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A STUDY ON THE EFFECTIVENESS OF AN UNDERGRADUATE ONLINE TEACHING LABORATORY WITH SEMANTIC MECHANISM FROM A STUDENT PERSPECTIVE

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ABSTRACT

Aim/Purpose	The current study was conducted to investigate the students' perceived satisfaction with the use of a semantic-based online laboratory, which provides students with a search mechanism for laboratory resources, such as instruments and devices.
Background	The increasing popularity of using online teaching labs, as an important element of experiential learning in STEM education, is because they represent a collection of integrated tools that allow students and teachers to interact and work collaboratively, whereas they provide an enriched learning content delivery mechanism. Moreover, several research studies have proposed various approaches for online teaching laboratories. However, there are hardly any studies that examine the student satisfaction provided by online laboratories based on students' experiential learning.
Methodology	To measure the effectiveness of the laboratory, we performed a case study in a Computer Fundamentals online course in which undergraduate students were able to manage devices and instruments remotely. Participants were a sample of

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	50 third semester students of Bachelor's degree in Information Technology Administration who were divided in experimental and control groups (online laboratory vs. traditional manner). Given a laboratory assignment, students were able to carry out the management of devices and instruments through a LabView virtual environment and web services. The data of the experiment were collected through two questionnaires from both groups. The first is a system usability score (SUS) questionnaire concerning lab usability and the second one students' cognitive load.
Contribution	The results of the study showed a high correlation between usability and cognitive load-satisfaction of students who used the online teaching laboratory compared to the students who did not use it.
Findings	On the one hand, the online laboratory provided students with an easy way to share and deploy instruments and devices, thus enhancing system usability. On the other hand, it offered important facilities which enabled students to customize the search for instruments and devices, which certainly had a positive impact on the relationship between cognitive load and satisfaction.
Recommendations for Practitioners	In this work we propose an intuitive laboratory interface as well as easiness to use but challenging and capable of providing similar experiences to the traditional laboratory.
Recommendations for Researchers	This study is one of the first to analyze the cognitive load-satisfaction relationship and compare it with usability scores.
Impact on Society	Our analyses make an important contribution to the literature by suggesting a correlation analysis comparing the results of experimental and control groups that participated in this research work, in terms of usability and cognitive load-satisfaction.
Future Research	Future work will also investigate other methodological aspects of instructional design with the aim to improve personalized learning and reinforce collaborative experiences, as well as to deal with problems related to laboratory access, such as authentication, scheduling, and interoperability.

Keywords	online labs, student's satisfaction, cognitive load, usability

INTRODUCTION

In online laboratories, ontologies and semantic descriptions of the laboratory provide a mechanism capable of centralizing resources and functional capabilities distributed across networks and presenting different types of devices to students. A semantic model improves the personalization of students (Halimi et al., 2014) according to their preferences, knowledge, interests, motivations, and objectives. When using online resources for learning, an important point to consider is student satisfaction, which is described as a specific result of learning rather than a condition for learning (Bradford, 2011). In design, satisfaction plays an important role so that instruction can be considered effective; as such, it is also important to distinguish between learning outcomes and learning conditions. Measuring satisfaction can provide information on the effectiveness of instructional design, based on our understanding of its relationship with cognition. In the case of online laboratories, the effectiveness of instructional design can provide a positive learning experience, which is related with some characteristics such as the easiness to install laboratory components, an intuitive laboratory interface as well as easiness to use but challenging and capable of providing similar experiences to the traditional laboratory. The concept of effectiveness of the online laboratory in teaching science is related with a set of teaching-learning variables such academic achievement, science processes, scientific attitudes, attitudes towards the use of e-lab technology, estimation of the classroom environment, visual thinking, and laboratory skills (Al-Musawi et al., 2015). Overall, it is important to keep in mind that online students can perform laboratory activities without direct expert supervision (Rowe et al., 2018).

RESEARCH OBJECTIVES AND QUESTIONS

The online laboratory is a controlled environment, where one can carry out experiments. An experiment is an empirical investigation under controlled conditions designed to examine the properties of and relationship between specific factors (Denscombe, 2014). In this work, we evaluate the benefits for learning based on a semantic model for online laboratories which allows semantic browsing of remote instruments and devices, collaboration among participants, and customization. The semantic model and experiments, on which the ontological design has been applied, are based on the work described in the doctoral thesis (Gutiérrez-Carreón, 2016).

The potential of the online laboratory for achieving learning objectives is based on the principles of experiential learning, which is related with student satisfaction. Indeed, experiential learning consists of four phases: active experimentation, concrete experience, reflexive observation, and abstract conceptualization (Kolb & Kolb, 2005). These objectives are basic learning elements in any program for STEM education (education of science, technology, engineering, and mathematics) (Bybee, 2010). As concerns evaluation, we focus on issues related with the correlation of Usability (Hollender, Hofmann, Deneke & Schmitz, 2010) and Cognitive Load Theory (Plass et al., 2010). Regarding the theory of cognitive load (CLT), primary knowledge cannot be taught, because it consists of generic cognitive skills that are acquired unconsciously, while secondary knowledge requires explicit instruction in education and training contexts (Sweller, 2019). It also concerns working memory of limited duration before being permanently stored in long-term memory from where unlimited amounts of return information can be turned into limited memory to govern actions affected by the environment.

To appraise student satisfaction and test the effectiveness of the proposed laboratory, we set the following research question:

- What is the correlation between usability and cognitive load-satisfaction of students who use an online teaching laboratory with ontology design and semantic concept detection compared to those students who do not use it?

Regarding cognitive load theory, we explore whether our instructional design proposal takes the limitations of working memory into account to avoid overloading the memory capacity and, therefore, deterioration of learning. As concerns usability, we examine the extent to which a user can satisfactorily, effectively, and efficiently fulfill a task, emphasizing the context that these users operate and the specific tasks they accomplish.

In the remainder of this paper, we first present related work for online laboratories; we then present the semantic modeling of online laboratory elements and discuss how it can be used to discover resources in a network. Subsequently, we present a case study of a Computer Fundamentals online laboratory implementing a common access point for instruments and devices, making them searchable by non-functional properties described in a semantic model. Lastly, we present and discuss the results, and we draw conclusions and future work.

RELATED WORK

The purpose of this section is to provide an overview of online laboratories that have been incorporated into various research projects as components that facilitate learning. Some approaches introduce online labs into curriculum disseminating a culture of technology-enhanced learning and sharing the knowledge that provides opportunities to develop and assess graduate attributes (Brouwer & Jansen, 2019). Liu et al. (2015) design and implement 3D virtual laboratories that combine advanced visualization, interactive management through complex virtual devices, and intelligent components. Al-Zoubi (2018) presents a communication engineering laboratory shared by several universities in Jordan. He developed a survey aimed at investigating students' comprehension, perception, and satisfaction, although their results are not measured in terms of cognitive load and usability, as well as without obtaining a correlation between both factors. The effectiveness of the virtual laboratories is measured in terms of the increase the learning abilities of the students, the level of understanding of concepts by implementing the virtual laboratory, and identifying whether the virtual laboratory helps them increase learning at their own space (Rajendran et al., 2010).

Despite the benefits that online laboratories represent, a limitation that arises is the difficulty of creating common knowledge among participants (Horton et al., 2011). Many systems that involve search mechanisms still use syntactic approaches to discover resources in a network, which do not satisfy the current needs of online teaching laboratories, in which the use of control devices and instruments takes place. Some works in the field of tool design to support learning (Angeli et al., 2009; Sawicka et al., 2008) have found that cognitive load theory (CLT) and some concepts of human-computer interaction (HCI), like usability, should be integrated to determine the benefits for systems and learning. According to CLT, the limitations of working memory should be considered by any instructional design if one wants to reduce cognitive overload in students and prevent a degradation of learning. Usability of a tool is achieved when a user can use this tool in an efficient and effective manner to accomplish a task satisfactorily. Working memory is restricted in capacity when dealing with novel, unorganized information since it becomes progressively difficult to find a suitable form of organization when dealing with a large amount of data (Van Merriënboer & Ayres, 2005).

The semantic description is essential to enhance web resources classification, findability, and discoverability (Qassimi, 2019). Previous work in semantic search and ranking in Web of Data (Butt et al., 2014) coped with the problem of discovering resources in a network. In that sense, in the area of virtual laboratories several ontology-based semantic search mechanisms have been developed. More specifically, Maier and Niederstätter (2010) developed Lab2Go, an online portal which is supported by the Semantic Web. Virtual laboratories, called Library of Labs (LiLa), have been implemented to provide an infrastructure to engineering and science undergraduate students so that they can perform network remote experiments, exchanging experimental setups and simulations among them (Richter et al., 2011).

De Jong et al. (2014) endowed their Go-Lab portal with a repository of online labs (remote, virtual, and datasets) as well as with scenario and lesson plan capabilities, which provide teachers with facilities of building dedicated inquiry learning spaces (ILS). For apps, Go-Lab follows the OpenSocial metadata specification and the ROLE Ontology. The FORGE initiative (Forging Online Education) (Marquez-Barja et al., 2014) integrates a rich linked-data ontology with a set of high-performance testbeds to construct specific learning paths in order to enhance Self-Regulated Learning (SRL).

These works use valuable technological solutions, which in all cases describe the components of online labs semantically, in some cases through an ontology and in others through a metadata system, but in all cases they implement a mechanism of semantic search. However, none of these studies has considered issues of usability and student cognitive load correlation. Regarding usability, Brooke (2013) defines usability accordingly effectiveness, efficiency, and satisfaction. He proposes the system usability score (SUS), which is a quick tool with a good ability to discriminate and identify systems with good and poor usability comparable to other standardized usability questionnaires. There are recent additions to standardized usability questionnaires, as is the case of Usability Metric for User Experience (UMUX) and its shorter form variant UMUX-LITE (Berkman & Karahoca, 2016). UMUX aims to measure perceived usability by employing fewer items that are in closer conformance with the ISO 9241 definition of usability. The scales significantly correlated with SUS, indicating their concurrent validity.

Our study explores these issues through a control and experimental group. The aim and results of our work are explained and justified in more detail in the following sections.

SEMANTIC REPRESENTATION OF ONLINE TEACHING LABORATORY

The objective of this section is to describe the semantic representation of our online laboratory. The use of semantic representation for learning scenarios is not new. Some of these representations try to reflect the context of user interaction with the learning scenario and the functionalities that are part of it. For example, Lim et al. (2018) build a semantic representation to monitor student engagement and evaluate its impact on student performance in Massive Open Online Courses (MOOCs). Vlachostergiou et al. (2016) used semantic technology to resolve the challenge of context-aware user modeling network communication in smart homes, where, like in an online laboratory, users interact with sensors and instruments. Robal et al. (2017) proposed an ontology for evaluating the usability of User Interface in real time.

Our semantic representation of an online laboratory is based on the user interaction with the learning environment. Then, the main classes of the ontology are the User, the Learning Scenario, and the Learning Service (Figure 1). The User defines the entity (which could be any person, group, or process) that employs the learning scenario. 'UserProfile' is a specific property which characterizes the entity that employs a service (teacher, student, or another process). The Learning Scenario describes the interaction that takes place between users and services. So, it constitutes the place where the learning process is carried out. 'Description' constitutes a specific property that allows one to define the ontology which is linked to the learning scenario. The Learning Services identify the activities that support the learning scenario as well as the principal functional and non-functional characteristics of the applications related with it. In the particular case of online laboratory, Learning Services are related with the devices and instruments of each laboratory.

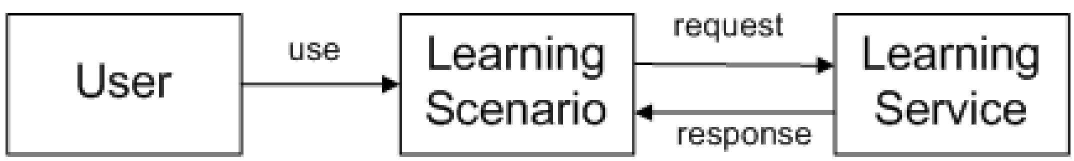

Figure 1. Semantic representation of online laboratory

The fundamental elements used for representing the Semantic Web consist of two core standards: The Resource Description Framework (RDF) (Cyganiak et al., 2014) and the Web Ontology Language (OWL) (Motik et al., 2009).

The form of this semantic representation is implemented via Linked Data (Hauswirth et al., 2017), which refers to data published on the Web in such a way that it is machine-readable, where its meaning is explicitly defined.

SEMANTIC SEARCH OF DEVICES AND INSTRUMENTS

It is important to clarify the way users can employ the laboratory to search and identify the devices and instruments they need. The Semantic model has been implemented as a prototype of an online laboratory aiming at helping students learn how to control devices through computer resources as well as how to browse and search resources which are handled by servers in various faculty departments. The laboratory enables teachers and learners not only to manage instruments or devices in real-time but also to access and exploit data.

As regards teachers, the online laboratory allows them to build a semantic model. As for students, especially those who are not familiar with the laboratory semantics, it enables them to perform spontaneous searches of available services, and, when students locate them, it enables them to have a direct access to the identified services. The search of learning services depends on a linked data semantic container and is based on non-functional attributes. The semantic container can be employed to collect information on each service, which provides a simple and effective way to search and query the necessary parameters, that is, the required functional specifications, to invoke the service.

METHODOLOGY AND RESEARCH METHODS

This section explains the research methodology we used in this study. The use of experiments in social sciences is employed as a research method to allow determining certain causal factors, establishing controls to manipulate them, and making empirical observations and measurements (Denscombe, 2014). The essential feature of experimental research is that investigators deliberately control and manipulate the conditions that determine the events in which they are interested, introduce an intervention, and measure the difference that it makes (Cohen et al., 2018). Embedding heuristics to cope with cognitive load issues led to the development of a framework to support designers of traditional instructional design models in their everyday design practices (Sentz et al., 2019). The aim of the experiment was to assign specific features to students so that they carry out a search based on non-functional information for identifying learning services to manage devices or tools that were necessary for performing their assignments. In addition, a validation tool was used to verify whether students had privileges to use this framework. Figure 2 shows the complete experimental process for control and experimental group, where we can notice that the process will be the same for the control group and the experimental group, with the difference that a new factor will be added to the experimental group, of which we intend to observe and measure the effect.

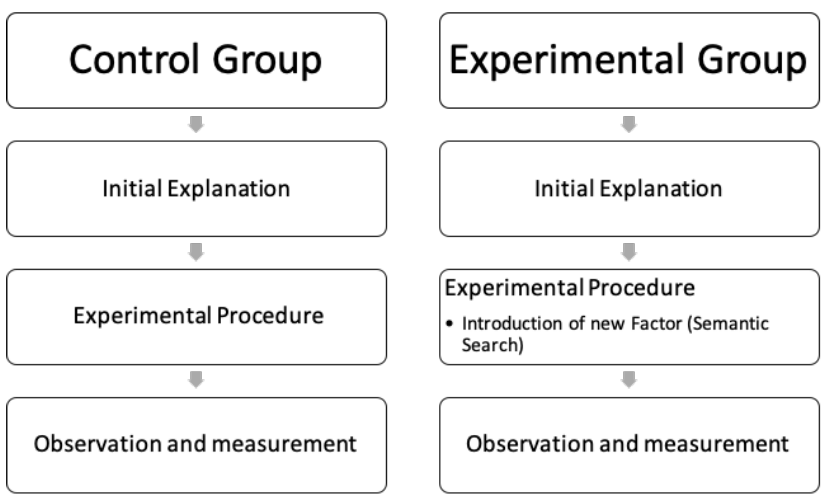

Figure 2. Complete Experimental Process

The main idea of using a semantic model in an online laboratory is that students, when carrying out an experiment involving remote control of instruments and devices, can have tools in the same environment that can help them browse and search for these services and publish the URLs to access them. All this is done to provide them with a tool with better usability and learning experience and with less cognitive load, thus enabling them to attain a more satisfactory learning. In the case study in which we experimented with our online laboratory, we have focused on defining instruments and devices. However, it can extend to any object that can be accessed through a URL, such as documents, videos, or other types of learning tools defined as a web service.

Participants and Experimental Procedure

In this section, we describe the participants who participated in the study (assigned randomly to experimental and control groups) as well as the procedure used in our experiment.

Participants

Participants were undergraduate students of the Computer Fundamentals course and used the online laboratory portal to carry out a laboratory practice. Computer Fundamentals is a third semester course of the Bachelor's degree in Information Technology Administration, in which the basic theoretical concepts of computer operation are taught, such as the binary number system, analog signals as well as digital and electronic device principles for students without prior knowledge of electronic principles. As a complement to the theoretical lessons, the laboratory practice is carried out for the measurement of analog and digital signals in devices, as well as the control and handling of measuring instruments, such as the multimeter and oscilloscope. After the first practical activities, students became acquainted with laboratory devices and instruments and obtained the basic knowledge to manage LabView virtually. A total of 50 students were selected to participate in the experiment. Regarding the small sample size, it is quite consistent with the nature of the qualitative data to be analyzed (Denscombe, 2014). These students belonged to the same class, and they were randomly divided into two groups: an experimental group (N=25) and a control group (N = 25). Among them, 19 were female and 31 male. Then, 9 female students were distributed in the experimental group (36%) and 10 female in the control group (40%). Likewise, 16 male students were assigned in the experimental group (64%) and 15 males in the control group (60%). All students have had a regular academic performance, that is, they do not have any outstanding credit from other previous courses, therefore, students had the same background and experience in the use of online laboratories, and the control and experimental groups were formed randomly.

Experimental procedure

During the laboratory practice students were able to carry out the management of devices and instruments through a LabView virtual environment and web services. Explanation of access and control of devices and instruments through LabView was given to both the experimental and control group. The control group students could access resources directly through the internet browser of the equipment that was connected to the instruments and devices in a traditional manner. The experimental group students received an additional explanation of the use of the online laboratory. The people who were responsible for the lab had the right to administer the ontological design of instruments and devices through registering, updating, or deleting them. Students could basically browse and search semantic concepts from online resources.

When the experiment was completed, both groups took two questionnaires: the usability one and the one which examined the relationship between students' cognitive-load and satisfaction. All participating students were informed that theirs answers would be treated anonymously, confidentially, and without including any personal data. So, students were eager to answer both questionnaires and provided the requested data.

Data Collection

Here we describe how the data of the experiment were collected, basically through questionnaires. (The link where the raw data is located is Data Collection .) Questionnaires offer benefits of standardized and open responses to a range of topics from a large sample or population. They can be cheap, reliable, valid, quick, and easy to complete. The field of questionnaire design is vast (Cohen et al., 2018).

This study has set two important goals to achieve which are related with the benefits of the semantic search that our online laboratory provides. These benefits are linked to the phases of experiential learning that students can go through: active experimentation, specific experience, abstract conceptualization, and reflexive observation. The first goal (benefit) concerns usability. Here, we examined how the semantic search functionality can improve the system ease of use and students' satisfaction. The second goal (benefit) concerns cognitive load. Here, by having an online laboratory based on ontology design and semantic concept detection, we examined whether this system achieved to guide experimental group students' attention to more appropriate learning by letting them have less cognitive overhead. Extraneous cognitive load has been shown to be reduced by the use of a learning environment whose design has been supervised by standard usability principles and guidelines (Hollender et al., 2010). The interrelation of these two goals needs to be further supported by an increase of students' satisfaction.

Concerning the evaluation of usability issues, we asked students to respond to a usability questionnaire (Brooke, 1996). Bangor et al. (2008) showed the following qualitative interpretation of SUS scores (Figure 3).

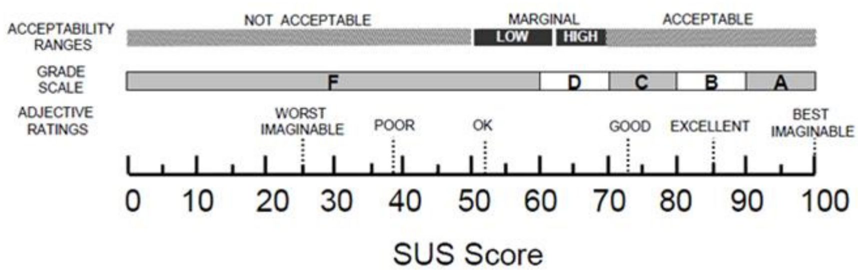

Figure 3. SUS Adjective rating – by Bangor et al. (2009)

As shown in Figure 4, we have considered ten questions, five positively and five negatively worded, arranging positive and negative questions in an alternate fashion.

Q1	I think that I would like to use this system frequently.
Q2	I found the system unnecessarily complex.
Q3	I thought the system was easy to use.
Q4	I think that I would need the support of a technical person to be able to use this system.
Q5	I found the various functions in this system were well integrated.
Q6	I thought there was too much inconsistency in this system.
Q7	I would imagine that most people would learn to use this system very quickly.
Q8	I found the system very cumbersome to use.
Q9	I felt very confident using the system.
Q10	I needed to learn a lot of things before I could get going with this system.

Figure 4. Questionnaire 1: The System Usability Scale (SUS) questionnaire

Concerning student's cognitive load, our interest is to determine how the use of ontology design and semantic concept detection can provide students with a common access point to laboratory resources. Doing so, students can obtain these resources anytime and anywhere. In addition, they will be able to customize them according to their preferences and privileges as well as to any specific needs they may have when collaborating with others. Our ultimate aim is to examine whether this laboratory can reduce students' cognitive load which, in turn, can lead students to improve their motivation for learning.

To that end, based on Bradford's (2011) proposal that suggested a coefficient that describes the relationship between students' cognitive load and satisfaction, we designed a survey instrument to evaluate our laboratory. In particular, this instrument focuses on three specific indicators: awareness, challenge, and engagement. According to Bradford there are three ways that these indicators could affect students' cognitive load: make students aware of the criteria that can be used for completing an online course successfully; determine the degree of effort or even the challenge needed to accomplish the course requirements; and identify the factors that enhance engagement.

We implemented a survey of ten items based on a five-point Likert scale. As with the SUS questionnaire, we have designed ten questions, five positively and five negatively worded, arranging positive and negative questions in an alternate fashion. As we do in SUS, a score is calculated by summing up the score contributions from each question item.

Indeed, the questionnaire in Figure 5 tries to record student's perception of satisfaction regarding the online laboratory in terms of the relationship between cognitive load and satisfaction, focusing on the indicators of students' awareness, challenge, and engagement. Based on Kolb and Kolb (2005) who claim that achieving an adequate learning space can enhance experiential learning, enabling students to assume responsibility for their own learning in the online laboratory can lead them to improve their capacity to learn from their involvement in this learning situation.

Q11	I think that the design of the experiment motivates me to participate
Q12	I think access to solve the experiment is confusing
Q13	I think the experiment facilitates discussions or debates with my classmates and the teacher
Q14	I think the activities of the experiment are complicated to do in an ordered way
Q15	I think there are enough resources to run the experiment in my own way
Q16	I think the environment of the experiment doesn't foment the collaboration
Q17	I think there are enough tools for instructor's feedback, advice or guidance to students
Q18	I think the development of the experiment isn't an enjoyable learning experience
Q19	I think there are enough options to resolve the experiment and make me responsible of my own learning
Q20	I think communication with others in the experiment makes my learning experience unsatisfactory

Figure 5. Questionnaire 2: Relationship between Cognitive Load – Satisfaction

RESULTS

In this section, we present the results of our experiment through density graphs and descriptive statistics which show the benefits obtained by our tool (online laboratory) regarding the two levels we defined: increased tool usability as well as perceived students' satisfaction regarding cognitive load.

In particular, after the completion of the experiment, students were asked to respond the questionnaires mentioned above. The first questionnaire shows the students' experience related to the tool usability, giving particular emphasis on the benefits of searching and locating instruments and devices semantically, compared to those students that did the search manually. In the positively worded questions (1, 3, 5, 7, 9), if the average SUS score of a question is low, it means that users are not positively disposed to the environment, whereas if the average SUS score of a question is high, then they have a favorable view of it. In the negatively worded questions (2, 4, 6, 8, 10), if the average SUS score of a question is low, it means that users have a negative attitude toward the environment, whereas if the average SUS score of a question is high it means that users tend to like the environment. To calculate the SUS score (Brooke,1996), first sum the score contributions from each item. Each item's score contribution will range from 0 to 4. For items 1, 3, 5, 7, and 9 the score contribution is the scale position minus 1. For items 2, 4, 6, 8, and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SUS. SUS scores have a range of 0 to 100.

For example, Table 1 shows the results for a student with the information of answer of each question, the score contribution of that question, the sum of scores and the overall value of SUS for the student. In this case the SUS Score is 80, related with a SUS Adjective of Good.

Table 1. Example of calculation of SUS score for a student

Question	Response	Scale Position	Contribution
Q1	Strongly Agree	5	4
Q2	Disagree	2	3
Q3	Neutral	3	2
Q4	Strongly Disagree	1	4
Q5	Agree	4	3
Q6	Neutral	3	2
Q7	Strongly Agree	5	4
Q8	Strongly Disagree	1	4
Q9	Agree	4	3
Q10	Disagree	2	3
		Sum=	**32**
		Multiply by 2.5=	**80**
SUS score (C ,Good) 80			

Taking into account the above, a calculation is made of the results of the total number of students, both from the control group and the experimental group. In Table 2 we show the maximum, minimum, mean, variance, and standard deviation for each of the groups, assigning the adjective SUS to the mean value found in each group. The analysis and discussion of these results will be done in the following sections, but at a first glance we can see that the adjective of the mean of the experimental group is better than that of the control group.

Table 2. Final SUS score for the experimental group and the control group

Experimental group					Control group				
N	Max	Min	M	SD	N	Max	Min	M	SD
25	92.5	77.5	86.3	4.513	25	75	65	72.1	2.857
SUS score (B, excellent) 86.3					**SUS score (D, ok) 72.1**				

n= students, max= maximum value, min = minimum value, M= Mean, SD = standard deviation

To understand better if there was statistical significance difference between the two groups (control vs. experimental), we provide density graphs associated with Table 2 that present the final scores of both groups. More specifically, in the case of usability, Figure 6 shows the density diagram with the average results for the control and experimental groups for each question between 1 to 10. In Figure 6, an adjustment has been made for the values of the contributions ranging from 0-4 to the values and adjectives associated with a Likert scale, ranging from 1-5 and representing adjectives ranging from strongly disagree to Strongly agree. Doing so, the perceptions of the experimental group students can be much better appreciated (being shown in a more visual way) compared to the control group students. As a consequence, one should seek the highest possible average for both positive and negative scoring questions. Any deviation from this rule indicates that we have a usability problem in the environment we are examining.

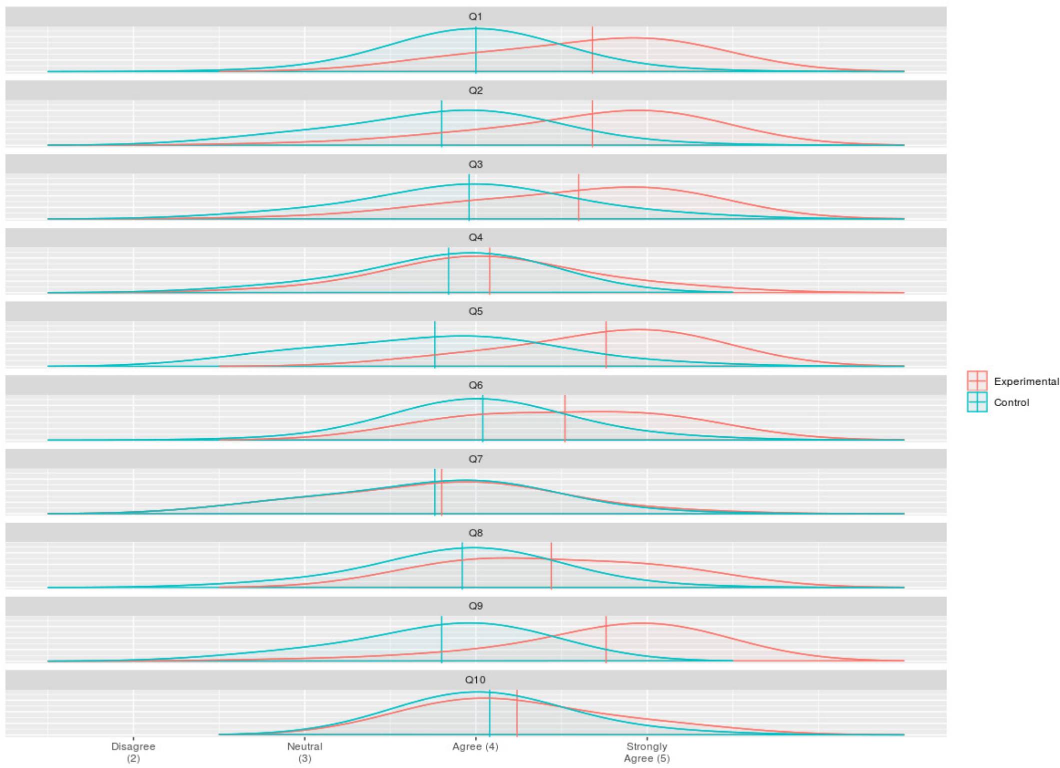

Figure 6. Density Diagram of Usability for both groups

The second questionnaire evaluated the relationship between cognitive load and satisfaction that students perceived when carrying out the tasks related to the experiment. As in questionnaire 1, questionnaire 2 has positively worded questions (1, 3, 5, 7, 9), and negative worded questions (2, 4, 6, 8, 10). Based on this and on the indicators of challenge, awareness, and engagement, a score is calculated representing the relationship between satisfaction and cognitive load. As with the calculation of the SUS score, each item's score contribution will range from 0 to 4. For items 1, 3, 5, 7, and 9 the score contribution is the scale position minus 1. For items 2, 4, 6, 8, and 10, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of the score, that has a range of 0 to 100.

In Table 3 we show the maximum, minimum, mean, variance, and standard deviation for each of the groups. The analysis and discussion of these results will be done in the following sections, But as in the case of the calculation of SUS, it can be observed that the students of the experimental group have a better perception of the relationship between the cognitive load and the satisfaction they experience when carrying out the experiment.

Table 3. The final score for the experimental group and control group of the second questionnaire

Experimental group					Control group				
N	Max	Min	M	SD	N	Max	Min	M	SD
25	90	75	80.8	4.128	25	72.5	57.5	67.6	4.049
Score 80.8					**Score 67.6**				

n= students, max= maximum value, min = minimum value, M= Mean, SD = standard deviation

In the case of relationship between cognitive load and satisfaction, Figure 7 shows the density diagram with the average results for the control and experimental groups for each question 11 to 20. In Figure 7, an adjustment has been made for the values of the contributions ranging from 0-4 to the values and adjectives associated with a Likert scale, ranging from 1-5 and representing adjectives ranging from strongly disagree to Strongly agree. A detailed analysis of the means of the contributions for each of the questions will be carried out in the following sections, being able to highlight at a glance that for all the questions the experimental group had a better appreciation of the relationship between cognitive load and satisfaction than the control group.

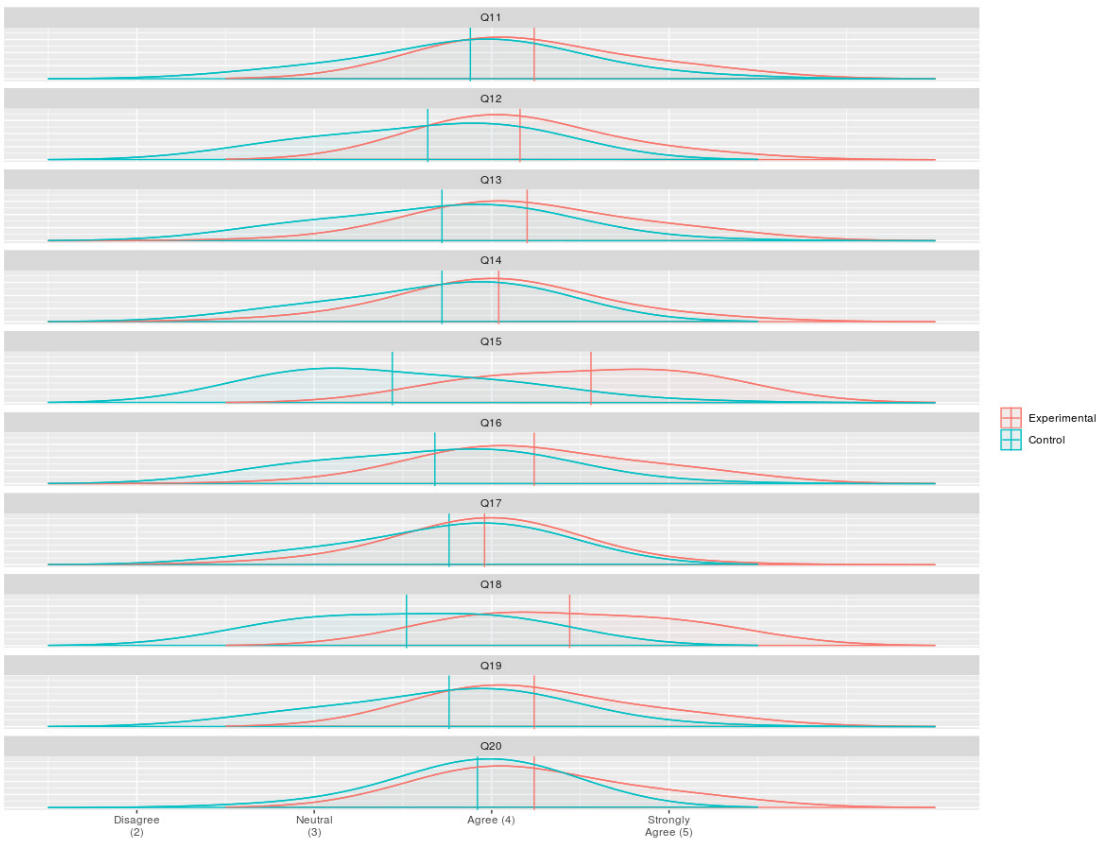

Figure 7. Density Diagram of Relationship between Cognitive Load – Satisfaction for both groups

QUALITATIVE DATA ANALYSIS

The purpose of this study was to analyze the benefits of the use of ontology design and semantic concept detection that helps lessen students' cognitive load while creating a more suitable environment for students and the correlation of these two variables. As such, the aim of this section is to provide a rather qualitative response to the usability of our online laboratory, based on the analysis of the SUS questionnaire (Figure 4) and the results presented in Figure 6 and Table 2. We now turn to discuss and interpret the average SUS score of each question for each group, especially the two questions with the highest score and the two questions with the lowest score, seeking to identify the strongest and the weakest aspects of our online laboratory.

In our case, in Figure 6, we observe that in the experimental group all questions and its respective contributions have higher values than the ones in the control group. In the experimental group, the questions with the highest average are questions 5 and 9, with a value of 3.76. This result means that students found that the various features of the laboratory were well integrated, which reinforces our claim that ontology design and semantic concept detection facilities provided by the laboratory supported students' work. In the control group, we see that in all questions, there is a lower appreciation of usability than in the experimental group, with the highest average values being questions 10 with 3.08 and 6 with 3.04. Question 10 is related to previous knowledge to perform the activities of the experimental procedure and question 6 with inconsistencies with the use of LabView. This result means that the students who did not use the online laboratory but made use of a manual system had the typical usability problems that hindered their work.

In contrast, in the experimental group, question 7 presents the smallest average (2.8), followed by question 4 with value 3.08. Our interpretation of these results is that science students may imagine that not all people (e.g., social science students) would learn to use this system very quickly, so it is not addressed to anyone. Moreover, some of them think they would need the support of a technical person to be able to use this system, mainly at the beginning. In the control group, question 7 also presents the smallest average score of 2.76, as well as question 5. As in the case of the experimental group, our appreciation is that it is not so easy for all people to use a system so quickly. In the case of question 5, the difference detected between the control versus the experimental group is in their perception of system integration. We note here that in the case of the experimental group, it is one of the best-evaluated points whereas in the control group was the weakest one.

Table 2 shows the mean SUS score (M) for both groups. For the experimental group, the SUS score (SUS > 80) is associated with the grade scale "excellent." Comparing the final SUS score (86.3) that our laboratory has obtained with the results of Bangor et al. (2008), we can conclude that the laboratory usability can be placed in the third quartile, which is an outstanding result. For the control group, the SUS score (72.1) can be considered in the grade scale "ok" (SUS>70). Consequently, we can conclude that an online laboratory based on ontology design and semantic concept detection had a better perception of usability for the students who used it than for those students who searched manually. In addition, according to experiential learning, if the learning space provides more flexible and practical features, it can also increase students' motivation for learning (Dreyer & Nel, 2003).

In Figure 7, we observe that in this questionnaire, the experimental group also has higher values than the control group in all the questions contributions. In the experimental group, the questions with the highest average are questions 5 with 3.56 and 8 with 3.44. This result means that students consider that the online laboratory provides them with sufficient resources to execute the experiment on their own, enjoying the experience while conducting the experiment. In the control group, the highest average values are questions 10 with 2.92 and 1 with 2.88. The students of this group focus more on the motivation and communication aspects that the experiment offered to them to participate. In fact, communication was one of the basic functionalities they were given by an environment that had only some fundamental built-in collaboration options.

In contrast, in the experimental group, question 7 presents the smallest average (2.96), followed by question 4 with value 3.04. Our interpretation of these results is that students generally have some difficulty to engage in new learning experiences, so it has not been easy for them to perform the experiment in an orderly way; as a consequence, students detected the need to maintain more interaction with their instructors so that to receive guidance during their learning process. In the control group, questions 5 with 2.44 and 8 with 2.52 had the lowest values. Based on these results, we saw that the control group students complained about the fact that they did not have enough resources to experiment, whereas they considered the experiment as a rather unsatisfactory activity. This result contrasts directly with the results of the experimental group because these questions were the ones with the highest values in this group.

Table 3 shows the mean score (M) for both groups as regards the relationship between satisfaction and cognitive load. In the experimental group, the score (80.8) is significantly better than in the control group (67.6).

Quantitative Data Analysis for the RQ

Based on the results obtained in the previous section, we proceed to make a correlation analysis, by discussing and providing a response to the research question we set at the beginning of our study:

- What is the correlation between usability and cognitive load-satisfaction of students who use an online teaching laboratory with ontology design and semantic concept detection compared to those students that do not use it?

The bivariate correlation analysis is used to explore the association between the usability score and satisfaction-cognitive load score, identifying possible positive and significant relationships, as it is shown in Figure 8 for the experimental group and in Figure 9 for the control group.

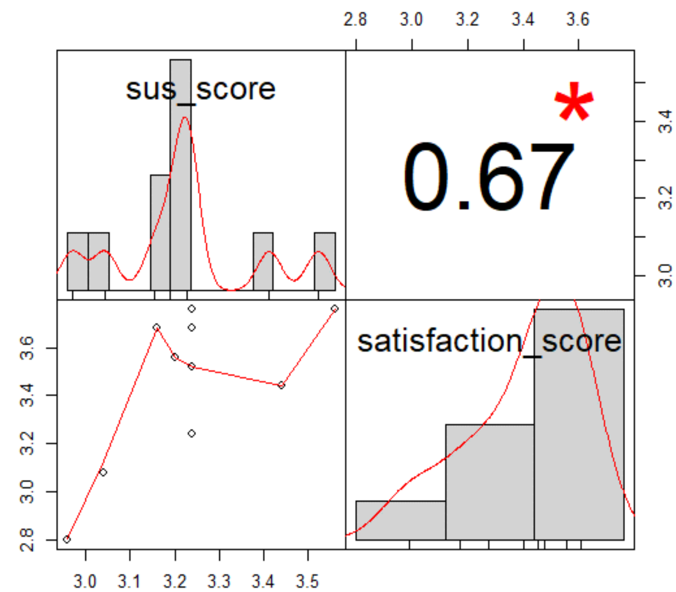

Figure 8. Experimental Group correlation

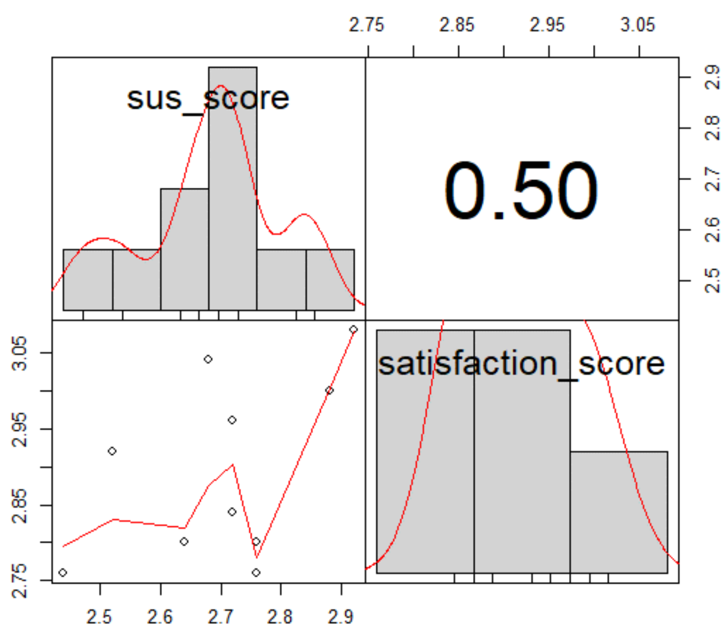

Figure 9. Control Group correlation

In the correlation obtained for the experimental group, we can observe that in the Pearson's product-moment correlation with t = 2.5255, df = 8, p-value = 0.0355, 95 percent confidence in an interval 0.06271051 - 0.91285451, the Pearson correlation is 0.6660388. The Spearman's rank correlation rho with S = 76.765, p-value = 0.1112, is 0.5347604. According to the assessment of the correlation factor, we can determine that the experimental group has a strong positive correlation between the usability and satisfaction-cognitive load.

In the case of control group, in the Pearson's product with t = 1.651, df = 8, p-value = 0.1373, 95 percent confidence in an interval -0.1838573 - 0.8605917, the Pearson correlation is 0.5041275. The Spearman's rank correlation rho with S = 98.19, p-value = 0.2458, is 0.404908. According to the assessment of the correlation factor, we can determine that the control group has a moderate positive correlation between the usability and satisfaction cognitive load.

DISCUSSION

There is a debate in the research community concerning the issue of proving students with greater freedom and self-regulation facilities through tools such as the online laboratory. On the one hand, there are studies examining how online resources can improve instruction and increase student satisfaction. Shen et al. (2013) show how technology, learning, and social interaction (which constitute important aspects of dynamic online learning environments) can be tightly related to self-efficacy which, in turn, can affect the satisfaction of online learning. In addition, they found gender differences regarding online self-efficacy. While literature has supported that the notion of action as well as the intentional and reflective interaction of students with their environment can promote performance and satisfaction of learning (Barnard-Brak et al., 2010; Zhu, 2012), there are other studies which have detected that courses with lower levels of student independence report best performance and assessment, indicating the need for less student autonomy (Luo et al., 2019).

The current study contributes to the current body of work in this area in several ways. First, the use of an online laboratory based on an ontology design and semantic concept detection provides an easier access to the components of the laboratory (Maier & Niederstätter, 2010), improving the sharing of resources (Richter et al., 2011) and offering teachers with the capability to create dedicated inquiry learning spaces (ILS). It also supports this process by proposing scenarios and lesson plans (De Jong et al., 2014). Also, this study examined whether the use of a mechanism of semantic search provides a good rating in usability. However, few studies have examined the cognitive load-satisfaction relationship (Bradford, 2011). The use of an ontology or the semantic description of devices and instruments provided is beneficial to students' cognitive load: it enables them to carry out an adequate search for instruments and devices, a more natural way to cope with the experiment, and more efficient collaboration with others. Moreover, it enhances student accountability, which helps them take responsibility for their learning. This study is one of the first to analyze the cognitive load-satisfaction relationship and compare it with usability scores.

Finally, in line with studies of students' comprehension, perception and satisfaction (Al-Zoubi, 2018) and with developing knowledge sharing in learning communities as a graduate attribute (Brouwer & Jansen, 2019), our analyses make an important contribution to the literature by suggesting a correlation analysis comparing the results of experimental and control groups that participated in this research work, in terms of usability and cognitive load-satisfaction. Doing so, we can conclude that the students who used the online laboratory based on ontology design and semantic concept detection had a better perception of cognitive load-satisfaction and usability than the students who did not use it. Certainly, further work is needed to examine whether these interactions are significant.

CONCLUSION, LIMITATIONS AND FUTURE WORK

This work presents an analysis of student's satisfaction using an ontology design that automatically discovers semantic concepts from online resources. This ontology design has been integrated into a web application for an online laboratory which, in turn, is based on non-functional attributes of learning services of distributed networks, especially those based on cloud computing. This work goes beyond syntactic search methods by employing modern technologies which provide a complete semantic description of Web services, involving also non-functional properties for the service selection. This resulted in a model with important features and benefits.

On the one hand, the online laboratory provided students with an easy way to share and deploy instruments and devices, thus enhancing system usability.

On the other hand, it offered important facilities which enabled students to customize the search for instruments and devices, which certainly had a positive impact on the relationship between cognitive load and satisfaction. The online laboratory was tested through a real experiment with undergraduate students (divided in control and experimental groups) who assessed it by means of surveys regarding usability and cognitive load-satisfaction. Subsequently, we performed a correlation analysis between the variables of usability versus satisfaction-cognitive load for an experimental group that uses the improvements of the semantic model and a control group that does not use them.

Based on the results obtained and the analysis carried out, we conclude that the proposed solution can benefit to remote, virtual, synchronous, and asynchronous online laboratories in teaching science in terms of effectiveness, increasing the learning abilities and laboratory skills of the students, the level of understanding of concepts by implementing the virtual laboratory, identifying whether the virtual laboratory helps them increase learning at their own space, improving a set of teaching-learning variables such academic achievement, science processes, scientific attitudes, attitudes towards the use of laboratory technology, estimation of the classroom environment, and, visual thinking.

Being a limitation of the current work, it would be interesting to experiment with a more extensive ontology and with a higher number of instruments, so that to validate that the results of usability and satisfaction – cognitive load would remain similar for the end-user in these scenarios as well.

Future work will also investigate other methodological aspects of instructional design with the aim to improve personalized learning and reinforce collaborative experiences, as well as to deal with problems related to laboratory access, such as authentication, scheduling, and interoperability.

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