Abstract: Teaching technical content in science and engineering requires the development of high-level competencies such as analytical and critical thinking skills, and is perceived by students as a difficult subject to understand. One way to help students learn this type of content is through the use of scaffolding, which dynamically regulates and adjusts learning according to the student’s needs. Although the use of scaffolding has already been applied in different educational contexts, so far there are no studies analysing its impact on students’ emotions and perception. In this paper we propose the LESCA system, which performs adaptive content feedback through scaffolding. The main hypothesis of this article is that the use of this tool together with teacher scaffolding improves the acquisition of content at higher cognitive levels and improves the student’s emotional state during learning. An experience has been carried out with 36 students of Industrial Electronics and Robotics Associate Degree with a pre-post design, where one group of students did not use the tool and another one did. The findings indicate that knowledge acquisition at the higher levels of Bloom’s taxonomy improved after the use of technological scaffolding and that this acquisition improved significantly when incorporating teacher scaffolding. On the other hand, students who performed the tasks with the system experienced significantly less anxiety and despair than students who did not use it. In addition, it has been found that students perceive teacher scaffolding to be significantly more useful than technological scaffolding.

Keywords: Scaffolding, Sustainable learning, Emotions, Bloom’s Taxonomy
Categories: H.5.1, L3.0, L3.6
DOI: 10.3897/jucs.110173
learning science, technology, engineering and mathematics (STEM). Learning this type of content has positive effects on students’ skills and attitudes [Uğur, 18]. STEM education plays an important role in developing skills such as innovation, creativity and problem solving [Cooper, 13].

However, teaching technical content such as science and engineering presents several difficulties [Diana, 21]. The need for new tools and materials suitable for students to understand science, technology and mathematics concepts is one of the current challenges [Milaturrahmah, 17]. In some cases, these contents are abstract [Milaturrahmah, 17] and difficult to understand for the student, which generates low student interest as they do not understand the essence of this type of content [Parmin, 20]. More specifically, in the field of engineering, education has been mainly content and design oriented, requiring the student to make an extra effort to develop critical thinking [Asgari, 21]. One way to assist the student in the process of forming this content can be scaffolding, which is based on the transfer of knowledge and implementation strategies between the teacher and the student. As the student acquires a greater degree of autonomy, the responsibility for the task to be performed is assumed by the student with the help of the teacher [Wood, 76], which is gradually withdrawn until the student becomes totally independent. Scaffolding is usually designed to promote higher-order thinking skills [Kim, 18], such as those set out in Bloom’s revised taxonomy [Krathwohl, 22]. However, in order to enhance learning, it is a priority to develop students’ ability to learn how to learn [Delors, 94]. This requires empowering them and facilitating a gradual transfer of knowledge that does not lead to feelings of rejection or anxiety, which are a determining factor in learning. Positive emotions experienced by students can reduce learning time and consequently improve their performance [Arguedas-Méndez, 16], which promotes the construction of knowledge and favours the development of their problem-solving skills.

The aim of this work is twofold. On the one hand, to propose an educational platform that supports a learning process by means of a scaffolding system of adaptive feedback to the student, called LESCA (Learning System with Technological Scaffolding). If the student has a good level of learning, the platform presents new content, and if there are errors or problems, the system identifies them and provides feedback on the content necessary to acquire the knowledge. On the other hand, the aim is to validate the impact of this scaffolding system on the learning results, as well as on the student’s emotional state while using it. For this purpose, a prototype of the LESCA system has been implemented and an experience has been carried out with Associate Degree students, which is a type of academic training of study post-secondary focused on technical skills.

The rest of the contribution first describes the main aspects of scaffolding and the influence of emotions on learning. Then, the proposed system and the experience carried out are described together with the results obtained. Finally, the discussion of these results and the conclusions and future work arising from this work are presented.

2 Related works

This section presents the main concepts related to technological scaffolding and the emotions experienced during the learning process.

2.1 Scaffolding

Scaffolding has its origins in Vygotsky’s educational psychology [Vigotsky, 79], where students learn when they receive support from more advanced sources (e.g. teachers or
peers) [Basu, 15]. In this case, learning occurs through social interaction and is based on the concept of Zone of Proximal Development (ZDP), which reflects the distance between the student’s current level of development and their potential level of development, defined by solving tasks under the supervision of a more skilled person [Pérez, 18].

The integration of scaffolding in educational resources allows motivating students to develop an integrated understanding of a complex domain [Linn, 95], reducing the ZDP. In that sense [Pata, 06] focused on the role and interrelationships of verbal scaffolding by the tutor and peers during a collaborative decision-making process. To achieve this, scaffolding must fulfill three characteristics [Van, 10]:

- Contingency, i.e. adaptation to the level of the students.
- Temporariness, which implies that support should be phased out over time.
- Gradual transfer of responsibility to students.

In most cases, scaffolding provides support with instructional materials, practical activities and other educational resources to help students independently acquire learning objectives. One of these resources can be technological tools, where scaffolding processes can not only occur peer-to-peer or by an expert, but also through technology [Belland, 17]. In which computerized scaffolding plays a fundamental role in improving higher order skills [Kim, 18] or in [Beker, 03] who uses computer-assisted learning to generate an interactive debate. There are four categories of technology-supported scaffolding [Kim, 18]:

- Conceptual scaffolding: Helps students determine what to consider in their learning, guiding them to prioritise key concepts. One experience of this type of scaffolding was proposed by [Fuentes, 2015] through the use of cybercafes as a playful training tool to bring groups of students together to develop new learning.

- Strategic scaffolding: Suggests alternative ways for students to deal with the learning problems they are experiencing. In this regard [An, 10] proposed a strategy for teaching students to solve problems by scaffolding them through a web-based tool.

- Metacognitive scaffolding: Guides students through their thinking process and helps them to self-assess as they learn. [Lopez, 18] proposed metacognitive scaffolding to facilitate student support through a web-based tool.

- Motivational scaffolding: This is based on the use of pedagogical strategies to favour student motivation, promoting for example aspects such as the perception of self-efficacy. An example can be found in [López, 20], whose authors propose an m-learning platform with motivational scaffolding for mathematical content learning.

To implement scaffolding, three important aspects should be considered [Abas, 11]:
(i) respond to the student’s needs, (ii) start with the lowest level of support, and (iii) use different strategies throughout a task. In addition, implementing technology scaffolding in general should include three types of support [Basu, 2015]:

- Interpretive, which helps students to structure their domain knowledge.
- Experimental, which helps in the creation and interpretation of experiments.
- Reflective, which facilitates students’ reflection on the learning process.
UNESCO highlights the importance of the use of technological scaffolding to favour the educational development and growth of society [Castellano, 11], which can be implemented in different ways. Some works implement scaffolding through hardware systems. [Gennari, 19] presents an electronic module with push buttons and LED lights called TurnTalk, which improves the development of some social skills such as intervening and expressing ideas in groups. These authors concluded that these aids reduced systematic failures in conversation and encouraged balanced social participation among students. Other work uses robots to increase student motivation in a social learning environment and improve learning outcomes [Deublein, 18].

Some work focuses on applying software resources to the implementation of scaffolding. For example, [Abas, 11] used augmented reality (AR) to develop a six-level scaffolding model to teach reading to primary school children. In this case, the scaffolding levels provided by AR changed to the next level when children were able to recognise words in a book. [Basu, 2015] combined scaffolding techniques with ecological environment simulation software using NetLogo language. In this work, scaffolding was provided to help students relate data from environmental experiments to the results of simulations in graphical forms, with the scaffolding disappearing as they progressed into more complex simulations. Experiments with high school students showed that the use of scaffolding with simulation systems provided students with better results in the competency of analyzing ecosystem maps. This improvement in students’ competencies is also noted by [Delen, 14], who proposed video scaffolding for groups of undergraduate and graduate students. Students who used video scaffolding obtained better academic results, experienced higher class participation and more motivation than students who did not use video scaffolding. This improvement in student motivation and perception with the use of scaffolding found by Delen and colleagues has been noted by subsequent work. [Sun, 21] indicates that the integration of scaffolding motivates the STEM student and improves the student’s perception and emotional state. Therefore, working with scaffolding with the student’s emotional context in mind can positively reinforce learning in STEM contexts [Vongkulluksn, 18].

### 2.2 Emotions in learning

The emotional state of students is a fundamental factor for meaningful learning [Lacave, 20]. However, [Wang, 23] mentions that research pays less attention to this type of factors. Although it is difficult to define “emotion,” it can be understood as a complex set of interactions with subjective and objective factors mediated by a hormonal/neural system [Kleinginna, 81]. Emotions, although a complex construct, can be classified according to different instruments. The PANAS (Positive And Negative Affect Schedule) model [Watson, 88] classifies emotions broadly into positive and negative. Positive emotions are related to enthusiasm, activity and alertness, while negative emotions are related to anger, contempt, disgust, guilt, fear and nervousness. Some authors attempt to identify emotions more specifically, although there is no unified agreement on emotions [Ortony, 88]. Other works identify emotions in the educational context using the self-report instrument AEQ (Academic Emotions Questionnaire) [Paoloni, 14] [Pekrun, 02a]. AEQ is based on Pekrun’s model, which classifies emotions into three dimensions [Pekrun, 02b]: (i) object focus (related to the success and outcome of activities), (ii) valence (pleasant or unpleasant) and (iii) activation (agitation or arousal). Consequently, the AEQ instrument allows measuring the following emotions in an educational setting (both pleasant and unpleasant emotions): enjoyment, hope, pride, anger, anxiety, embarrassment, despair and boredom.
Some experiences have analyzed different factors that may affect student emotions and their learning outcomes. For example, [Lishinski, 17] and [Steinmann, 13] studied the behavior of emotions in novice computer engineering students, and found that their emotional states varied according to the student’s behavior in the different phases of the task (building the program – design phase, coding, debugging, etc.). Another factor that can affect students’ emotions is the learning modality. In this regard, [Luo, 17] developed an online course using the Moodle platform and found that students with positive emotional state during the course obtained better scores than those who experienced negative emotions. On the other hand, [Velásquez-Palacios, 15] evaluated the impact of the use of interactive experiential tools on emotions from two different approaches: online and face-to-face. These authors found that students in the face-to-face group experienced more intense emotions and significantly increased positive emotions compared to those in the online group.

Interest in the scientific community has led to a limited number of studies that have analyzed the implications of scaffolding on emotions. Technological resources appropriately combined with scaffolding methods foster students’ motivation by influencing their emotions and behavior [Delen, 14]. [Chen, 19] developed a two-level scaffolding with a web platform for social reading and applied it in a group reading comprehension and discussion workshop with university students. These authors concluded that the use of scaffolding fostered students’ collaboration, satisfaction and motivation. [Vongkulluksn, 18] assert that teachers should offer scaffolding that helps to improve the emotional state of students and thus reinforce a positive impact on the learning experience.

However, the effects of scaffolding on student emotions are still unclear, with some studies raising doubts. In some cases, no significant improvement has been found by the use of scaffolding. This is the case of the studies of [Deublein, 18], who applied scaffolding with students who were learning a second language and found no significant differences in motivation with other students who did not use scaffolding. In other cases, unintended effects have been found. For example, a high use of scaffolding can negatively affect students’ emotions and motivation by limiting their autonomy in the learning process [Chen, 16]. In the case of technological scaffolding, it can generate some computational anxiety in the student [Valle, 21]. Despite this, there are studies that point to the great potential that motivational feedback can offer in the learning process [Deublein, 18].

In summary, it is necessary to better understand the cognitive and affective effects of scaffolding-based learning in order to design scaffolding tools that promote learning with a good emotional state for the student [Barzilai, 14].

3 Learning System with Technological Scaffolding (LESCA)

This section describes the LESCA system that provides a framework for learning through technological scaffolding. The system implements strategic and metacognitive scaffolding and is oriented to Bloom’s taxonomy. Even though variations to Bloom’s Taxonomy have been proposed [Krathwohl, 22], in this work the revised taxonomy definition that establishes six levels in the cognitive domain has been used: Remember, Understand, Apply, Analyze, Evaluate and Create. These levels are ordered from simple to complex and from concrete to abstract.

Firstly, the pedagogical procedure and the architecture of the system are described. Secondly, the implementation of an exploratory prototype derived from this framework for learning electronic engineering concepts is showed.
3.1 Learning model with LESCA

The learning model is oriented towards integrating scaffolding into the process at the higher levels of Bloom’s taxonomy. This model consists of three sequential phases which are described below.

Phase I: Theory. In this first phase, students are introduced to the contents in a theoretical-practical and synchronous way, by means of an explanation by the teacher.

Phase II: Activity. In this phase, students must solve several challenges or activities that must be handed in to the teacher. These activities are framed in the following increasing levels of knowledge according to Bloom’s revised taxonomy [Krathwohl, 02]: remember, evaluate and create. Although the proposed learning model is oriented towards the higher levels of the taxonomy, it has been decided to incorporate the first level remember with the aim of incorporating previous cognitive levels in order to make scaffolding techniques effective at the higher levels [Kim, 18]. Within the more complex levels (evaluate and create), a computer-based scaffolding is integrated, based on the strategy of clues and questions and of a metacognitive and strategic type. The scaffolding is fading and is customizable (self-selection) by each student according to their particular needs and abilities. The activities of this phase should be integrated into a technological platform so that students can develop them at their own pace and in any place. During the resolution of these activities, students can make use of communication tools such as chat or virtual forum to comment with their classmates or with the teacher. After students have submitted the requested activities, they are shown automatic feedback based on their answers. This feedback has been previously integrated by the teacher in the technological platform.

Phase III: Feedback. This is the third and last phase, in which the students present their questions and doubts to the teacher synchronously, using the feedback they have received during the end of the second phase. The teacher answers the students’ questions and the students finish working on the parts of the activities from the second phase that they were not able to solve completely if this was the case. The teacher gives feedback to the students based on what they require during the lesson, thus developing teacher-student scaffolding based on feedback. Finally, the teacher and students conduct a retrospective on the activities of the second phase.

3.2 Architecture

LESCA is based on a scaffolding-oriented architecture consisting of two main components (see Figure 1). The first component is called Interface and is the component of user interaction with the tool. It allows the visualization of all the educational material to be accessed by the student. The second main component is the Scaffolding Engine, which implements scaffolding based on the questions posed to the student and their answers (Test components), and based on the task they are doing (Material components). All this information is stored personalised for each student (Profile component). Taking this information into account, the system adapts the feedback to be generated by the scaffolding (Feedback component). The learning tasks, the questions posed to the student and the feedback to be provided are organised into different levels of learning complexity (Boom Taxonomy component). According to the level of complexity reached by the student and their profile, the engine determines whether more or less scaffolding is required for the learning process.

Figure 2 shows the metamodel of the system, which consists of the following meta-classes:
3.3 Prototype for learning operational circuits

Taking into account the described architecture, a first exploratory prototype of a tool for learning the concepts of operational electronic circuits was implemented. This prototype
Figure 2: Scaffolding Architecture Metamodel

was implemented using Google Forms technology and integrated into Google Classroom. The result is a web platform that integrates scaffolding functionalities with communication capabilities between students and teacher: chat, noticeboard and forum. Its HTTP access via a simple web browser makes it universally accessible. The tool guides the navigation flow according to the student’s responses. According to these, the scaffolding (based on hints and questions) is either removed or maintained. If, for example, a student answers the set of questions and clues correctly, the scaffolding is removed and the final resolution proceeds. Otherwise, more scaffolding blocks continue to be displayed. In addition, when submitting answers, the student receives feedback for each of their answers. Figure 3 shows as an example a flow of screens of the scaffolding-guided system (the screens have been translated into English for better understanding). On screen 1, the student is given the task to perform and indicates that they need help and the level of complexity they perceive (very difficult). Based on that, the system proposes to solve a simpler exercise (screen 2). The student does not answer correctly and the system intensifies the scaffolding, asking questions that help the student to reflect and better understand the key concepts to be addressed (screen 3). When the system observes that the student is understanding simpler questions, it asks them if they feel they are able to retry the initial task (screen 4). The LESCA’s architecture allows the system to be used in multiple subjects and educational domains, requiring only that the learning tasks, questions and scaffolding feedback be updated specifically for each subject. That duty should be carried out by the teacher.

4 Experience

In order to validate the impact of scaffolding and LESCA prototype, an experiment was carried out with Associate Degree students during the 2020-2021 academic year. The design of the experience corresponds to a quasi-experimental pre-post study. The research questions together with the respective hypotheses were the following. In relation to the impact of scaffolding on knowledge acquisition:

RQ1. Does the scaffolding technique have a positive impact on the acquisition of knowledge at the higher levels of Bloom’s revised taxonomy?
H1: Students using LESCA tool in conjunction with teacher scaffolding significantly improve knowledge acquisition at the higher levels of Bloom’s revised taxonomy.

In relation to the impact on emotions the following was raised: RQ2. Does the scaffolding technique have a positive impact on students’ emotions and perceptions?

H2: The use of the LESCA tool together with teacher scaffolding significantly improves students’ emotional state.

Finally, in relation to possible differences in impact between teacher and technological scaffolding: RQ3: Is there a difference in the impact on knowledge acquisition and student perception between teacher and technological scaffolding?

H3: Teacher scaffolding significantly improves knowledge acquisition at higher levels of Bloom’s revised taxonomy than technology scaffolding.

H4: Teacher scaffolding is perceived to be significantly more useful for knowledge learning at higher levels of Bloom’s revised taxonomy than technological scaffolding.

4.1 Participants and process

The experience was carried out at the IES Julio Verne High School in Leganés (Madrid), Spain, within the Higher Level Training Cycle in Industrial Automation and Robotics and involved 36 students, who were organised into two groups. As it was not possible to randomly distribute the students into these two groups, since the classes were held according to the attendance and teaching shifts imposed by the school management, the students were divided into groups of two subjects, but randomly between subjects. Therefore, a group of 21 students from the 1st year Power Systems subject was formed to use the tool and the proposed learning model, constituting the experimental group (EG). On the other hand, with the aim of contrasting the impact of emotions, another group was formed with 15 students from the Industrial Robotics subject in the 2nd year of the same training cycle, which used the traditional lecture class methodology. This group was called the emotion control group (CG_EMO).
Both groups worked for the same amount of time, with the methodology being the main difference. Neither student received financial compensation or a score increase to motivate them to participate in the experiment. Participation was voluntary and anonymous. In order to preserve anonymity and to be able to correlate measures during the experiment, the EG students entered a personal code in the questionnaires they filled in, which was known only to them. In CG_EMO, this was not necessary as the students only completed one questionnaire.

In the academic year in which the experience took place in Spain there were still health restrictions on the capacity limits imposed by the health authorities due to COVID-19. Because of this, the students combined face-to-face classes with distance learning via the Google Classroom platform provided by the training centre. In addition, the EG was provided with the LESCA prototype integrated in this platform.

The EG was applied the teaching methodology proposed in subsection 3.1. Therefore, the treatment was organised in three stages corresponding to the three phases of the teaching method:

- **Stage 1**: Corresponds to Phase I-Theory, in which the teacher gave a classroom lecture explaining concepts about operational amplifiers (Op-Amps) and their functioning. This session lasted 2 hours and was given on the first day of the intervention.

- **Stage 2**: Corresponds to Phase II-Activity. Students performed three activities from home using Google Classroom and the LESCA prototype. Following the teaching methodology, one activity was for the remember level without scaffolding and the other two for the two higher levels of the revised Bloom’s taxonomy with technological scaffolding (evaluate and create). This stage took place from day 5 to day 14 of the intervention.

- **Stage 3**: Corresponds to Phase III-Feedback. In class, students presented questions and doubts to the teacher and completed the activities that they were not able to solve completely in stage 2, applying teacher scaffolding. This stage was carried out on day 15 in a 3-hour session.

In order to assess learning gains, several intermediate tests were set up during stage 2 for the levels of remember, evaluate and create. In addition, at the end of stage 3, a post-test of knowledge was conducted for these three levels. In addition, during stage 2 and for the two levels under study (evaluate and create), students took pre-tests and post-tests of perceived task difficulty, the former just when they were presented with the task statement before starting to do the task, and the latter after they had done it. In addition, a test of the perceived usefulness of scaffolding was carried out at these same levels under study. Therefore, this questionnaire was carried out at the end of activities 2 and 3 of stage 2 (to evaluate computer-based scaffolding) and at the end of stage 3 (to evaluate teacher scaffolding). Finally, at the end of the experience, in stage 3, a questionnaire was carried out to evaluate the students’ emotions.

The teaching methodology applied to the CG_EMO were lectures given by the teacher in the classroom, combined with teaching activities proposed by the teacher to be carried out at home, mainly using pencil and paper. In addition, like the EG, this group used the Google Classroom platform as online support. At the end of the experience, the emotions of the students in this group were measured.

Figure 4 shows a summary of the stages, activities and time sequencing carried out, where the planning for both the EG and CG_EMO groups can be seen.
4.2 Variables and instruments

The variables measured during the intervention and the instruments used are described below. The names of some variables may contain suffixes, which have the following meaning:

- **PRE**: Indicates that it is a variable measured at an initial point of a process (pre-test).
- **POS_INTER**: Indicates that it is a variable measured at an intermediate point of a process (intermediate test).
- **POS_FINAL** or **POS**: Indicates that it is a variable measured at the end of a process (post-test).

Table 1 shows the defined variables grouped by the instrument used to measure them. Specifically, four instruments were used. The first three are scales designed for the experience and the fourth is a validated scale:

1. **Knowledge scale**: Made up of multiple-choice and open-ended questions, using a correction rubric for the latter, weighting the score from 1 to 10. This scale was made up of a total of 12 items.
2. **Perception of difficulty scale**: Measures the student’s perception of the difficulty of a learning task. It consists of four questions on a Likert scale from 1 to 5.
3. **Perception of usefulness scale**: It measures the students’ perception of the usefulness of the scaffolding received using two Likert scale questions from 1 to 5.
4. Emotions scale. The validated AEQ questionnaire [Pekrun, 02b] was used. This questionnaire is made up of 85 items grouped into three parts that measure emotions at three different times of learning: before, during and after. In this experience, the 15 items of the part after learning were used, using a Likert scale from 1 to 5.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge scale</td>
<td>KN_REMEMBER_POS_INTER</td>
<td>Knowledge at the remember level after Activity 1 and after the experience respectively.</td>
</tr>
<tr>
<td></td>
<td>KN_REMEMBER_POS_FINAL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>KN_EVALUATE_POS_INTER</td>
<td>Knowledge at the evaluate level after Activity #2 and after the experience respectively.</td>
</tr>
<tr>
<td></td>
<td>KN_EVALUATE_POS_FINAL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>KN_CREATE_POS_INTER</td>
<td>Knowledge at the create level after Activity #3 and after the experience respectively.</td>
</tr>
<tr>
<td></td>
<td>KN_CREATE_POS_FINAL</td>
<td></td>
</tr>
<tr>
<td>Perceived difficulty scale</td>
<td>PER_DIF_PRE</td>
<td>Perception of the difficulty of the activities before and after the activities respectively (calculated as the arithmetic mean of all activities).</td>
</tr>
<tr>
<td></td>
<td>PER_DIF_POS</td>
<td></td>
</tr>
<tr>
<td>Utility perception scale</td>
<td>PER_UTIL_SCAFF_TEC</td>
<td>Perception of usefulness of technological and teacher scaffolding during the experience.</td>
</tr>
<tr>
<td></td>
<td>PER_UTIL_SCAFF_TEACHER</td>
<td></td>
</tr>
<tr>
<td>Emotions scale</td>
<td>ANXIETY, ANGER, PRIDE, EMBARRASSMENT, HOPELESSNESS, ENJOYMENT</td>
<td>Emotions experienced by the students</td>
</tr>
</tbody>
</table>

| Table 1: Variables and instruments |

5 Results

The statistical analysis of the data collected was carried out with the IBM SPSS Statistics 27 software. Due to the sample size (N < 30) and the rejection of the normality hypothesis (Shapiro-Wilk test) for most of the variables collected, non-parametric tests were used. The results are presented in detail below.

5.1 Knowledge acquisition

Table 2 shows descriptive statistics of the variables related to knowledge measured at the three cognitives levels. In addition, a hypothesis test for equality of means (Wilcoxon test) was performed, finding statistically significant differences (p < 0.05) as shown in Table 2 in bold.

5.2 Emotions and student perceptions

The emotions felt by students of the experimental and control groups after the experience were compared. Figure 5 shows the mean by groups of the emotion variables, where it can be seen that the experimental group has higher values for positive emotions and lower values for negative emotions.

To test whether these differences in emotions are significant, we applied a test of equality of means between the two groups for each emotion (U-Mann Whitney test), finding statistically significant differences (p < 0.05) in ANXIETY and HOPELESSNESS (see Table 3).
Alulema D., Paredes-Velasco M., de Arriba Lasso R.: LESCA: Scaffolding and...

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>KN_REMEMBER_POS_INTER</td>
<td>25</td>
<td>2.50</td>
<td>7.50</td>
<td>5.78</td>
<td>1.98</td>
</tr>
<tr>
<td>KN_REMEMBER_POS_FINAL</td>
<td>16</td>
<td>5.00</td>
<td>10.00</td>
<td>9.38</td>
<td>1.71</td>
</tr>
<tr>
<td>KN_EVALUATE_POS_interp</td>
<td>12</td>
<td>2.33</td>
<td>10.00</td>
<td>6.39</td>
<td>3.33</td>
</tr>
<tr>
<td>KN_EVALUATE_POS_FINAL</td>
<td>16</td>
<td>3.00</td>
<td>10.00</td>
<td>8.63</td>
<td>2.50</td>
</tr>
<tr>
<td>KN_CREATE_POS_interp</td>
<td>11</td>
<td>1.40</td>
<td>7.00</td>
<td>4.04</td>
<td>2.11</td>
</tr>
<tr>
<td>KN_CREATE_POS_FINAL</td>
<td>15</td>
<td>6.00</td>
<td>10.00</td>
<td>8.93</td>
<td>1.16</td>
</tr>
</tbody>
</table>

Table 2: Descriptive statistics and test of contrast of the knowledge variables

<table>
<thead>
<tr>
<th>Contrast test of means</th>
<th>Variables</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KN_REMEMBER_POS_INTER-KN_REMEMBER_POS_FINAL</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>KN_EVALUATE_POS_INTER-KN_EVALUATE_POS_FINAL</td>
<td>0.023</td>
</tr>
<tr>
<td></td>
<td>KN_CREATE_POS_INTER-KN_CREATE_POS_FINAL</td>
<td>0.005</td>
</tr>
</tbody>
</table>

![Image of Figure 5](image-url)

Figure 5: Mean of the variables on emotions

We also compared students’ perceptions of the difficulty of the activities (before and after applying scaffolding) and the perceived usefulness of technological scaffolding versus teacher-student scaffolding. Table 4 shows the descriptive statistics and the contrast of equality of means between the variables of perceived usefulness and difficulty using Wilcoxon test, with statistically significant differences marked in bold (p < 0.01).

### 5.3 Relationship of emotions to perception and knowledge

A correlation analysis was carried out to check whether there was a relationship between the emotions experienced by the students in the EG and their perceptions of the difficulty of the task and usefulness of the scaffolding approach, as well as the knowledge

<table>
<thead>
<tr>
<th>ANXIETY</th>
<th>EMBARRASSMENT</th>
<th>ANGER</th>
<th>PRIDE</th>
<th>HOPELESSNESS</th>
<th>ENJOYMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.025</td>
<td>0.294</td>
<td>0.240</td>
<td>0.334</td>
<td>0.012</td>
<td>0.552</td>
</tr>
</tbody>
</table>

Table 3: Contrasts of the variables emotions between the control and experimental Groups (p-value)
Table 4: Descriptive statistics for student perception variables

Table 5: Main relationships between variables

6 Discussion

This section discusses the results obtained from the experience in two parts. On the one hand, the results related to knowledge acquisition and on the other hand, the results related to students’ emotions and perceptions.

6.1 Scaffolding enhances knowledge acquisition at higher levels of Bloom’s taxonomy

In relation to learning, the results indicate that there was an improvement in the acquisition of knowledge at the end of the activities with technological scaffolding. It should be taken into account that, at the beginning of the experience, the students had not studied the specific topic in previous subjects (operational amplifiers). Furthermore, it was asked if any student had studied it or had any knowledge of it, and all of them stated that they did not know it. Therefore, at the beginning, the students had no knowledge of the contents to be learned during the experience. However, at the end of the experience, the students obtained average scores in the two higher levels of the taxonomy analysed of 8.63 and 8.93 out of 10 (evaluate and create levels respectively). Therefore, the significant
learning gain after the experience is obvious, thus accepting hypothesis H1: “Students using the LESCA tool together with teacher scaffolding significantly improve knowledge acquisition at the higher levels of Bloom’s revised taxonomy.”

On the other hand, the level of knowledge was significantly higher at the end of the experience completely (after applying teacher scaffolding) compared to the level of knowledge in the intermediate phases of the experience, where only technological scaffolding had been applied. Therefore, hypothesis H3 is accepted: “Teacher scaffolding significantly improves knowledge acquisition at higher levels of the revised Bloom’s taxonomy than technological scaffolding.”

These findings on the impact of knowledge acquisition are in line with previous work. [Pata, 06] did a preliminary study in which a double-level scaffolding was applied among students in a university reading workshop and found that participants developed critical thinking skills, a competence present in the higher levels of Bloom’s taxonomy. The study by [Kim, 18], whose authors conducted a review of related work, found that computer-based scaffolding positively impacted knowledge outcomes in problem-based learning in STEM education. The work presented in this article makes two contributions to the findings of [Kim, 18]. First, the results of [Kim, 18] are supported by a literature review using a Bayesian meta-analysis, placing the focus of the study on the meta-analysis itself and its comparison with classical methods. In contrast, the work in this article focuses on the empirical evidence of the impact on the higher levels of the Bloom’s revised taxonomy. Secondly, the study by [Kim, 18] analyses only the impact of computer-based scaffolding and does not take into account teacher scaffolding. However, the study presented here has found that teacher scaffolding significantly improves learning outcomes over technology scaffolding (confirmation H3). [Sun, 21] found that the use of teacher scaffolding strategies can improve mathematics learning in primary education, although these studies did not analyse whether it had a significant impact, which the present study did.

However, it should be noted that improved learning outcomes have not always been found when incorporating scaffolding into STEM learning. [Valle, 21] found no statistically significant difference between the groups analysed suggesting that the scaffold intervention did not have an appreciable impact on learning outcomes. [Barzilai, 14] found no learning gains with the Scaffold intervention, although they found that combining it with game-based learning significantly improved learning. The study presented here provides evidence that the combination of teacher and technology scaffolding can have a positive impact on STEM content learning.

Finally, there was one finding from this work that was not the focus of the research and has appeared in the results. The results indicate that teacher scaffolding significantly improves learning outcomes at the remember level (see Table 2). On the one hand, this finding constitutes an indication that scaffolding techniques can improve the lower levels of Bloom’s taxonomy, and on the other hand, it raises uncertainty as to whether technological scaffolding could also have a positive impact on learning at these lower levels (please note that no technological scaffolding was applied at this level during the experiment). In this regard, some studies have already pointed out the need to study this issue [León, 18].

6.2 Emotional state and student perception

In relation to emotions, the results indicate that the positive emotions of the experimental group (pride and enjoyment) were higher than those of the control group, while the negative emotions (anxiety, embarrassment, anger and despair) were lower. However,
statistical analysis confirms that these differences between the experimental and control groups are not significant for all emotions. Therefore, H2 is rejected: "The use of the LESCA tool together with teacher scaffolding significantly improves the emotional state of the students." However, although the improvement is not significant in all emotions, there is a tendency to improve emotions in the experimental group with respect to the control group, with the former experiencing higher positive emotions and lower negative emotions, including some of them in a significant way as the results show. Therefore, it can be affirmed that the scaffolding techniques had a positive impact on the students’ emotions.

Nevertheless, some previous work has found undesirable effects when applying scaffolding. Technological scaffolding can have a negative impact on student competence, autonomy and interest [Chen, 16]. Teacher-based scaffolding or scaffolding in a collaborative context may decrease the perception of autonomy [Chen, 16] and negatively impact on student intrinsic motivation [Ciani, 08]. These studies have focused on analysing student motivation and perception and have not delved into the impact on emotions, which is the focus of the study presented here.

On the other hand, there are studies that are in line with the results found in the present study. Although some studies have not found evidence of improvement when applying scaffolding, they have found that scaffolding does not have a negative impact on emotions [Barzilai, 14]. The study by [Nie, 11] found no significant differences in student attention and satisfaction when applying scaffolding of motivation but did find positive effects on students’ overall attitude towards learning. [Vongkulluksn, 18] states that the integration of emotion-related scaffolds positively reinforces the learning of STEM content, and even the incorporation of scaffolds interspersed in various phases of the learning process can improve students’ perception of the subject matter [Sun, 21]. Therefore, the present study corroborates the positive effects of scaffolding on emotions already pointed out by previous work.

An additional finding of the present study is related to anxiety and despair. On the one hand, anxiety and despair were found to be directly related to the perceived difficulty of the learning task and inversely related to the perceived usefulness of scaffolding. On the other hand, the results indicate that these two emotions, anxiety and despair, were significantly reduced in students who used scaffolding compared to those who did not.

This finding is contrary to the results of the work of [Valle, 21], whose authors found that students who used scaffolding during a statistics course had higher levels of anxiety at the end of the course than those in the control group. The authors explain this divergence from the results of Valle and colleagues on two grounds. The first reason is related to the perceived importance that the student attaches to the learning task. High levels of task importance perceived by students are related to high levels of anxiety [Nie, 11]. It is possible that emphasising the importance and usefulness of the task generates student fear of failure at a significant psychological cost [Eccles, 20] and generates anxiety that may be increased by the perception of failure [Boehme, 17]. Valle and colleagues applied task-value scaffolding, which emphasises the importance of the task. However, in the experience presented in this article, metacognitive and strategic scaffolding was applied, with less attention paid to task importance.

The second reason may be related to the perception of difficulty. On the one hand, as already indicated above, one of the findings of this work is that anxiety is related to the perception of difficulty. On the other hand, the results indicate that the perceived difficulty of the task decreased significantly at the end of the experience. Therefore, a second reason for the decrease in anxiety may have been the low perceived difficulty of the task noticed by the student at the end of the experience. The work of Kusmaryono
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and colleagues found that scaffolding significantly decreased anxiety and improved the perceived difficulty of the subject matter [Kusmaryono, 2020].

Thus, the type of scaffolding may influence student anxiety. Further studies are needed to understand what type of scaffolding intervention may be beneficial in reducing anxiety [Valle, 21].

Finally, two findings have been found in relation to the usefulness of scaffolding. First, it has been found that the perceived usefulness of technological scaffolding is directly related to enjoyment. [Barzilai, 14] combined scaffolding in a game-based learning teaching methodology and found that enjoyment was related to perceived playfulness, but found no relationship with scaffolding. This work provides empirical evidence for a relationship between enjoyment and scaffolding. Secondly, it was found that students perceive teacher scaffolding to be significantly more useful than technological scaffolding. Therefore, hypothesis H4 is accepted: “Teacher scaffolding is perceived to be significantly more useful for knowledge learning at the higher levels of Bloom’s revised taxonomy than technological scaffolding.” Confirmation of this hypothesis suggests that technological scaffolding can be optimised when integrated with teacher scaffolding [Pata, 06] and delivered effectively in a problem-based learning context [Kim, 18]. Teacher scaffolding encourages students to explore and activates their interest in the subject matter [Sun, 21].

6.3 Threat to validity

In relation to the validity of the design of this study, the treatment and control groups were formed with different individuals. Nevertheless, the experiment presents some challenges or drawbacks. First, the groups were not created by chance, but by the students who attended different schedules, so there is no guarantee that the sample reflects the population.

Second, the experiment had a control group which was used to validate only the results of emotions and there was not a control group to validate learning outcomes. Besides, although all students enrolled in the same Higher Level Training Cycle, they belonged to different courses of two different years. Therefore, students’ profiles and background could be different.

Finally, in relation to the statistical study, a descriptive analysis was performed and then an inferential study in which errors of type 1 (incorrect rejection of a null hypothesis) and type 2 (failure to reject a false null hypothesis) could occur [Lazar, 17].

7 Conclusions and Future Work

This article presents a learning platform based on strategic and metacognitive scaffolding oriented to different cognitive levels called LESCA. The platform presents content to the student and if they make mistakes, the system identifies them and provides feedback on new content based on a strategy of hints and questions. To validate the impact of the proposal on learning outcomes, emotions and student perception, a pre-post design experiment was carried out, with experimental and control groups. The participants were students of Industrial Electronics and Robotics Associate Degree. Several questionnaires were used to measure knowledge, perceived difficulty of the task, perceived usefulness of the scaffolding system and student emotions.

The main findings found as a result of the study have implications for both the cognitive and emotional aspects of the student. In relation to cognitive aspects, it has
been found that the use of scaffolding improved knowledge acquisition at the higher levels of complexity of Bloom’s revised taxonomy. In addition, the results indicate that teacher scaffolding significantly improved the results with respect to computer-based scaffolding. In relation to students’ emotions and perceptions, it was found that students who performed the tasks with scaffolding experienced significantly less anxiety and despair than those who did not use scaffolding. In addition, the perceived usefulness of technological scaffolding was found to be related to the emotion of enjoyment. On the other hand, the results indicate that students perceived teacher scaffolding to be significantly more useful than computer-based scaffolding.

As future work, we consider replicating the experience with a larger sample size and analysing the impact of scaffolding on the lower levels of Bloom’s taxonomy, since the study has found indications of a possible positive impact on knowledge acquisition at these levels.

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