Blue flame, $^l$Green flame

3.2. Validation of the experimental knowledge appropriation mechanism

This research is considered field research, since an analysis of the data was applied, based on the experiences of the participants, where the appropriation of knowledge in physical sciences, and concepts about the characterization of materials, are the object of study, so it is possible to identify a latent reality. In this sense, collecting data directly where events occur without manipulation or control, the information is obtained without alterations [14,15].
For this purpose, an assessment instrument was designed, structured in eleven criteria, these criteria evaluate each of the steps that make up the phases for the development of the remote laboratory practice; the methodology implemented is shown in Table 3. Therefore, according to this, each participant obtains a score according to the development of each phase, for each of the eleven stages, from these data, the level of development of competencies (LDC) is obtained. In our case, three competencies were analyzed: conceptual competencies, procedural competencies, and attitudinal competencies, each with a series of indicators to be assessed.

| Table 3. Calculation of the level of development of the competencies to be evaluated. |
|-----------------------------------------------|
| Item $j_1 \ldots j_n$ | $\sum x_{ij}$ | $M_x$ | $LDC_i$ | $e_i$ | $LDC_{ic}$ |
| $i_1$ | | | | | |
| $i_{n-1}$ | | | | | |
| $i_n$ | | | | | |
| | | | | | $LDC_{sum}$ |
| | | | | | $LDC_{total}$ |

According to the statement of the previous variables, to calculate the sum of the score obtained by each participant in the same item, Equation (1) is used, to know the mean of the item in the score obtained by the participants [14] Equation (2) is used, to calculate the level of development of competency $i$ in participant $j$ [14] Equation (3) is used, however, it is necessary to calculate the error assigned to each item [14], for this purpose Equation (4) is used, in this way the level of development of the competency is calculated without the error, from Equation (5) [14].

Finally, the level of development of the total competency $i$ for the group is obtained, using Equation (6) [14]. The above process is carried out for each of the 11 items and each participant, to obtain the results per group for each of the competencies, in this case, three competencies: conceptual competencies, procedural competencies, and attitudinal competencies. For analysis purposes and to optimize and synthesize content, Table 4 presents the results of the level of competence $i$ for the whole group, and by items for the whole group, according to each competence. Therefore, for the present investigation, it is agreed to accept items with a $LDC \geq 0.80$.

$$\sum x_{ij},$$  \hspace{2cm} (1)
$$M_x = \frac{\sum x_{ij}}{j},$$  \hspace{2cm} (2)
$$LDC_i = \frac{M_x}{V_{max}},$$  \hspace{2cm} (3)
$$e_i = \left( \frac{1}{j} \right),$$  \hspace{2cm} (4)
$$LDC_{ic} = LDC_i - e_i,$$  \hspace{2cm} (5)
$$LDC_{total} = \frac{\sum LDC_i}{i_n},$$  \hspace{2cm} (6)

where, $i_n$ represents the item to be valued, from 1 to 11, $j_1 \ldots j_n$ represents the scores obtained by each participant, from $i$ to $j$, $\sum x_{ij}$ represents the sum of the score obtained by each participant on the same item, $M_x$ represents the mean of the item in the score obtained by the participants, $V_{max}$ represents the maximum score that the item can reach, $e_i$ represents the error assigned to each item, where $j$ represents the number of participants in the practice, and, $LDC_{sum}$ represents the summation of the level of development of competency $i$ in the group, $LDC_{total}$ represents the value of the development level of competency $i$ in the group.
Table 4. Level of development of competencies by the group under study.

| Item | LDC conceptual | LDC procedural | LDC attitudinal |
|------|----------------|----------------|-----------------|
| i1   | 0.920          | 0.920          | 0.840           |
| i2   | 0.880          | 0.920          | 0.920           |
| i3   | 0.960          | 0.800          | 0.840           |
| i4   | 0.840          | 0.840          | 0.920           |
| i5   | 1.000          | 0.760          | 0.800           |
| i6   | 0.840          | 0.880          | 0.800           |
| i7   | 0.840          | 0.800          | 0.960           |
| i8   | 0.960          | 0.800          | 0.840           |
| i9   | 0.880          | 0.880          | 0.800           |
| i10  | 0.880          | 0.840          | 0.840           |
| i11  | 0.920          | 0.800          | 0.880           |

LDC total 0.901 0.858 0.840

According to Table 4, the LDC values were calculated according to the results of the evaluation obtained by the participants, this process allows evaluating the remote laboratory practice and its implications in the context of the appropriation of knowledge through experimental practices using the scientific method, evaluating the practice according to three types of competences and each phase or items of the experiment process, therefore, the results with a LDC ≥ 0.80 are accepted, which indicates that an appropriation of knowledge and a development of competences of outstanding character were obtained in each item.

On the other hand, in item i5, a value lower than the limit established in this research was presented, in other words and in the context of our interest, it indicates that the participants presented difficulties in the development of the procedural competence, that is, there were deficiencies in the determination of the thickness of the polymer samples to be characterized, probably because they did not have a regular geometry, or because the thickness was too minimal to be measured with common elements and not with specialized equipment, which is identified as an opportunity for improvement, however, this does not demerit the successful results obtained by using this practice, since in most of the items values higher than the limit were obtained, which indicates an appropriation in the evaluated competencies, thus achieving the objective of the remote laboratory, which is to bring participants through the scientific method, to experience the conceptualization, theories and other concepts such as experimental physics, characterization of materials, in this particular case, in the characterization of polymers.

4. Conclusions

The design and implementation of a remote laboratory using basic elements achieved a development of research and experimentation skills in the participants, in materials science, polymers and physical science, from the implementation of the concepts taught. The participants that make up the study sample, present a weakness in the procedural competence in the phase of determining the thickness of the sheets or films of the thermoplastic polymer, evidently, due to the requirement of this activity, since it demands a greater precision in the determination of this factor. During this experience, the participants were able to discuss ideas, concepts and above all to demonstrate an appropriation of knowledge, enhancing and replicating the experience of a real laboratory. The development and implementation of a strategy such as the remote laboratory for the identification of polymeric materials, allows the participant to develop skills such as critical thinking, research, and innovation, as it strengthens their training in the area of engineering.

On the other hand, the results allowed us to prove the hypothesis that the implementation of a remote laboratory for the identification of polymeric materials contributes to the improvement of skills such as research and experimentation, on the other hand, it also allows us to affirm that the strategy works as an alternative to strengthen skills such as problem solving, the development of experimental activities, the organization of information, educational simulation, and scientific research.
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