The Impact of the Virtual Lab on the Hands-on Lab Learning Outcomes, a Two Years Empirical Study

Mahmoud Abdulwahed
Engineering Centre for Excellence in Teaching and Learning, Loughborough University, Loughborough, UK, m.abdulwahed@lboro.ac.uk

Zoltan K Nagy
Chemical Engineering Department, Loughborough University, Loughborough, UK, z.k.nagy@lboro.ac.uk

Keywords: Virtual Labs, Constructivism, Process Control.

Abstract*: Virtual labs provides handy and cheap way for supporting laboratory education. Some use virtual labs as replacement of hands-on labs, but this has been reported to be unsatisfactory for students and in some cases it left a negative impact. However, virtual labs can be an important supplement of hands-on labs. In this paper, we report on an empirical two years study where a virtual lab was used in a pre lab session for supporting the students learning. The approach proved to be effective in enhancing the students learning outcomes during the hands-on session.*

Introduction

Hands-on laboratories are the oldest and most widespread form of laboratory education. Feisel notes that hands-on laboratories were the first and only place that engineering was taught about three centuries ago (Feisel and Rosa, 2005). Hands-on labs have been used generally for demonstrating how theory can be applied in practice, for the acquisition of haptic skills, design skills, instrumentation treatment skills, etc. It is commonly accepted in science and engineering that one of the most important laboratory objectives is to help students in conceptual understanding and constructing new knowledge. Ma and Nickerson's (2006) literature review states that 100% of the surveyed articles concerning Hands-on Laboratory considered that labs should be platforms for facilitating conceptual understanding, and 65% considered that labs should also facilitate the design skills. However, constructing knowledge is a complex process that which can be out of the time frame of the planned laboratory sessions. For instance, constructing knowledge has four main phases according to Kolb's experiential learning theory, which include stimulation, abstraction, reflection, and experimentation (Kolb, 1984). Constructivists consider learning as an iterative process (Kolb 1984). Meaningful learning does need reflection (Hofestein and Lunetta, 2004). These practices are generally missing in the classical hands-on taught laboratories. Gunstone (1991) considers classically taught laboratories as a poor platform of knowledge constructing, mainly because the students have less time to interact and reflect while they are busy with the technical and the operational side of the lab. Many researchers considered that laboratory should be a platform for facilitating, developing, analysing and solving problems (McComas, 1997). Kirschner (1988) shows that some labs requires students to solve problems that are more difficult than the cognitive ability of the student that is constrained with the short time period the lab normally offers. The teachers generally assume that the students will be able to overcome the problems in the assigned time, however this is not always true. Hands-on labs are usually taught as one single demonstration due to economical and logistical reasons. However, forming and understanding concepts require more than one single demonstration. Kirschner reports that there is general consensus that laboratory work generates poor learning outcomes compared to the time, effort, and costs invested in laboratory. This drawback has been frequently reported in laboratory literature (Johnstone and Al-Shualil, 2001; Hofestein and Lunetta, 2004; Ma and Nickerson, 2006).

Despite their many constraints, hands-on laboratories promote the most important aim of using laboratories, that is the realism. Affective factors play an important role in the learning process. The absence of the realism sense may serve as a demotivating factor in the learning process. Many studies relate the significantly higher order learning or behaviour in real settings vs. virtual settings to the realism factor (de Kort et al., 2003; Heise, 2006).

Computer simulations on the other hand have become an integrated part of engineering education as early as the 1970s (Smith, 1976; Gosman, et al., 1977; Ingram et al., 1979; Kinzel et al., 1981; Campbell, 1985; Laghari et al.; 1990; Gladwin et al., 1992). Virtual laboratories (simulated versions of the hands-on labs) present a series of advantages, such as they are more cost-effective to implement and run, are not constrained by time or space, they are safe, etc. In science and engineering education virtual labs have emerged as alternative, or complementary tools of the hands-on laboratory education, e.g. using them for preparing for the lab. However, students attitude has been frequently reported to value the hands-on experience, not considering virtual labs as alternative, but as an assisting tool.

Virtual Labs in Preparation Session

Laboratory preparation can be conducted in many ways, for instance, students can be asked to prepare by reading the manual and developing an experimental procedure. Alternatively the lab manual preparation can be combined with using a simulated version of the lab (virtual lab). The lab manual + virtual lab preparation can result in enhanced preparation due to many reasons. According to the dual coding theory of information cognition, the human mind perceives and stores verbal and visual information through two distinct channels (Paivio, 1971). The implication on educational processes is that incorporating visual objects with verbal information can lead to better learning (Slavin, 2005). The virtual lab presents a suitable tool of visualizing the experimental rig in a simplified way and for showing the experimental plots. The VARK learning styles model suggests that there are four main learning styles: read/write, visual, aural, and kinesthetic (VARK, 2008). Preparing from the lab manual could be suitable for those students who have strong read/write learning style. However, combining the virtual lab with the lab manual in the preparation accommodates the students who have visual and kinesthetic learning styles. The learning pyramid model (Weenk, 1999) suggests that information retention rates are different depending on the learning method (5% lecture, 10% reading, 20% audio/visual, 30% demonstration, 50% discussion group, 75% practice by doing, 90% teaching others). Virtual lab provides a chance for doing the experiment and hence resulting in much higher knowledge retention rate than using the lab manual alone. One key shortcoming of the classical hands-on laboratory teaching is the poor conceptual learning outcome due to time constraints, lack of repetitions, and the high cognitive load (Johnstone and Al-Shuaili, 2001; Hofestein and Lunetta, 2004; Ma and Nickerson, 2006, Roth, 1994; Kirschner, 1988). In general, supplementing the hands-on labs with a virtual version has been found useful, but in most cases, students do not believe that virtual lab can be alternative to hands-on labs (Engum et al., 2003; Raineri, 2001; Ronen and Eliahu, 2000; Spicer, 2001; McAteer et al., 1996). Offering to the students a pre-lab session by which they prepare using the lab manual and the virtual lab, may assist in overcoming some of shortcomings of the hands-on labs. Additionally, the use of the virtual labs provides an ideal framework for inducing reflections during the preparation and hence enhancing, according to Kolb's model, the conceptualization and learning already during the preparation for the lab.

Case Study: Process Control Laboratory

The case study was conducted on the process control laboratory in the context of the second year Instrumentation, Control and Industrial Practice module at the Chemical Engineering Department at Loughborough University, UK. The laboratory is a compulsory part of the module designed for undergraduate engineering master (MEng), bachelor (BEng), and bachelor in science (BSc) programmes in Chemical Engineering at Loughborough University. The lab aims to introduce students to the principles of control engineering, such as the main components and instruments of a feedback loop, the concepts of open-loop control, feedback control, proportional-integral-derivative (PID) control, and PID controller tuning. The hands-on laboratory consists of two sessions, each of 3 hours duration. The sessions are scheduled for two consecutive weeks. In the first week, the students are introduced into the elements of typical feedback loops such as sensors, actuators, controller, and process. The main objectives of the first session are: (i) calibration of the level sensor, (ii) calibration, hysteresis detection, installed characteristics and relative resistance of the control valve. During the second week, students are introduced into control engineering concepts, the main objectives being: (i) to develop an appreciation of automatic control vs. manual control, (ii) to obtain a qualitative grasp of the differences among, proportional controller (P), proportional-integral controller (PI), and proportional-integral-derivative controller (PID), (iii) to develop rules for control structure selection based on the observed qualitative information, and (iv) to perform automatic controller tuning. A virtual version of the lab has been developed using National Instrument's software environment, LabVEIW, and it was made available to students for download from http://www.ilough-lab.com. The Process Control Virtual Laboratory allows students to perform all experiments in a simulation mode using an interface identical with the real operator interface in the laboratory.

The number of students registered for the class was about 70 in both academic years 2007-2008 and 2008-2009. In the laboratory, 6 experimental rigs were used, with students working in groups of 2 or 3. Students were divided into four session groups, each of which consisted of 13-18 students. Each group used the rig for 2 consecutive weeks to complete the experiments. The lab teaching spread over 8 weeks from the academic week 2 until the academic week 9. A pre-lab preparation session was organized for two of the groups, during which students came to the computer room and worked on the virtual laboratory software following the procedure form the lab manual, working under minimal supervision. These pre-lab sessions (treatment) were applied to the Groups 3 (G3) and 4 (G4), whereas Groups 1 (G1) and 2 (G2) had no treatment. To guarantee equivalence as much as possible among the four groups, students were distributed evenly based on their percentage average in the previous academic year. The averages of the groups were, G1=64.2%, G2=63.6%, G3=63.1%, and G4=63.7% for the 2007-2008 academic year. For the 2008-2009 year, the averages were, G1=66.81%, G2=66.46%, G3=67.03%, and G4=66.68%. About 6-10 students of each G3 and G4 have responded to the request of attending the preparation session each time, forming the experimental group. The average mark of the experimental group was 66.7% in the 2007-2008 academic year. Students from Groups 1 and 2 formed the control group with a group average of 63.8% (only 2.9% less than for the experimental group), similar difference in average was present also for the 2008-2009 academic year. The groups G1 and G2 represented the control group, whereas those of G3 and G4 who responded to the request of attending the virtual lab session have formed the experimental group. Both groups had to take pre and post lab tests to evaluate their learning outcomes. For the evaluation of the statistically significant difference between the control and the experimental group (if any) in response to the treatment the null hypothesis was used. The null hypothesis in this case states that: "There is no statistically significant difference in the learning outcome between the control group and the experimental group due to using the virtual lab in a pre-lab preparation session". For accepting or rejecting the null hypothesis, the Mann-Whitney non-parametric test was used. According to this approach the null hypothesis is rejected (meaning that there is a statistically significant difference between the data) if the significance p-value of the test is less than 0.05.

Results analysis

Questions Q1 and Q2 of Week 1 pre-lab test were strongly related to the experimental procedure of 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, respectively. Questions Q3-Q7 were mainly designed to test relevant general knowledge of the students that they may have gathered through the lectures, from the remote lab demonstrations that were conducted in the classroom, or by reading the lab manual. The results of the evaluation of the week 1 pre-lab test of the academic year (2007-2008) are shown in Table 1. 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 a preparatory session using the virtual laboratory has lead them to an overall enhanced grasp of the procedural tasks needed for performing the lab. The lower mean of the control group students is related to the fact that those students never or poorly prepared for the lab (all students were asked to prepare for the lab, the software and the lab manual were available to download from the Web). Poorer results of the control group could be explained that those students may have only read the manual and have not experienced the procedure with the virtual lab, or did they did the latter but not comprehensively as the experimental group did. The difference between the control and the experimental groups is less significant ($p= 0.116 > 0.05$ for the 2007-2008 academic year) for the questions Q3 to Q7 (general questions, not directly correlated with the experiment) though the average mean is still higher for the experimental group. The level sensor calibration procedure is relatively easier than the procedure for the control valve calibration. This may explain the higher mean of Q1 compared to Q2. The results of the week 1 of the 2008-2009 academic year very was consistent with the results of the previous academic year such as shown in Table 1.

Table 1. Pre-Lab test results of week 1 (2007-2008/2008-2008).

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

Question	Exact Significance, (the p-value) (Mann-Whitney U test)	Means % (Experimental-Control,)
Q1	0.002/0.000	73.9-40.0/75.3-18.7
Q2	0.002/0.000	55.3-21.7/38.8-7.3
Sum Q3 to Q7	0.166/0.261	72.3-58.2/62.1-55.8
Sum Q1 to Q7	0.009/0.004	70.1-50.4/59.8-43.5

The analysis of the post-lab test for the academic year 2007-2008 are shown in Table 2. In question Q1 of the Week 1 post-lab test, students were asked to create a qualitative plot of the level sensor characteristic curve based on their observations and the data they had collected during the experiment. The level sensor characteristic is represented by a simple linear curve with no hysteresis. The students' answers were rather close 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 statistically 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 experimental group students could distinguish these features (which require higher ability of in-depth analysis) whereas fewer of the control group students could discover the hysteresis. 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. For the other questions (Q3-Q6, Q9 and Q10), which are rather general, students from the control and the experimental group showed close outcome. 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 2). It deserves mentioning that the simulation of the control valve in the virtual lab is not identical to the real behaviour of the physical control valve in the test rig. The simulated control valve has linear characteristics and no hysteresis, hence these features were not observed by the experimental group students in the preparation session. Nevertheless, they showed higher ability of detecting these features than students from the control group. The detailed results for the academic year 2008-2009 are shown in Table 2 as well. These results are consistent with the previous year findings. The p-value of Q2 is $0.012 < 0.05$, also for Q7 and Q8 the p-value is smaller than 0.05. For the total sum of the post test result, the p-value was smaller than the threshold in both years, 2007-2008 and 2008-2009.

Table 2. Post-Lab test results of week 1 (2007-2008).

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

Question	Exact Significance, (the p-value) (Mann-Whitney U test)	Means % (Experimental / Control)
Q1	0.302/0.671	90.6-72.8/75.0-68.1
Q2	0.025/0.012	76.7-59.2/70.6-43.5
Q3	0.257/0.042	43.3-31.3/51.1-27.7
Q4	0.498/0.007	48.3-38.6/73.3-41.2
Q5	0.847/0.272	51.1-48.6/75.6-55.
Q6	0.829/0.794	53.9-47.2/49.4-50.4
Q7	0.034/0.048	64.7-39.5/76.1-52.3
Q8	0.026/0.021	65.8-38.0/73.3-45.4
Q9	0.543/0.587	30.6-37.2/36.7-28.1
Q10	0.211/0.008	43.1-31.9/55.3-23.9
Sum Q1-Q10	0.031/0.008	56.8-44.5/63.3-43.6

Similar results have been obtained for the Week 2 pre- and post-lab tests. This statistical analysis shows that preparing for the laboratory through a virtual lab bases session have lead the students to students acquire enhanced learning outcomes in the lab and also lead to reduce their cognitive load during conducting the experiment. Hence, it should be strongly recommended to make a preparation session with minimal supervision as a compulsory or coherent part of the laboratory course.

Conclusions

The study shows clearly the importance of hybrid utilization of different access modes during the laboratory didactic. Both virtual and hands-on labs hold advantages and disadvantages, blending the two together may result in optimal learning experience. Virtual labs have been reported frequently to enhance conceptual understanding, this study shows that conceptual understanding have been risen during the hands-on lab as a result of introducing the virtual lab in a preparation session. Furthermore, it seems that the latter treatment has also contributed to reducing the students' cognitive load.

References

Campbell,DR, 1985. Interactive Graphics Software for an Undergraduate Course in Digital Signal Processing, Computers & Education, 9, 2, 79-86.

de Kort YAW, Ijsselsteijn W.A, Kooijman J, and Schuurmans Y, 2003.Virtual laboratories: Comparability of real and virtual environments for environmental psychology. Presence, 12(4), 360–373.

Engum SA, Jeffries P, and Fisher L, 2003. Intravenous catheter training system: Computer-based education versus traditional learning methods: The American Journal of Surgery, 186, 1, 67-74.

Feisel LD and Rosa AJ, 2005. The Role of the Laboratory in Undergraduate Engineering Education, J Eng Educ, , 94, 1, 121-130, The Society, Washington, D.C.

Gladwin RP, Margerison D, and Walker SM, 1992. Computer-assisted learning in chemistry, Computers & Education, 19, 1-2, 17-25.

Gosman AD, Launder BE, Lockwood FC, and Reece GJ, 1977. Computer Assisted Teaching of Fluid Mechanics and Heat Transfer. Computers & Education, 1, 3, 131-139.

Gunstone RF, 1991. Reconstructing theory from practical experience. Practical Science.

Ingram D, Dickinson CJ, Saunders L, Sherriff M, Bloch R, Sweeney G, and Ahmed K, 1979. Application of a Pharmacokinetic Simulation Program in Pharmacy Courses Computers & Education, 3, 4, 335-345.

Heise D, 2006. Asserting the inherent benefits of hands-on laboratory projects vs. computer simulations. J. Comput. Small Coll. 21, 4, 104-110.

Johnstone AH and Al-Shuaili A, 2001. Learning in the laboratory; some thoughts from the literature, University Chemistry Education.

Hofstein Avi and Lunetta VN, 2004. The laboratory in science education: Foundations for the twenty-first century, Science education., 88, 1, 28, W.G. Whitman, Salem, Mass.

Kirschner PA, 1988. The Laboratory in Higher Science Education, Problems, Premises, and Objectives. Higher Education, 17, 1.

Kolb DA, 1984. Experiential learning: experience as the source of learning and development. Prentice-Hall.

Laghari JR, Suthar JL, and Cygan S, 1990. PSPICE applications in high voltage engineering education, Computers & Education, 14, 6, 455-462.

Ma J and Nickerson JV, 2006. Hands-on, simulated, and remote laboratories: A comparative literature review. ACM Comput. Surv. 38, 3.

McAteer E, Neil D, Barr N, Brown M, Draper S, and Henderson F, 1996. Simulation software in a life sciences practical laboratory, Computers & Education, 4, 26, 1-3, 101-112.

McComas WF, 1997. The Nature of the Laboratory Experience: A Guide for Describing, Classifying, and Enhancing Hands-On Activities. CSTA Journal, p6-9 Spr.

Raineri D, 2001. Virtual laboratories enhance traditional undergraduate biology laboratories. Biochemistry and Molecular Biology Education, 29, 4, 160-162

Ronen M and Eliahu M, 2000. Simulation — a Bridge Between Theory and Reality: the Case of Electric Circuits. Journal of Computer Assisted Learning, 16(1), 14-26.

Slavin RE, 2005. Educational Psychology. Prentice Hall.

Smith PR, 1976. Computers in engineering education in the United Kingdom. Computers & Education, 1, 1, 13-21.

Spicer JI, and Stratford J, 2001. Student Perceptions of a Virtual Field Trip To Replace a Real Field Trip, Journal of Computer Assisted Learning, v17 n4 p345-54 Dec.

VARK, 2009, http://www.vark-learn.com/english/index.asp, retrieved on 06.08.2009.

Weenk GWH, 1999. Learning Pyramid. Educational Center, University of Twente.