Computers & Education 69 (2013) 250–262

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

The objectives, architectures and effects of distance learning laboratories for industrial engineering education

Miladin Stefanovic*

Faculty of Engineering, University of Kragujevac, Sestre Janjic 6, 34 000 Kragujevac, Serbia

ARTICLE INFO

Article history:
Received 6 November 2012
Received in revised form
6 July 2013
Accepted 8 July 2013

Keywords:
Engineering education
Distance learning laboratories
Remote control
Virtual
Simulation

ABSTRACT

The concept of laboratories for distance (e-learning) with remotely controlled laboratory set-ups or virtual laboratories with different simulations have an important role in industrial engineering education and training. Although the concept is not new, there are a number of open issues that should be solved. This paper will present the fundamental objectives of learning through distance learning laboratories as well as the special issues connected with these labs, including their effectiveness. Other important questions will be addressed such as pre requests for remote controlled/virtual labs according to different stakeholders, different architectures will be compared and, finally, evaluations and students' feedback will be presented.

1. Introduction

In modern industrial engineering education and training, many different strategies have been used in order to improve learning outcomes and to provide better education for students and trainees. It is clear that the concept of improvement of industrial engineering education could be addressed from a number of different perspectives (Keytack, 1994). Usage of modern technology and computers in education presents a very important issue. A leading idea to all educators was given in Dormido (2002): "Educators must have an open attitude towards new technologies. They should sensibly incorporate new technological development to avoid the risk of teaching the students of today, how to solve the problems of tomorrow, with the tools from yesterday." Much attention has been given recently to modern education and e-learning. The concept of laboratories for distance learning that are based on control of remote laboratory set-ups or remote control of experiments, as well as the concept of virtual laboratories that are completely based on software simulation, have an important place in the concept of e-learning. The idea of having a remote web-based laboratory corresponds to attempts to overcome different constraints and provide the next step in remote distance learning (Fabregas, Farias, Dormido-Canto, Dormido, & Esquembre, 2011; Forinash & Wisman, 2005; Gallardo, Barrero, Martınez-Torres, Toral, & Duran, 2007). Remote/virtual laboratories are important in overcoming the major drawback of an e-learning environment: the lack of practical and laboratory work. Over the years, however, the nature of laboratories has changed (Feisal & Rosa 2005). These changes could be defined as changes in the role of laboratory work, as a part of a course, as well as changes in different technologies applied in a laboratory environment. The concept of laboratories for distance (e-learning) has its place in training and education, but also a number of questions and issues have to be solved.

Some questions are connected with the objectives, effective design and architecture (Barrios et al., 2013) of remote controlled and virtual laboratories, and focus is needed on the design of both the pedagogy and the technical infrastructure as well as how these elements interact (Lowe, Murray, Lindsay, & Liu, 2009). In many cases, lack of a proper architecture and software design, both in the client and server sides, degrades a labs' quality and academic usefulness (Garcia-Zubia, Orduna, Lopez-de-Ipina, & Alves, 2009). On the other hand, the best designed laboratory and laboratory experiments may not lead to reach higher order learning outcomes if they are not designed by considering specific objectives for laboratory learning (or learning outcomes, stated by different taxonomies) or by considering the pre-

* Tel.: +381 34 335 990; fax: +381 34 333 192.
E-mail address: miladin@kg.ac.rs.

0360-1315/$ – see front matter
http://dx.doi.org/10.1016/j.compedu.2013.07.011

requests for a specific laboratory experiment. In addition, it is of great importance to stress the variety of stakeholders who are involved in the design, implementation and usage of virtual/remote laboratories: students, lecturers, developers, faculty/university administration. Different stakeholders have a set of opinions and views towards usage of open source vs. proprietary solutions or towards requests for client platform, laboratory experiments or laboratories as a whole.

Other questions related to efficiency of the concept of virtual or remote laboratories, compared to physical (real life) laboratories, as well as to a comparison of virtual and remotely controlled laboratories. Different authors have had a number of approaches. Sicker, Lookabaugh, Santos, and Barnes (2005) had three perspectives: students' exam results, students' lab reports, and students' satisfaction with the distance experience (based on interviews). They concluded that remote laboratories provide similar learning outcomes to their in-class analogs, but that there are important differences in student perceptions of the experience, including perceived difficulty and pace. Other authors also made an assessment according to learning outcomes (Gustavsson et al. 2009; Kostaras, Xenos, & Skodras, 2011; Lindsay & Good, 2005; Mohtar, Nedic, & Machotka, 2008; Nedic, Machotka, & Nafalski 2003), or they started with learning outcomes as pre-requests for development of laboratories, Zhai and Xu (2011). Nickerson, Corter, Esche, and Chassapis (2007) presented a model for testing the relative effectiveness of engineering laboratories in education, comparing versions of remote labs vs. hands-on labs; the results suggest that students learned lab content information equally well from both types of laboratories, and that they have a realistic understanding and appreciation of the practical advantages of remote laboratories. Garcia-Zubia, Hernández, Angulo, Orduña, and Irurzun (2009) measured the acceptance, usability and usefulness of the remote laboratory from the students' point of view. Gadzhanov and Nafalsk (2010) analyzed the pedagogical effectiveness of distance education, with a special focus on remote laboratories, while Pati, Misra, and Mohanty (2012), Wolf (2010) addressed the evaluation of the effectiveness of virtual labs, proposing a conceptual model for evaluating the effectiveness of virtual lab courses. Tzafestas, Palaiologou, and Alifragis (2006), compared the effectiveness of real, virtual and remote experiments according to the educational impact of such systems.

It is clear that number of researches have focused on evaluation of the effectiveness of virtual or remote labs according to students' satisfaction, or learning outcomes or even educational impact. However, in some cases, specific learning outcomes could be connected with a specific laboratory exercise in a clear one to one relationship. The situation is even more blurred if we evaluate students' satisfaction, on the other hand results of exams or reports could be influenced by many different things (previous knowledge, theoretical lectures, and motivation). Additionally, some researches do not offer the background, requests, architectures and implementations of specific (laboratory) solutions which were evaluated. In other researches authors (Corter, Esche, Chassapis, Ma, & Nickerson, 2011; Jara, Candelas, Puente, & Torres, 2011) addressed the evaluation of general issues such as students' satisfaction, quality as a global concept or others, which could not be easily tracked back to the characteristics of an experiment or laboratory as a whole. In this paper, it is stated that laboratory experiments (for both remote and virtual solutions) should be developed following objectives for laboratory learning (adopted for distance implementation). In the further process, the set of pre-requests presented by different stakeholders (students, teachers, developers and management) for the client/server solution, laboratory experiments and the laboratory as a whole were defined (analyzing the implementation issue: programming languages vs. dedicated proprietary software). Two sets of laboratory experiments were developed: remote controlled and virtual experiments (inverted pendulum and four tanks' system) using the same set of objectives and same set of requests. The systems have been in practice for two years, and the results of the survey are presented (covering 1595 students, 24 teachers and instructors, 4 developers and 4 study program managers) in order to evaluate achievement of the set of pre-defined objectives for laboratory learning and evaluate the set of pre-requests.

2. The fundamental and specific objectives of distance learning laboratories

A number of institutions have their own remote/virtual laboratories and different issues connected with this topic have been the focus of research (Balamuralithara & Woods, 2009). By having a number of these laboratories developed and installed, different questions emerged. Having a remote or virtual laboratory outside the course syllabus, without real connection with learning objectives, makes this, or any other educational tool, useless. The basic idea is to have a specific laboratory (and laboratory experiments) "integrated" in the course, with a specific position in assessment methods and grading policy, for a specific course (accompanied with textbook/reference), linked with specific learning outcome(s) and course competences. The main theoretical concepts should be tracked up to course description and introduction. This is very important because remote controlled experiments and virtual experiments need to be included and used as a regular teaching and learning tool in the scope of specific courses (as other physical based laboratories). Remote/virtual laboratories should not be the "video game" or demonstration of a "we are too advanced" attitude for an institution, but need to give an answer to what students will be able to do by completing the laboratories in an engineering curriculum. So the main idea and the very beginning in the definition, development and implementation of a remote/virtual laboratory for industrial engineering education (as well as any other educational field) is the definition of fundamental objectives for distance laboratory learning.

The following objectives for remote/virtual laboratories could be stated (Feisal & Rosa, 2005):

1. Instrumentation. This objective means that students should apply appropriate sensors, instrumentation and/or software tools to make measurements of physical quantities. This objective could only be partly met because in the case of remotely controlled experiments, a low level of flexibility could be reached due to the need for equipment to be placed and remotely controlled using different hardware and software solutions. In the case of complete virtual reality and virtual labs this objective could be achieved.
2. Models. Students need to identify the limits and scopes of theoretical models. It is very important to provide a real connection between theory and a laboratory experiment. This may include evaluating whether a theory adequately describes a physical event and establishing or validating the relationship between the measured data and underlying physical principles. This objective could be achieved with both remote/virtual laboratories.
3. Equipment. Students or trainees need to specify equipment, and procedures in order to acquire results and to interpret the data. In the remote/virtual laboratories it is possible to implement different procedures and for students to have the opportunity to interpret data.