A Novel Reusable Learning Object Development (RLO) for Supporting Engineering Laboratory Education

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1. Introduction

A learning object (LO) is a resource, usually digital and web-based, that can be used and re-used to support learning. Learning objects offer a new conceptualization of the learning process: rather than the traditional "several hour chunk", they provide smaller, self-contained, re-usable units of learning. The advantage of this micro design of learning materials in terms of small chunks is the usability and transferability to another related courses or learning activities with minimal modification effort. LOs will typically have a number of different components, which range from descriptive data to multimedia and information about copy rights and educational level. At their core, however, will be instructional content, and probably assessment tools. A key issue is the use of metadata. The idea of learning objects could have been borrowed from the notion of object oriented programming in software engineering where many objects are utilized, linked, and operated together to perform larger macro operation targeted by the final software product. LOs are characterized with many attributes, some of them are:

- Micro elements: LOs are micro learning elements, small chunk of information that may take couple of minutes instead the couple of hours approach of learning.
- Encapsulation: LOs are self-contained and can be taken independently.
- Reusable: LOs are reusable, and they can be mutated to another courses or learning activities easily.
- Aggregation: an LO can be grouped with other LO's or into larger learning content, course, etc.
- Metadata Description: every learning object has descriptive information allowing it to be easily found by search engines [1].

Learning object deployment in the tuition process has been found to bring added positive value to the learning process in many pedagogical studies [2][3][4]. In the recent years, research and funding in LOs have considerably increased. Many services and databases have arise, such as the specialized LOs journal "Interdisciplinary Journal of E-Learning and Learning Objects ", the web data base of LOs MERLOT [5], and the Reusable Learning Objects Center of Excellence in Teaching and Learning in the UK, Rlo-CETL [6], which has received £2.5 million initiative fund, spread over five years for the further development and research the LOs. A learning object is not a piece of text or a graphic or a video clip. However, these elements can be used in the process of developing a multimedia LO. Also, the LO is not an entire course on a particular topic. Since most LO's are designed to be delivered online, they have particular benefits of rapid and rich prototyping of distance learning courses as well as blended learning courses.

The importance of a laboratory experience in engineering education curricula has been emphasized in a large number of science and engineering education articles [7][8][9][10][11]. The essential role of laboratories can be correlated with the fact that engineering is, in general, an applied science that requires very good hands-on skills and involves elements of design, problem solving, and analytical thinking. Well-designed laboratories during undergraduate engineering degrees can improve these skills for graduate engineers. In fact, engineering started as a result of the accumulation of hands-on experiences (it had been taught as pure hands-on up to the 18th century). However, engineering education has benefited from advances in science and it began to embed deeper theoretical concepts by the end of the 19th century, for example in the US schools [6]. Since then, the pedagogical emphasis in engineering education has shifted more towards

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Fig. 1. Process control test rig.

classroom and lecture based education, while less attention has been given to the laboratory education particularly during the last 30 years [8][12]. Wankat [14] observes that only 6% of the articles published in the Journal of Engineering Education from 1993-2002 had 'Laboratory' as a keyword. But, laboratory pedagogy has been recently reported to be a fertile arena of research for the coming years [8][12]. Especially in the need to make more use of the new developments in information and communication technology (ICT) for enhancing the laboratory education for the purpose of further training, sharing and facilitating access.

In response to the recent recommendations in the literature regarding the engineering laboratory education, we worked on developing an Online Laboratory Learning Object (OLLO) for enhancing the students' laboratory experience. The OLLO was developed for the process control laboratory taught through various courses at the Chemical Engineering Department of Loughborough University.

2. THE PROCESS CONTROL LAB

The process control lab is a coherent part of the second year "Instrumentation, Control and Industrial Practice" module taught in the Chemical Engineering Department at Loughborough University. The experimental rigs of the hands-on process control lab were designed to mimic a real surge tank system, which is a typical chemical engineering process. Figure 1 shows a picture of one of the hands-on test rigs. The laboratory is a compulsory part of the module designed for undergraduate engineering master (MEng), bachelor (BEng), and bachelor in science (BSc) programmes at the Department. The lab aimed to introduce students to the principles of control engineering, such as the main components and instruments of a feedback loop, the concept of open-loop control, feedback control, proportional-integral-derivative (PID) control, and PID tuning. The hands-on laboratory consists of two 3 hours sessions, scheduled for two consecutive weeks. In the first week, the students are introduced to the elements of typical feedback loops such as sensors, actuators, controller, and process. The main objectives of the first session are: (i) calibration and hysteresis of the level sensor; (ii) calibration, hysteresis, installed characteristics and relative resistance of the control valve. During the second week, students are introduced to control engineering concepts. The aim of the experiments in the second week is to help students appreciating the advantages of automatic control compared to manual operation, and to equip the students with qualitative and quantitative evaluation of the differences among proportional (P), proportional-integral (PI), and proportional-integral-derivative (PID) controllers, and to perform automatic tuning of different PID control structures.

3. THE ONLINE LABORATORY LEARNING OBJECT (OLLO)

There has been recent shift in engineering education towards embracing constructivist pedagogy and experiential learning practices. There is more demand on supplementing the theoretical lectures in the engineering courses with authentic real applications, i.e. laboratory demonstrations. Additionally, more and more engineering institutes embed project based learning practices in their curricula, which implicitly require extra laboratory resources. However, due to the costs involved in building and running laboratories it is not

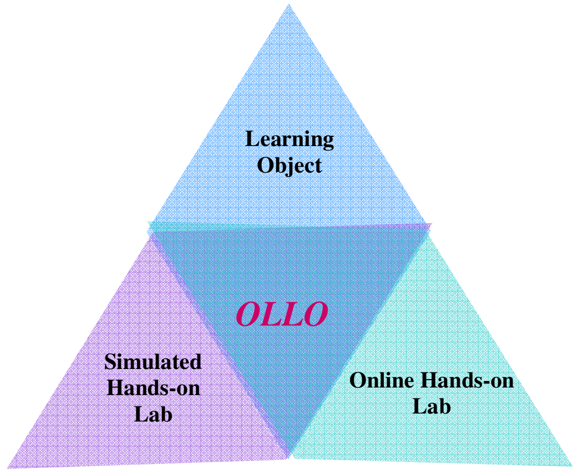

Fig. 2. Conceptual Model of the OLLO.

feasible to supply large number of laboratory experiments for each single taught course. Furthermore, successful operation of a laboratory experiment usually requires considerable teacher tuition effort for both the conceptual profile of the experiment as well as the hardware operations. Most of the previous obstacles can be overcome by developing a self-contained entity that includes instructions and information about the experimental rig, the hardware operation, the purpose of the experiment, a brief background of the theory, simulation of the rig, and experimental procedure for the sake of learner-centered approach of conducting the experiment. Additionally, the remote operation capability of the hands-on lab allows sharing the whole entity and the lab rig among different institutions, which could result in dramatic drop of the cost of setting up new labs and will considerably enrich the engineering pedagogy by embedding new laboratory resources that would not have been possible to access. We call such entity the "Online Laboratory Learning Object", or in brief OLLO.

In definition, the Online Laboratory Learning Object (OLLO) is a learning object that is particularly designed for the laboratory pedagogy and is characterized by the following:

- It is a learning object which includes self contained learning content related to the hands-on laboratory experiment that enables learner-centered approach of learning the experiment.
- It is incorporating remote operation of the physical hands-on lab rig, mainly through the internet.
- It is designed to mimic a relevant hands-on laboratory when operated offline by using virtual instrumentations.
- It is preferred that OLLO would include video transmission of the hands-on test rig.

The OLLO without remote operation of the physical instruments is a learning object LO only and is NOT an OLLO. Conceptual model of the OLLO is shown in Figure 2, the core communication architecture of an OLLO is shown in Figure 3. Each engineering department have many laboratories which their access is limited to the department's staff and students mainly. The benefits of developing OLLO's for as much labs as available within the institute is beyond the teaching and learning process, since collaborative research could be significantly fostered when such large database of OLLO's is easily operatable and accessible. For further enhancing the collaborative part of an OLLO, video conferencing and editing tools can be added on the top of the OLLO.

The importance of developing online laboratory learning objects comes from the fact that labs themselves are self contained learning chunks which are provided as supplemental support for understanding theory. Furthermore, in many cases, a laboratory experimental rig can be used in different courses and in different contexts. The latter two are inherent characters in the learning objects philosophy. For instance, a control experimental rig can be used for a control course that is taught in chemical engineering, mechanical engineering, or electrical engineering; the process control rig can be used as experimental rig in a control course, or in modeling course. Laboratories are often developed for providing the students with authentic real experience, if we restrict the OLLO for simulation only as the case of LO's, the developed laboratory learning object will loose the most important motivation behind labs tuition, which is realism.

4. ARCHITECTURE OF THE OLLO

Many software platforms have been used for developing LO's such as Flash, Photoshop, and web design tools. However, the OLLO is considerably of much more complex structure than the normal LO's due the factor of incorporating physical hardware in the LO and the fact that the laboratory rig should be operated remotely through the internet. The latter requires onsite Data Acquisition (DAQ) and hardware interfacing, automated operation, web server installation, software interface, and web interfacing. Figure 2 illustrate the generic design of the core communication structure of an OLLO. An OLLO also requires designing automated virtual instrumentation simulation of the real rig. There are many tools that can be used for each of the previous requirements. For instance, Java Servlets and web server such Apatche could be used for establishing the webserver and the communications among the hardware, the server, and the client. Matlab and dSPACE can be used for DAQ, Matlab/Simulink and other programming languages such as VB could be used for programming a mimicking behavior of the lab. Java applets and other web programming and authoring tools could be used for web publishing of the content. However, incorporating all the previous tools together for implementing an OLLO could result in load of bugs, weak robustness, and it is extremely complicated and requires too many working hours.

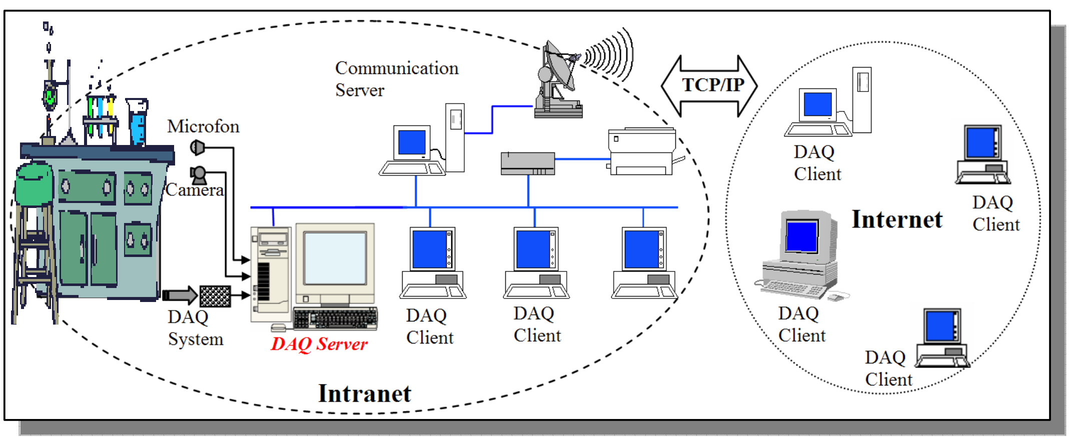

Fig. 3. Core Communication Architecture of The OLLO.

National Instruments (NI) has developed many industrial hardware and software interfacing tools which have been increasingly used in academia during the last 10 years. The hardware interfacing tools of NI range from a simple USB DAQ to a complex programmable automation controllers (PACs). NI developed a virtual instrumentation software platform called LabView for simulation, processing, programming, DAQ, and interfacing with the physical instrumentation. LabView is a G-Programming (Graphical Programming) language. Virtual instruments developed in Labview consist of two panels; (i) the first is to the user GUI where the operating elements are placed, whereas (ii) the second contains the G-Code. LabView has ActiveX connectivity capabilities which enable the developer to embed any ActiveX-compliant software such as Microsoft office in the G-Code. LabView has connectivity capability with Matlab/Simulink as well which enables incorporating already implemented models or codes in Matlab into LabView G-Code. Furthermore, LabView has remote panels tool that enables developing distributed operation of remote physical instrumentations through the internet, it includes web publishing tools, and software package installer development tool. All the aforementioned features of Labview make it an excellent software environment for developing the process control lab OLLO. We developed a virtual simulated version of the laboratory, which allows student to perform all experiments in a simulation mode using an interface identical with the real operator interface in the lab. The developed OLLO allows remote operation and provides real-time video transmission for creating the feeling of telepresence. The DAQ hardware device we used is a NI USB-6000 series USB data acquisition (DAQ) device worth about 150£. Part of the process control lab OLLO G-Code is shown in Figure 4 while the OLLO GUI is shown in Figure 5. The developed OLLO has been deployed on the web for internal use only currently but a simulated version can be downloaded and installed as stand alone application from http://www-staff.lboro.ac.uk/~cgzkn/).

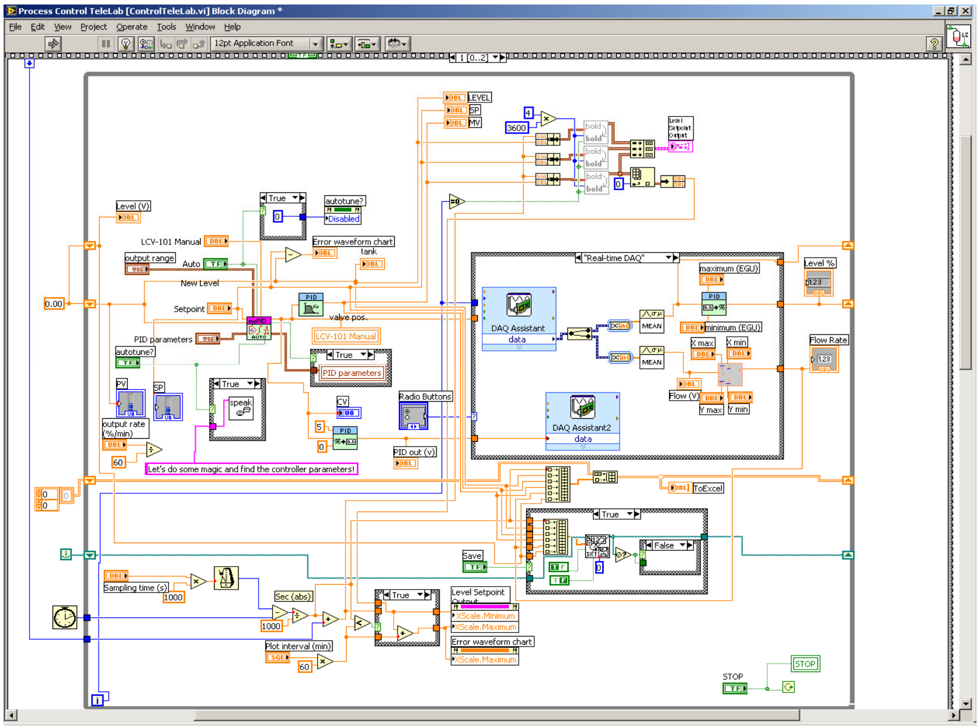

Fig. 4. G-Code of the Process Control Lab OLLO.

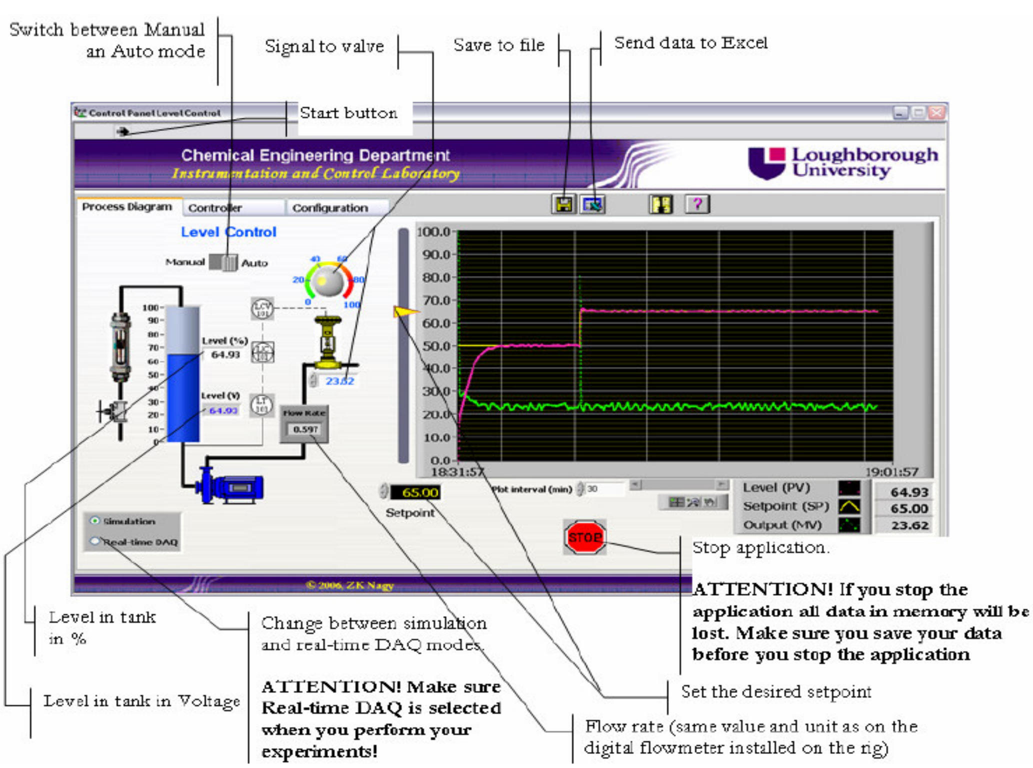

Fig. 5. The Process Control Lab OLLO GUI.

5. EDUCATIONAL UTILIZATION OF THE PROCESS CONTROL LAB OLLO

The process control lab OLLO (PCL-OLLO) has been used in the master module "Advanced Computational Methods for Modelling and Analysis of Chemical Engineering Systems" and in the second year undergraduate "Instrumentation, Control and Industrial Practice" module, and students performances were evaluated. The first module aims to introduce students into topics such as dynamic modelling, optimization, PID control, which are applied to chemical process. In this course, we used the PCL-OLLO remote operation property in the course exam, where students were asked to explain the behavior of the real process and give suggestions of how to change the controller parameter to enhance performance. There suggestions were implemented and they were able to evaluate the results using the real process operated remotely. In this way the examination has become a very intuitive learning exercise not only an evaluation process of their knowledge.

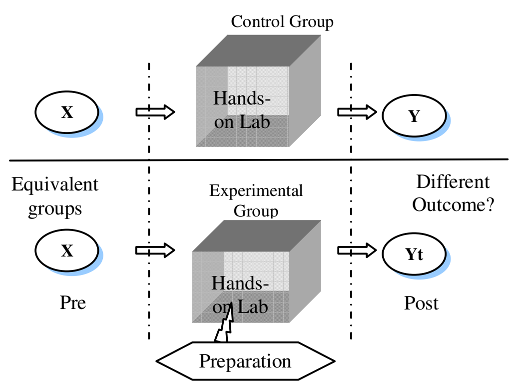

Fig. 6. Conceptual model of the experimental methodology.

In the undergraduate course (Instrumentation, Control and Industrial Practice), the OLLO was used in pre-lab session for preparing the students before they conduct the hands-on experimentation. Part of the students performed the preparation session with the OLLO (experimental group). A control group was also formed from students who did not attend the optional preparatory session with the PCL-OLLO. In surveying the students' willingness of conducting extra experimental work, we found that those who did the preparation have got more motivation towards experimenting further ideas after the hands-on session, facilitated by remote operation. The responses of the two groups differed considerably. The average of the control group is 4.19/6 while the average of the experimental group is 5.27/6. We also found that students from the experimental group have developed higher conceptual understanding of the theory behind the experiment. We conducted post test quiz right after the lab for the students. The quiz contained several questions with emphasis on the conceptual and hands-on experience that the students were expected to gain after conducting the lab. The mean in general was higher for most questions fro students from the experimental group. The hypothesis statistical test revealed a higher difference in the significance factor for the conceptual questions.

The number of students registered for the class was about 70. In the lab 6 experimental rigs were used, with students working in groups of 2 or 3 at each rig. Students were divided into four session groups, each of which consisted of 16-18 students. Each group used the rig for 2 consecutive weeks to complete the experiments. The lab teaching spreads over 8 weeks from the academic week 2 until the academic week 9 of the first semester. In week one an introductory lecture was organized in a classroom to all students when the experiment was described. In this session the laboratory was "brought into the classroom" by using the remote laboratory module. A pre lab preparation session was also organized during which students came to the computer room and worked on the virtual laboratory software following the procedure form lab manual working in group under basic supervision.

This procedure was applied to session Groups 3 and 4, whereas Groups 1 and 2 had no treatment. To guarantee equivalence as much as possible among the four groups, students were distributed evenly based on their GPA in the previous academic year. The average GPA of each group is about 63%. There have been 8-10 students each time who responded to our request of attending the preparation session. Groups 1 and 2 formed the control group, whereas the students from Groups 3 and 4 who responded to our request in attending the preparation session were considered the experimental group. Figure 6 illustrates the methodology used for the pedagogical experiment, with **X** representing the equivalent groups (control and experimental before treatment) and **Y** and **Yt** the results from the control and the experimental groups after treatment, respectively. The treatment is the preparation session using the virtual lab. For the evaluation of the statistically significant difference between the control and the experimental group in response to the treatment the *null hypothesis* was used [15]. For accepting or rejecting the null hypothesis, the Mann-Whitney non parametric test [15] was used. According to this approach the null hypothesis is rejected (meaning that there is statistically significant difference between the data) if the significance value of the test is less than 0.05.

TABLE I
PRE-LAB TEST RESULTS*

Question	Exact Significance (Mann-Whitney U test)	Means % (Experimental / Control)
Q1	0.002	73.89 / 40.00
Q2	0.002	55.28 / 21.67
Sum Q3 to Q7	0.166	72.33 / 58.23

* Number of samples (Experimental/Control) is 18/30.

TABLE II
POST-LAB TEST RESULTS*

Question	Exact Significance (Mann-Whitney U test)	Means % (Experimental / Control)
Q1	0.302	90.56 / 72.81
Q2	0.025	76.67 / 59.22
Q7	0.034	64.72 / 39.53
Q8	0.026	65.83 / 37.97
Sum Q3 to Q10	0.124	50.10 / 39.06
Sum Q1 to Q10	0.031	56.86 / 44.45

* Number of samples (Experimental/Control) is 18/32

Questions Q1 and Q2 of the pre lab test of Week I are strongly related to the hands-on laboratory session. In these questions, students were asked to develop an experimental procedure that they will follow for calibrating and deriving the characteristics of the level sensor of the tank, and the control valve that controls the outflow rate of the tank. Questions Q3-Q7 were mainly designed to test relevant general knowledge of the students that they may have gathered through the lecture theory, through the remote lab demonstration that was conducted in the first lecture, or through reading the lab manual. The results of the evaluation of the pre lab test are shown in Table I. Using the Mann-Whitney test, the exact significance value of Q1 and Q2 were smaller than 0.05 indicating that the null hypothesis can be rejected, hence there is indeed strong statistical evidence that exposing the students to laboratory learning object preparatory session has lead overall to enhanced grasp of the information needed for performing in the lab.

Table II shows the results with the analysis of the post lab test. In question Q1 from the post lab test from week one, we asked the students to create a qualitative plot of the characteristics curve of the level sensor, based one their observations and the data they have collected during the experiment. The level sensor characteristics is simple linear with no hysteresis. The students' answers were adequate for both the experimental and the control groups. The exact significance value for Q1 is 0.302 which is larger than the threshold of 0.05, indicating that there is no significant difference between the control and the experimental groups. In question Q2, students were asked to plot the control valve characteristic, which is nonlinear and shows hysteresis. A significantly larger portion (more than double) of the students from the experimental group observed these features (which requires more in depth ability) than from the control group. The statistical significance value of Q2 is 0.025. This value is smaller than the threshold of 0.05 indicating a high probability (97.5%) that the higher score is not by chance, hence the null hypothesis can be rejected. Questions 7 and 8 were purely conceptual, testing the students understanding of open and closed loop systems. Students from the experimental group performed overall much better in these questions than students from the control group (see Table II). These results provide evidence hat *students who have been exposed to preparation session with the Laboratory Learning Object have had more in depth understanding during the hands-on lab session.*

Note that the simulation of the control valve in the virtual lab is not identical to the real behavior of the physical control valve in the test rig. The simulated control valve has a linear characteristics and no hysteresis, hence these features were not observed by the students from the experimental group in the preparation session. Nevertheless, they showed better ability of detecting these characters than the control group students. The statistical test of the in depth question from the post lab test from week two, has also revealed acceptable significance for rejecting the null hypothesis (exact significance was $0.013 < 0.05$). This also indicates that constructivist learning in the hands-on lab session cab be improved with the assistance of the Laboratory Learning Object. We also noticed a different behavior during the laboratory in the case of the experimental group students compared to the control group students. The former showed more interest in the hands-on lab session and insisted more on answering the pre and post lab tests compared to the control group students.

6. CONCLUSIONS

Laboratory education is a central part in engineering and science education. Laboratories give a chance for developing student-centered learning activities, and foster experiential learning. Labs can be used in different courses, and experimental rigs can be used for demonstrating different experiments. Yet, labs are expensive tools for academic institutions, they are limited to access, and often they cannot be synchronized properly with the progression of the thought material in the lectures. The concept of learning objects can provide a solution for reusability and enriching education with multi style and sharable chunks of learning materials. In this paper, we built upon the learning object philosophy and proposed the Online Laboratory Learning Object (OLLO) model for sharing a reusable experimental objects amongst academic and research institutions. The main difference of OLLO from an LO is that it embeds an additional layer that incorporates physical hardware in the learning process. The OLLO architecture is considerably more complex than a usual LO. We further developed initial OLLO prototype for the process control lab (PCL-OLLO) and completed a pilot educational experimentation for the evaluation of its benefits. Results obtained so far refers to enhanced learning experience and increased potential towards experiential learning when an OLLO is embedded in the learning process. The PCL-OLLO is still in the development process, further steps are to add metadata tags according the IEEE standards and deployment in the WWW for global reusable sharing with interested partners.

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