Identifying Success Criteria for Sustainable AI-based Online Laboratory Courseware System

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***Abstract*— The great transformation of e-learning during the Covid-19 pandemic has led to the emergence of new learning tools and virtual learning environments through Internet. Despite many advantages of e-Learning courseware systems such as availability, flexibility and accessibility, students of some sectors such as engineering, science and technology are facing several limitations in conducting their practical works remotely through online platform for laboratory experiments. The specific objective of this study was to come up with an updated success criteria and list of requirements that should be considered for developing a sustainable artificial intelligence-based online laboratory courseware system. Data for this study were collected using online questionnaire distributed to a group of e-Learning experts. NVivo software was used to analyze experts' comments on how to construct the online laboratory courseware systems. This research revealed 16 basic design and development criteria for the online laboratory courseware system, which are distributed into eight sub-branches and organized into four primary aspects. These findings suggest that in general 30 accurate indicators for the design of an effective laboratory learning system (LLS) for engineering, science and technology sectors dealing with content management, assessment, accessibility and usability as well as the adoption of artificial intelligence techniques.**

***Keywords*— Online laboratory, courseware, e-learning, criteria, artificial intelligence, Covid-19.**

I. Introduction

The impact of Covid-19 pandemic has affected educational systems around the globe. In an effort to halt the spread of this pandemic, most governments have temporarily closed schools and other learning institutions. On March 15, 2020, UNESCO announced that nearly 94% of educational institutes have already closed, and nearly 1.6 billion students globally have been absent from attendance [1]. The e-Learning courseware and applications have emerged as a logical solution to overcome this situation [2]. By the end of 2020, more than 70% of students had access to some form of e-Learning, meanwhile, educational experiences oscillate between virtual and hybrid learning as they represent a balance between the need to keep students and faculty safe, and the need to provide an effective learning environment that achieves the desired learning outcomes [3].

Despite many characteristics of e-Learning courseware systems such as availability, flexibility, accessibility, ease in updating learning content, personalized learning, and saving time, students of engineering, science and technology are facing several limitations in conducting their experiments remotely [4]. These students have fewer opportunities to learn at home, due to the nature of their scientific experiments i.e., hands-on experiments and design-oriented tasks [5]. The research to date has tended to focus on learning management systems (LMS) rather than laboratory learning systems (LLS) [6].

One of the most significant current challenges in conducting hands-on and design-oriented experiments in LMS is how to transfer the learning experiences for students who need to conduct practical experiments in laboratories. Moreover, allowing students to gain practical skills through online experiments and the opportunity to have a deeper grasp of the learning content is difficult to achieve under the current circumstances. Hence, there is an urgent and necessarily need to design an effective laboratory learning courseware system for implementing hands-on and design-oriented experiments remotely. This system could be used innovatively to fill this gap and address LMS limitations.

Several studies have indicated the importance of design standards in e-Learning programs, as they achieve many benefits, including helping the instructional designer to adopt the learning material and providing them with clear instructions on how to improve students learning, assessment, feedback, virtual assistance, improves student confidence, self-awareness, and enthusiasm for learning, in addition to the teacher can follow up on his students electronically through online evaluation system. There are number of large cross-sectional studies which suggest that the finest criteria are those set by a group of experts. These finest criteria are represented directives for the instructional designer on implementing the learning tasks through authoring tools and express the qualitative level that all learning components must have. Research on the e-Learning standards has been mostly restricted to LMS design. This study therefore set out to determine a revised list of criteria, standards and requirements that should be considered in designing the Laboratory Learning System (LLS) for virtual and remote controlled laboratory experiments.

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II. RELATED WORK

Virtual classrooms and laboratories are among the most important elements of the educational process that provide a free space for students to discuss their work, as well as follow up on their scientific experiences. There are a number of large cross-sectional studies which suggest some applications to access an array of resources and services specifically addressing their in-classroom and research needs [24]. Students have the opportunity to participate in activities such as investigating, inventing, and realizing abstract concepts and making actual items with digital technology in makerspaces such as Fab Labs [25]. In Slovenia researchers attempted to evaluate the impact of virtual laboratories on improvising students' academic performance and the results showed that, virtual laboratories tools aids in the better understanding of knowledge acquisition of chemistry in primary school [26]. The virtual laboratories have the potential to open up new avenues for the long-term sustainability of higher education [27]. The authors in [28] conducted a series of trials to investigate the differential impact of virtual laboratories in blended learning form and they concluded that the virtual laboratories may be utilized as a new instructional tool for undergraduate students, and the blended laboratory is the ideal laboratory.

Together, these studies indicate that online learning is an acceptable trend for some universities in recent times. The e-Learning sector is growing at a 35.6% annual rate worldwide, but there are still some issues related to its design and implementations [7]. Dropping out of online courses and not completing educational tasks is a negative factor affecting the success of this experience. It is unclear why so many students abandon online learning after their first few attempts. More recent attention has focused on identifying a number of success factors that influence user satisfaction with e-Learning.

Miu et al. (2020) use a unique large-scale dataset derived from collaborative online programming competitions to investigate in a real-world setting, how individual differences in innovation, social-information use, and performance generate technological progress and their impact on the development of self-efficacy, cognitive, and skill competencies among educational technology students, as well as the criteria for designing e-Learning environments to achieve this goal [8].

Alhabeeb and Rowley (2018) conducted an extensive study on a sample of students and faculty members that addressed a main question about what are the factors that help the success of e-Learning experience. Their study was conducted in Saudi Arabia, and the results were analyzed, which showed that there is a slight difference between specialists and students about these standards, but in general there was agreement on several standards, including student traits, instructor qualities, accessibility and assistance [9].

Dousay and Trujillo (2019) examine gender variations in situational interest in three different that linked online, multimedia learning environments. The most interesting finding was that multimedia learning is much important in the learning process and it needed for the university professor to keep pace with online authoring technology. In addition to the importance of the presence of specialists and technical designers in the design and production of these multimedia learning environments according to the technical foundations and standards. Learning by multimedia in the educational process, knowing the university professor's directions for those programs and the importance of the technical specialist and his creativity in designing, directing and producing these programs in light of the technical foundations and standards, in addition to knowing the obstacles that prevent the application of design and technical direction methods in the production of multimedia learning programs [10].

Moreover, the interface design affects the learner's impression of the LMS and the extent to which learners understand it and desires to use. For authoring tools where texts and images are placed on the screen affect reading and understanding them. The online learning and then towards the content (learning material) presented through LMS and emphasized on writing the objectives in the educational formulation and in an appropriate sequence, and using them in designing the list of commands, setting the screen, then choosing the appropriate programming language and authoring system, considering the use of images and illustrations with sound to support interaction and visual attention. Al-Fraihat et al. (2020) conducted a study which aimed to evaluating e-Learning systems success in one of the UK universities and they found seven quality factors are success determinants: system, information, service, educational, support, learner, and instructor [11]. Kanwal and Rehman (2017) including crucial external aspects into the technology acceptance paradigm, the adoption and acceptance baseline for e-Learning systems. They recommended a set of criteria for designing online LMS within its results in the item on screen design and ways to place texts and images on them, confirms the need to use appropriate multimedia as basic elements in the transfer of content, and in a manner functional and integrated with the texts, and according to the educational need for them [12].

It is now well established from a variety of studies that there are success factors of online courses based on LMS, which we believe there importance in implementing sufficient and effective e-Learning courses, but the significant gap is how to create a laboratory learning courseware for science, engineering, and technology. So far, we have not been able to find an integrated study that will allow us to create these virtual and remote labs. The first attempts were made by identifying LLS settings and specifications, which were examined in Elmesalawy et al. (2021), the proposed LLS architecture was designed to have a set of core modules operating together to provide flexible LLS. These modules include a built-in authoring tool, Lab hardware and software resources, laboratory resources management, LMS integration module, in addition to a virtual lab assistant in addition to evaluation and assessment modules that rely on AI techniques [13]. In light of those general design requirements, the current study aims to accurately define the set of standards required for implementing virtual learning laboratories courseware, and thus it is possible to bridge the current gap and provide a codified model for those standards based on a careful analysis of the needs as well as the feedback of educational technologies experts.

III. Methodology

The use of qualitative analysis by collecting opinions from a group of experts is a well-established approach in identifying design criteria and collecting systems requirements [14].

A. Study design

Our method consists of eight main activities as illustrated in Figure 1. In the first step, we defined the study objective which was for designing an online laboratory learning courseware system to conduct student experiences in the field of science, engineering, and technology. Steps 2, 3 and 4 being conducted partly in parallel and independent from each other, based on a literature review that confirmed the research gap in the design criteria for those laboratories. The open questionnaire was used as one of the strategies for gathering data from a panel of experts in this study. This questionnaire relies on experts who are knowledgeable about design and implementations of e-Learning applications so they can forecast the outcome of future LLS design scenarios, predict the likelihood of LLS use cases, or reach consensus about LLS design criteria.

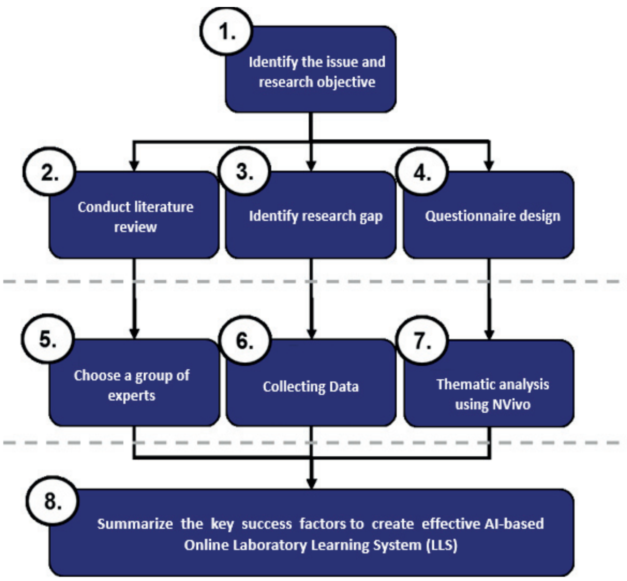

Fig. 1. Research method

B. Experts Participatory

The fifth step dealt with identifying a group of experts to participate in the open-ended questionnaire. The expert has to meet certain criteria, such as designing some e-Learning applications and publishing research in the same field. An invitation to participate in this study was sent to (60) e-Learning experts and (43) participants were accepted, and (31) of them completed the questionnaire successfully. The participants were representative with respect to gender, just over half the sample (52%) was male, the ages ranged between 35 and 60 years old. The sample was also representative of a number of different cultures, as 48% are representatives of Arab universities, 30% of European universities, and the rest are from North America.

C. Data colleaction

Researchers used an open-ended questionnaire to obtain information from the panel of experts regarding the following questions:

- What are the core design requirements of an authoring tool for LLS that supports you to create lab experiments?
- Which design requirements to provide an accessible LLS application?
- What are the collaborative learning tools that helps in building cooperation among group members?
- Which design requirements that contributes to assessing the learner performance?
- How to provide real-time remote access to LLS?

D. Thematic analysis using NVivo

The responses of the 31 experts were collected, and NVivo software was used to conduct a coding analysis [15]. To get a quick feel for the kinds of things covered in that code, we are creating a word cloud as presented in Figure 2. The word cloud helped to give a general idea about the main points that were frequently repeated by the experts, which was the primary indicator for data analysis.

For a more in-depth investigation, a concept map has been created for these codes, indicating the relationships between them, as shown in Figure 3.

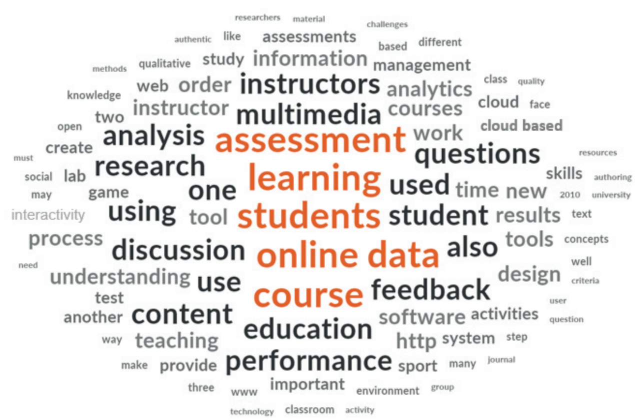

Fig. 2. Word cloud for experts responds

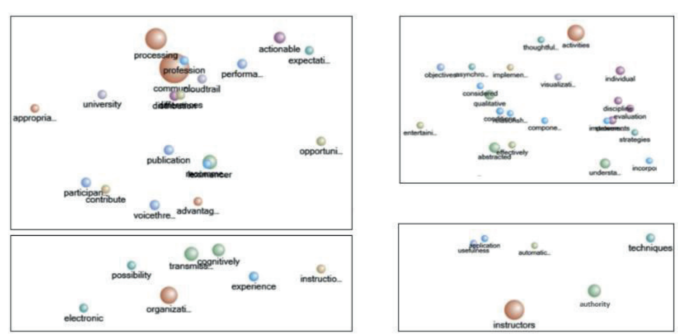

Fig. 3. Coding map categorization using NVivo

IV. RESULTS AND DISCUSSION

The results of this coding schemes as shown in Figure 3 indicate that there are 4 sets of design criteria. In order to obtain a more accurate classification, assigning attributes to data was done as shown in Figure 4, which reflects the presence of 16 basic standards, divided into eight sub-branches, grouped into four main dimensions of design and development standards for LLS courseware [16]. In light of this analysis, the properties of LLS criteria will be described according to each design dimension in the following sections.

A. Content mangment

The first dimension is concerned with the content management using of authoring tools, embedded Virtual Machine (VM), dealing with authority and privacy issues. embedded virtual machine. LLS authoring tool is a software package that developers use to create e-learning content and communicate it to course participants. The most important component of LLS authoring tool is integrating program packages responsible for managing the learning material through Internet.

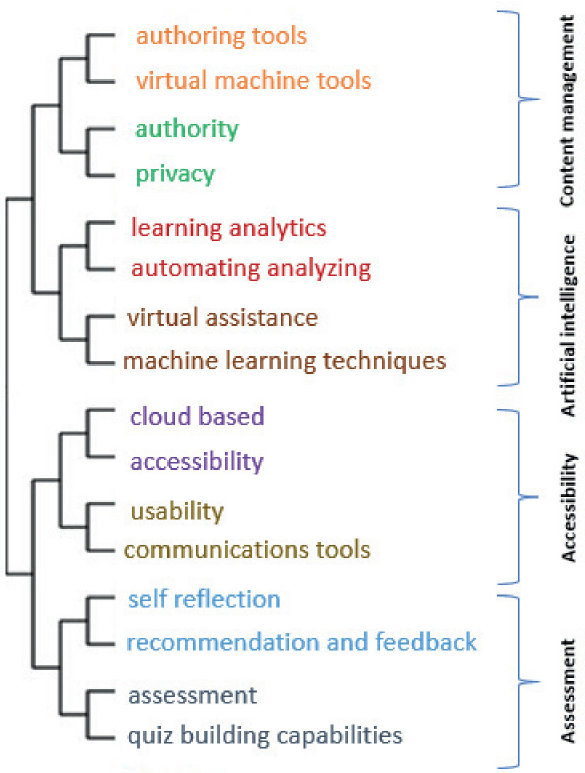

Fig. 4. Assigning attributes to coding schemes using NVivo

The specific indicators that should be considered in the design of the LLS authoring tool include the following:

1. Create and display scientific content within the system.
2. Create interactive activities between the learner and the educational program.
3. Importing different educational units and linking the educational units together.
4. Create templates for content display pages for facilitating the reuse of educational units.
5. Create tests and various assessment methods and exporting educational units in various forms.

The next items dealing with the embedded VM-based simulators in the LLS platform. Virtual machines that are accessed by students are considered one of the success factors of the system which include the following:

6. The VM-based simulators should be run through hypervisor.
7. Running multiple VMs on a single piece of hardware.
8. The VM window should be opened through the LLS in the form of iframe.

Ensuring authority and privacy of LLS information has been a big challenge due to the lack of quality control mechanism in the internet resources and communications. Yan et al. (2012) supports the idea of raising privacy awareness among users [17]. In addition, we argue that integrated LLS in the university learning system can find the key to protect learners and provide a safe learning environment. The following criteria should be considered when using LLS through LMS platforms.

9. Enhance learners' privacy awareness in using LLS platforms.
10. Use private VM networks (i.e., only course participants who can access these VM-based simulators).
11. Use the LLS module in the university learning system.

B. Artificial intelligence

In the past decade, several studies have sought to focus on the use of Artificial Intelligence (AI) in educational context [18]. Indeed, the capabilities of AI technology have increased considerably, with an opportunity to provide learners with automating analytics and virtual assistance based on their cognitive style [19] which can be presented in four basic forms as depicted in Figure 5.

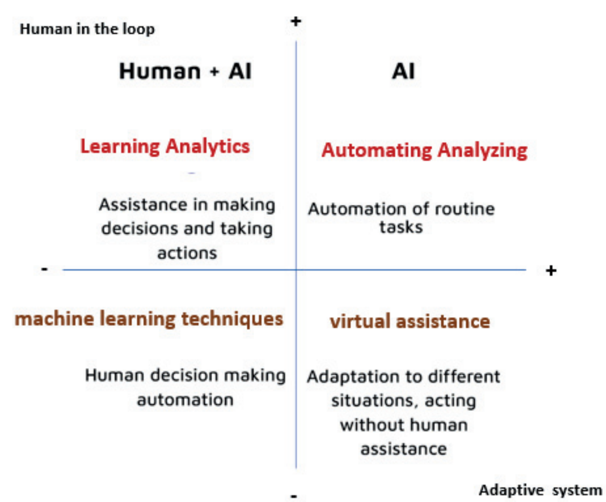

Fig. 5. The four basic forms of applied AI in education

The specific indicators that should be considered when adopting AI in LLS include the following:

12. **Personalization:** LLS should adapting experiments feedback to meet the needs of each individual student.
13. **Tutoring:** Providing online help and guidance based on the learning difficulties faced by students i.e., visual assistance can provide one-on-one instructions without the presence of a course instructor to answer questions.
14. **Chatbot:** LLS should support automation and conversational intelligence that can help lab participants get answers to their most frequently asked questions.
15. **Learning analytics:** Provide course dashboard that including measurement, collection, and analysis of student performance.

C. *Usability and Accessibility*

According to the International Standards Organization (ISO), usability is defined as "the extent to which a site can be used by a specified group of users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" [20]. The purpose of LLS usability in this study is how virtual laboratory layout looks like? As well as, how learners can easily find information on experiment? Moreover, the usage of online laboratory and learning content formats that were not designed to address the needs of students who used various learning devices created further impediments to their full participation in their online learning [21]. In this study, experts identified a number of indicators that should be followed when designing LLS considering, usability and accessibility as follow:

16. Cloud-Based authoring tool that enable teachers to create their experiments easily.
17. Responsive design to fit all screen size.
18. Use high-contrast text and background colors, so that type is as legible as possible (e.g., Black text with White Background).
19. Hyperlinks should lead directly to the detailed page for the discussion topic.
20. Navigation controls should be located at the same position of each page.
21. Provide learners with the opportunity to search (i.e., search box).
22. Support compatible contents for all main browsers (e.g., Internet Explorer, Opera, Firefox, Safari, Google Chrome, as well as, mobile browsers).
23. Provide students with a collaboration workspace to discuss their lab tasks.
24. Providing transcribing audio and captioning videos.

D. *Assessment*

The main purpose of the assessment process is to provide such kind of feedback usually involve teaching staff correcting and grading the learning assignments. Assessment has been implemented in a variety of evaluation practices in online learning, whether in formative or summative evaluation [22]. Summative assessment is utilized as part of the grading system at the end of the learning process to certify competency and evaluate the success of the teaching and learning process. While, formative assessment, which includes intermediate, diagnostic, predictive, and benchmark assessments, is used to provide real-time feedback to improve the learning process [23]. Experts have identified a number of criteria that must be taken into account when designing assessment in LLS as details below:

25. Authentic Assessment in the LLS replicates or simulates the contexts in which students are “tested” in the workplace, in civic life, and in personal life.
26. Use formative assessment during experiments to ensure students understand the content of the Lab.
27. Implement drag-and-drop formative assessments that demonstrate a learner's capacity to connect information and use knowledge to solve a real-world problem.
28. The assessments allow for a holistic approach rather than a piecemeal one.
29. Students can adapt the tasks to their own requirements and interests because they are sufficiently flexible i.e. time and self-reflection.
30. Use the same simulation program in evaluation operations when necessary.

V. CONCLUSION

The Covid-19 has caused a great challenge in the world accompanied by massive changes in our daily lives in the ways of learning, working, and interacting socially. In education, for example most governments have temporarily closed their educational institutions and then e-Learning has been relied upon. e-Learning was always a secondary option, then it turned into an urgent need due to the Covid-19 pandemic. Although there are many educational and technical standards for designing learning management systems, there are clear shortcomings in how to design virtual laboratories courseware for students of engineering, science, and technology. This study aimed to define a list of specialized standards for designing a virtual learning environment to conduct experiments using simulation systems from a distance. The study reached 30 criteria divided into four main categories: content management, artificial intelligence, usability and accessibility, and assessment.

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