Int. J. Engng Ed. Vol. 25, No. 3, pp. 577–584, 2009
Printed in Great Britain.
0949-149X/91 $3.00+0.00

Using Engineering Remote Laboratories to Enhance Student Learning—a Distributed Learning Experience*

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We present our experience of the operation of the solar energy e-learning laboratory (Solar e-lab) in Cyprus, and demonstrate the benefits of distributed learning by employing a remote engineering application. We focus on experientially-based learning which allows remote and distributed training with laboratories, workshops and real working-places over the Internet. The aim of the solar energy e-learning laboratory is to use today's technology as a tool to make laboratory facilities accessible to engineering students (especially handicapped) and technicians located outside the e-lab premises. In this way, the laboratory, its equipment and experimental facilities can be shared by many people, thus simplifying availability and widening educational experiences. Over its four years of operation, users from more than 400 locations in 75 countries have visited the solar e-lab. The results of an online evaluation showed a high degree of satisfaction by the remote students using the solar e-lab. Also, a number of foreign educational Institutions of higher learning have included the solar e-lab in their curricula.

Keywords: Remote engineering, remote laboratories, distributed learning, real world experiments, e-learning, internet, solar energy.

INTRODUCTION

REMOTE ENGINEERING is becoming an important element in engineering education [1, 2, 3, 4]. Consequently, there is a growing need for new educational concepts, learning media and tools to accommodate these new advancements in technology. Without the necessary educational tools to handle the possible drawbacks, the use of remote learning can easily lead to functional problems, mistaken conceptions and wrong outcomes [5, 6]. The solar energy elearning laboratory developed within the MARVEL project of the Leonardo da Vinci programme [7] focuses on experientially-based learning arrangements allowing remote and distributed working with laboratories, workshops and real working places to train students in remote engineering.

The solar energy e-learning laboratory (Solar e-lab) comprises a pilot solar energy conversion plant equipped with instrumentation and control devices needed for remote access, control, data collection and processing. A major goal of the solar e-lab is the usage of real worlds in virtual learning environments in order to support work-process-oriented and distributed cooperative learning with real-life systems. Telematics, remote and mixed reality techniques are used cooperatively within a network that includes colleges, industry partners and national bodies dealing with certification and standardisation issues.

* Accepted 25 February 2009.

TRAINING NEEDS IN TODAY'S ENGINEERING EDUCATION

Engineering work is undergoing significant structural changes worldwide. As online education becomes an everyday part of engineering education [8, 9, 10], online methods in engineering education will increase the breadth and scale of engineering education, thus extending the reach of institutions and the delivery of education to broader audiences [11]. Various studies [10, 12, 13] give evidence for the increasingly telematic-based work environment important in the context of geographically distributed commissioning, installation, maintenance and repair of plant and machinery [14]. Remote engineering, remote maintenance, teleservice or emaintenance are all catchwords for these novel engineering and management concepts whereby construction and maintenance of plant and machinery are monitored and managed over the Internet [15, 16]. The emergence of these techniques has roots in the dissemination of mechatronic components—which are nowadays available in almost all modern systems—and the Internet of course [17, 18]. Remote service techniques have benefits for the engineering and plant construction industries as well as for their customers: problems can be diagnosed off-site and local engineers can be supported by a central team of remote experts. This helps to reduce service costs while increasing the availability of systems [19].

In contrast to 'traditional' engineering, experts in remote engineering are deployed in a relatively broad range of activities that span different sectors of industry. They typically work in locally distributed teams and coordinate their work amongst themselves. This requires not only competent handling of tools and methods for diagnosis, maintenance, monitoring and repair, but above all the ability to communicate effectively with others (e.g. customers, users, installers) with the help of computer-aided means of communication. Skilled service technicians must solve the 'mutual knowledge problem', for example, by integrating the knowhow of others in order to accomplish their goals using appropriate tools (e.g. electronic conferencing or groupware applications). Special focus must be placed on accessing distributed information from suppliers, customers and manufacturers over the Internet. Because e-maintenance is primarily immaterial, the quality assessment made by customers is highly dependent on those employees who perform such services. For this reason, technicians and engineers must also be trained in customer orientation with an emphasis on communication training and customer-centred action.

With the above requirements in mind, and the work done by Lindsay, E. and Good, M. [6], the solar e-lab was designed in such a way as to produce evaluated working examples of remotely accessible laboratories with all the real world problems that occur during an ordinary experimental exercise, to train engineering students in remote engineering, e-maintenance, remote process control and supervision. The pedagogical approach followed is based on key aspects such as teamwork, action orientation, work process orientation and customer orientation.

Action orientation applies learning and work assignments where students can learn from hands-on experiences with concrete tools and systems. Thus laboratory exercises [1, 2, 3] play a fundamental role in the experimental learning settings. Teamwork, however, is the core element of e-maintenance. The ability of students to work in teams must therefore be fostered and trained through collaborative learning. The ability to work in teams can only be experienced and practised within learning situations that are also organised in a team-centred manner.

The educational concept behind the approach offered in this article combines experiential and collaborative learning. The theory of experiential learning [20] propagates learning through experience and by experience: learning is a process whereby knowledge is created though the transformation of experiences.

One of the main exponents of experiential learning is David A. Kolb [21], who proposes a learning theory comprising four main stages, as illustrated in Figure 1: active experimentation, concrete experiences, reflective observation and abstract conceptualization.

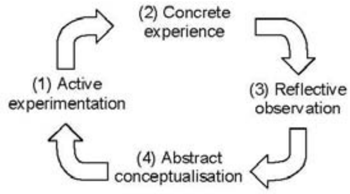

Fig. 1. Experiential learning cycle, adapted from Kolb [21].

This model suggests that a participant has a Concrete Experience, followed by Reflective Observation, then the formation of Abstract Conceptualizations before finally conducting Active Experimentation to test out the newly developed principles. In his model the process begins with an experience, which is followed by reflection; the reflection is then assimilated into a theory and finally these new (or reformulated) hypotheses are tested in new situations. The model is an iterative cycle within which the learner tests new concepts and modifies them as a result of reflection and conceptualization activities. Two aspects are noteworthy: the use of concrete, 'here-and-now' experience to test ideas; use of feedback to change practices and theories.

Laboratory experiments seem to be very ideal for experiential based training, because laboratory experiments provide a 'hands-on' approach to learning. They allow a learner to 'experience' data in a more familiar form, since the practical experiment proposed to the students enables them to 'observe and reflect' on what they have just witnessed. Each experiment may therefore be seen as a starting point on the way that will lead them to understand its underlying theoretical principles.

According to the theory of social constructivism, students learn through collaborative interaction with others [22]. The theory of social constructivism addresses two basic aspects of collaboration. The first one involves the relationships among students; students work together as peers, applying their combined knowledge to the solution of a problem. The dialogue that results from this combined effort provides students with the opportunity to test and refine their understanding in an ongoing process.

The second aspect of collaboration involves the role of the teacher; teachers should serve as moderators during the learning process by helping students to reflect on their evolving knowledge and providing direction when students are having difficulty. Thus, collaborative learning does not occur in a traditional classroom where students work independently on learning tasks and take responsibility only for self.

The focus of traditional groups is generally on individual performance and accountability so that they are not dependent on each other for learning. Independence is actively discouraged. In many cases, working in groups is also much closer to real work situations, when compared with isolated learning. As described above this is particularly evident when concerned with the provision of various Internet-based services associated with complex systems and networked machinery.

Use of the Internet is not only widespread today, but also available to almost all schools and students. This work takes a step towards the introduction of collaborative learning to the regular engineering student by introducing real experiments and highly prized experimental setups for everybody with access to the Internet. The solar energy e-learning laboratory is thus available for use as a learning task both as teamwork and as an independent exercise.

SOLAR ENERGY E-LEARNING LABORATORY SETUP

The solar energy e-learning laboratory comprises a pilot solar energy conversion plant which consists of two flat-plate solar collectors having a surface area of 3 m^2 located on the roof of the laboratory, an insulated thermal storage tank located in the solar energy laboratory and other auxiliary equipment and accessories. It is also equipped with all necessary instrumentation, control and communication devices which are needed for remote access, control and data collection and processing. The schematic diagram of the system is illustrated in Figure 2.

The installed hardware and software includes features for controlling external devices, responding to events, processing data, creating report files and exchanging information with other applications. All relevant weather data as well as operational and output data of the system are registered

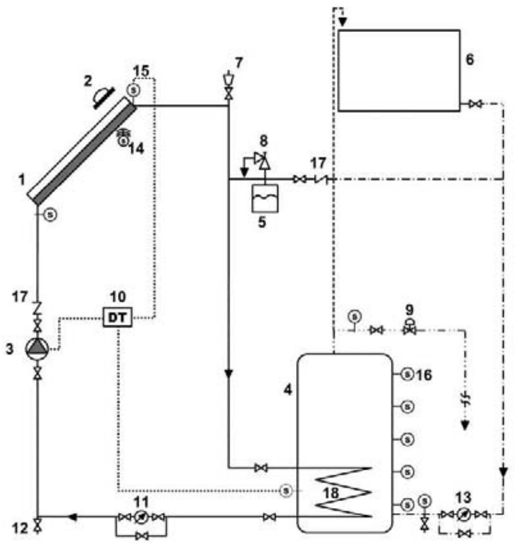

Fig. 2. System schematic diagram of the experimental setup: (1) Solar collector; (2) pyranometer; (3) pump; (4) storage tank; (5) expansion tank; (6) feed water; (7) and (17) check valves; (8) pressure relief valve; (9) motorised valve; (10) differential temperature controller; (11) and (13) water flow meters; (12) drain valve; (14) ambient air temperature sensor; (15) and (16) temperature sensors; (18) heat exchanger.

during an experimental session and can be stored on the users' PC for various calculations and/or documentation.

A major goal of the solar e-lab is the use of real worlds in virtual learning environments in order to support work-process-orientated and distributed cooperative learning with real-life systems. Its aim is to use the Internet as a tool to make the laboratory facilities accessible to engineering students (especially handicapped) and technicians located outside the laboratory, including overseas. In this way, the solar energy e-learning lab and its equipment and experimental facility will be available and shared by many people, thus increasing availability and reducing costs.

A number of laboratory experiments and learning tasks were already developed including familiarisation exercises as well as system performance investigations and e-maintenance tasks. All exercises and learning tasks are supported by web-based learning materials in the form of 'online books' [23].

SYSTEM ARCHITECTURE AND LEARNING PLATFORM

The system architecture used in the solar energy e-learning lab is illustrated in Figure 3.

The user can access the solar e-lab through a PC which acts as a web server. This server hosts the e-learning platform with all necessary extensions for PHP support as well as the database necessary for this platform. It also communicates with the machine hosting the application software (TestPoint) [24]. Whenever a user wishes to get into the system, the communication will be done through this server. That is, the user sends his/her request to the system, the web server communicates with the TestPoint web server and it collects the data and transfers them to the user.

The actual running of the setup is done via the TestPoint, which is an interface tool capable of acquiring data through various sensors, storing the data in a form that the user likes, processing and handling the data in a meaningful manner. This particular software consists of two parts, programming and runtime. Programming is needed only by the system designer, while the runtime is necessary to run the particular experiment and is available to the interested user free of charge. Any collected data can be stored in popular program formats (Word, Excel, etc.) allowing the user to print personally chosen report formats and hand in a report of choice. This tool is located on a dedicated server allowing faster data handling.

A user may visit the laboratory website anytime from anyplace in the world. The only requirements are a computer connected to the Internet and any of the standard web browsers. By typing the address of the solar energy e-learning laboratory (http://e-lab.hti.ac.cy), the user can visit the initial page of the website. It is possible for visitors with

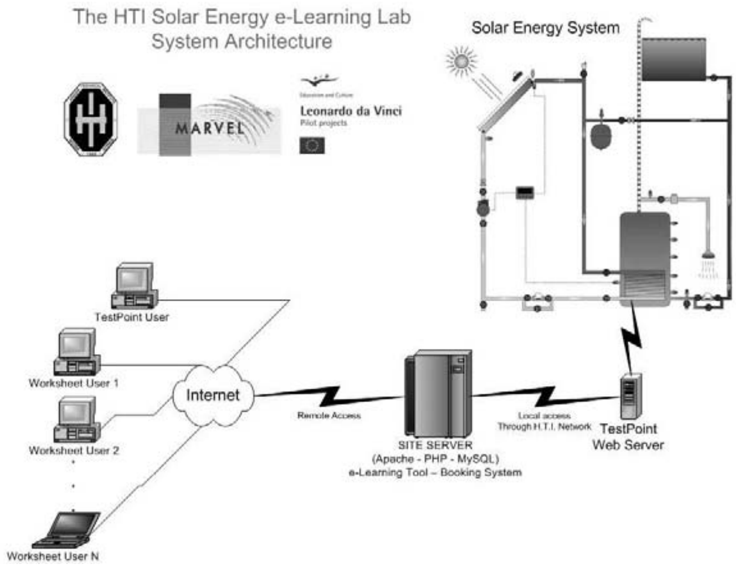

Fig. 3. Solar e-lab system architecture.

little interest in solar energy to read and study the subject with no requirements or registration or testing. So, not all of the pages require login. As a matter of fact, anyone can see most of the pages without the need to create an account. Login, thus creating an account, is only needed when the user decides to take the so-called pre-lab test and conduct an online live experiment through the internet. All activities in the web site are presented in Figure 4.

A booking tool is available to control access time to the system. To be able to make a booking, to have access to the system for conducting an experiment, a remote student has to attempt a pre-lab quiz and get a passing grade. In case the system is busy, because another user is online performing an experiment, the user is entitled to get into the e-lab as an observer. The system will open a new window and the remote user will be able to view the system in operation and get the readings but will not be allowed to intervene in the operation and control of the system. The 'observer user' can, however, record the readings and use them for calculations.

In the solar e-lab web page, apart from the possibility of live access to the system, the user can find documentation material, as well as a glossary of technical terminology that is used in the system, with automatic linking of the terms used in the documents with those included in the glossary.

The selected e-learning platform at the web server is Moodle [25], which is a course management system provided freely as Open Source software (under the GNU Public Licence). Moodle will run on any computer that can run PHP, and can support many types of database, particularly MySQL [26]. This choice allows for flexibility in the learning tools and provides various learning environments to suit the requirements of the various courses [27]. In this particular case Moodle is used as a demonstration, a quiz and an experimental tool.

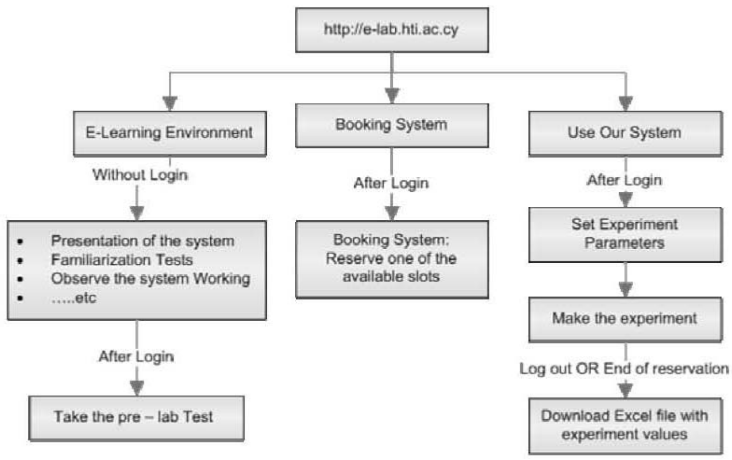

Fig. 4. Activities in the solar e-lab.

Moodle capabilities were enhanced so that running of the actual experimental setup is only allowed after the successful completion of preliminary exercises. With this platform, the user can work independently or as a team with people from the same class or even from a different school far away, talking to each other on the special tool provided at the platform.

THE LEARNING EXPERIENCE

The solar e-lab is designed for real time online live experiments in the field of solar engineering. Design of the learning scenarios comprises a series of exercises of different degree of difficulty and complexity. Introductory work with all the notes, system explanations and glossary allow the student/interested party to get familiar with the system and the work to be followed. Subsequent exercises with the difficulties and unexpected problems of real-life experimentation allow the student to realize the difficulties of the work (Kolb's first and second steps). For each exercise, the student undergoes an online assessment and is allowed to proceed to a real experiment only if successful in the pre-lab test.

During these introductory exercises, the student becomes familiar with the solar e-lab and conversant with the components of the pilot solar energy conversion plant. Upon completion of these exercises the student should be able to name each component in the plant and identify the various components needed to construct a solar plant (Kolb's third step).

More advanced exercises were also prepared. The objective of these exercises is to familiarize the student with the system layout, make him conversant with the function of each component and the system operation. At the end of these exercises the student should understand the function and operation of each piece of equipment in the system as well as provide an introduction to the hydraulics and flow circuits of the plant.

As a last step into the real world of experimentation the student may get access to the system and perform system control and data gathering. During this part of the work the student will become acquainted with the remote control of the system and exercise in taking the readings of the various measuring devices, such as temperatures, flow rates and solar radiation. The student will take sets of readings for various conditions and different scenarios. One of the scenarios will be to elaborate on the stratification of temperatures in the vertical type storage tank, get first-hand experience of the variation of temperatures across the tank at different operational conditions, explain the stratification effect and comment on the results.

Another experiment is to investigate the instantaneous efficiency of the collector or determine the rate of thermal energy removed from the storage tank to the consumption. For this purpose, the student can record a number of readings (incident solar radiation, water flow rates, temperatures, etc.) and, using certain thermodynamic equations [28], determine the performance characteristics of the collector and compare them with those given by the manufacturer. The test can be conducted at various conditions and with different scenarios such as, for example, with or without consumption of service hot water, at different temperature differentials, etc, and ,should more time be available, data recorded in the Excel file downloaded at the logout or any time during the experiment, could be used to plot graphs for the system thermal behaviour.

Figure 5 shows a screenshot of the diagrammatic layout of the system and the real readings during a real time live experiment. On purpose, the screen refreshes every five minutes in order to allow the student enough time to see the readings and discuss them with classmates or the teacher. The student can see, for example, the temperature stratification in the storage tank (in Figure 5 the temperature at the bottom level of the storage tank is 27.2°C, at mid-point it is 48.3°C and at the top of the tank it is 50.6°C), the solar radiation intensity, the water temperatures at the inlet and the outlet of the solar collector, etc. It is to be noted that all the data are recorded in an Excel file and can be downloaded at the end of the live experiment.

If the system is busy, because a user is online performing an experiment, another user may get into the e-lab as an observer, without any booking and without needing to conduct the pre-lab test.

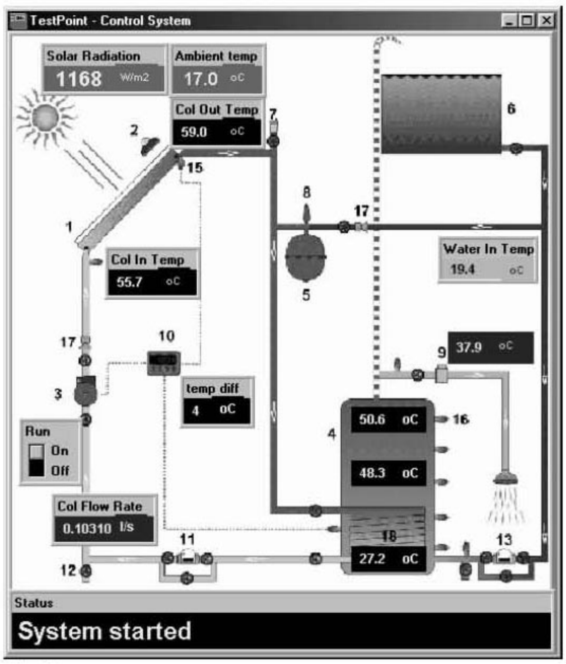

Fig. 5. Live online experiment. System real-time readings: solar radiation 1168 W/m^2; ambient air temperature 17.0°C; water flow rate through the collector 0.10 l/s; collector inlet and outlet temperatures 55.7 and 59.0°C respectively; temperatures in the storage tank: bottom 27.2°C, mid-point 48.3°C, top 50.6°C; temperature differential controller setting 4°C.

The system will open a new window and the newcomer will be able to have a view of the system in operation and get the readings but will not be allowed to intervene in the operation of the system or to control it. However, the readings can be recorded and used for calculations. There is no limitation to the number of 'passive' participants.

SYSTEM TRIALS, VALIDATION AND IMPACT

Several course trials were conducted at the Higher Technical Institute to test the system operation and reliability and check for the consistency and reliability of the data acquisition and transfer as well as the validity and reliability of the temperature differential controller settings. During these tests a number of problems were traced and appropriate corrective measures were taken before arriving at the final system.

The aspect of remote experimentation through the Internet was tried and validated by a number of academic institutions in Thessalonica (Greece) in November 2004, Delmenhorst (Germany) several times during March–April 2005, Brussels in April 2005 and Stockholm (Sweden) in 2006 and 2007. The validation tests included navigation through the e-learning part but emphasis was given to the reliability of the booking system and the live connection and remote experimentation. There is a continuous feedback from the e-lab users through the 'Online evaluation' which is seriously taken into consideration for improvements.

One of the main concerns was whether data were transferred to the user in the appropriate format and the correct way and also whether the differential temperature controller was controlling the pump according to the settings. Following a good number of validation tests it was verified that the system worked successfully.

The impact that the solar e-lab had during its four years of operation is indeed high. Throughout this period, the solar e-lab had been accessed by users from over 400 locations in 75 countries spread all over the world [29]. Furthermore, a number of colleges and universities are using the solar e-lab as part of their training programme. Most of them logged in as 'guests' and surfed through the various parts of the solar e-lab site and its courses. Other users registered and went through the various steps ending with remote access to the online live experiments; some of them communicated their experiences to the lab administrator. It is, however, worth mentioning that in addition to individual users, the e-lab is used on an organised basis by a number of institutions as part of their curricula, especially by those offering distance learning. This is the case with The Royal Institute of Technology (KTH) in Stockholm, where for three continuous years the solar e-lab was used by the students doing an MSc course as part of the curriculum. That course is also available to distance learning students from other countries, who use the solar e-lab from their home; they perform online real time experiments and they submit their work to the Institute for assessment. Remote students can communicate with the e-lab administrator and discuss possible questions or problems they may have.

Judging from the online evaluation reports that these students send as feedback to the solar e-lab administrator, it can be said that there is nearly excellent satisfaction by the users. Comments such as 'The resources in the course (quizzes, notes, glossary, etc.) were straightforward and easy to use', 'The course was flexible and met my time expectations', 'The course was a valuable learning experience', were given a high score by the great majority of the students. Table 1 shows the results of the online evaluation submitted by 28 students enrolled in a postgraduate level course that included the solar e-lab in the curriculum. Five were enrolled as distant learning students. Some of the surveys were sent directly to the e-lab administrator via e-mail while others were sent through their local supervisor.

The results provide useful information about student satisfaction with the organisation of the e-lab interaction and the course content and organisation. The great majority of the students, especially those enrolled as distance learning, expressed a high degree of satisfaction with the resources in the course, the clarity of the content, the quality of the diagrammatic layouts and animations, the laboratory sheets and the clarity of the course objectives. Most students indicated that they would recommend the solar e-lab to other students.

Students expressed their dissatisfaction with regards to the structure of the course content and the e-learning course, the pre-lab test and the booking system. They suggested that booking slots of two hours were long and the one-hour interval between two successive lab slots not needed. This is indeed true due to the nature of the experiments and the field of application (solar energy); as a matter of fact, the long lab sessions and the 1-hour interval restrict the number of experiments to four per day, owing to the fact that the actual sunshine duration is limited to a number of hours ranging from five to twelve depending on the season and the weather conditions.

Overall, the majority of students expressed a moderate to high degree of satisfaction with the solar e-lab.

CONCLUSIONS

The solar energy e-learning laboratory goes beyond traditional remote engineering laboratories by providing distributed work places for complex remote learning tasks. An important innovation

Table 1. Results from the online evaluation

1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent

Course level: MSc. Number of students: 28 (5 of them distance learning)

Item	Mean score	SD
The resources in the course (quizzes, notes, glossary, etc.) were straightforward and easy to use	4,54	0,64
The structure of the content was easy to follow	3,75	0,80
The e-learning course was interesting and enjoyable	3,32	0,48
The objectives for each course were clear	4,25	0,80
The content was clear and easy to understand	4,50	0,75
The content gave me sufficient information	4,39	0,74
The course materials were easy to read	4,11	0,83
Diagrammatic layouts and animations were clear and helpful	4,57	0,74
The course was a valuable learning experience	3,89	0,63
Lessons flowed in logical order	4,04	0,92
The material was explained in a clear and understandable manner	3,75	0,84
The course was flexible and met my time expectations	4,04	0,58
The pre-lab test as a condition for the live access to the system was reasonable	4,00	0,61
The pre-lab test was well prepared	4,00	0,61
The booking system was well organized	3,64	0,78
The laboratory sheets contained useful information and instructions	4,54	0,84
The Excel file with the results was well organized and presented	4,25	0,89
Overall impression of the e-lab web site	4,29	0,66
I would recommend this course to others	4,57	0,57

within the solar e-lab is that concepts and examples for real working and learning are developed and accessed virtually through remote processes. Accordingly it goes beyond 'traditional' remote laboratories, because it provides distributed work places for remote engineering in technical training.

The four years of operation of the solar e-lab demonstrated how the Internet can be used as a tool to make laboratory facilities accessible to engineering students and technicians located outside the laboratory, including overseas. In this way, the solar e-lab and its equipment and experimental facilities are made available and are shared by many people, thus reducing costs and widening educational experiences.

Learning by experience and through experience in a real and social context is restricted in virtual environments. We have presented an alternative approach where learning is understood as a process for acquiring information and processing experience in which the learner selects and constructs knowledge that is useful and appropriate. In turn, learners use this to drive and determine their own continuous learning process. In this way learning becomes a process of interaction between individuals and the work environment, in which the subjective reality of the learner is actively constructed. These concepts support the social aspects of learning, as learning is necessarily integrated in communication processes between different learning groups while working at the same system or device.

Acknowledgements—This work was compiled from data recorded in the solar energy e-learning laboratory (http://e-lab.hti.ac.cy) which was developed as part of the MARVEL project of the European Leonardo da Vinci Programme.

REFERENCES

1. M. Auer, A. Pester, D. Ursutiu, C. Samoila, Distributed virtual and remote labs in engineering, *Proceedings of the IEEE International Conference on Industrial Technology 2*, (2003) pp. 1208–1213.
2. H. Benmohamed, A. Lelevé, P. Prévot, Generic framework for remote laboratory integration, ITHET 2005: *6th International Conference on Information Technology Based Higher Education and Training, 2005* art. no. 1560229, (2005) pp. T2B-11–T2B-16.
3. A. Agrawal, S. Srivastava, WebLab: A generic architecture for remote laboratories, Proceedings—CIS Workshops 2007, International *Conference on Computational Intelligence and Security Workshops*, art. no. 4425988, (2007), pp. 301–306.
4. M. Helander, R. Emami, Engineering Laboratories: Integration of Remote Access and eCollaboration, *Int. J. Eng. Educ.* **24**(3), 2008, pp 466–479.
5. E. Lindsay, M. Good, Virtual and distance experiments: pedagogical alternatives, not logistical alternatives, *ASEE Annual Conference and Exposition, Conference Proceedings* (2006).
6. E. Lindsay, M. Good, Effects of laboratory access modes upon learning outcome, *IEEE Transact. Educ.* **48**(4), 2005, pp. 619–631.
7. D. Müller, J. M. Ferreira, MARVEL: A mixed-reality learning environment for vocational training in mechatronics, *Proceedings of the Technology Enhanced Learning International Conference,* (TEL'03), (2003).
8. E. Aziz, C. Chassapis, S. Esche, On the integration of remote and virtual experiments into a comprehensive student laboratory experience, *Proceedings of 2006 ASME International Mechanical Engineering Congress and Exposition, IMECE2006*—Mechanical Engineering Education (2006).

9. J. Machotka, Z. Nedic, Students' responses to remote laboratory NetLab, *Proceedings of the Fifth IASTED International Conference on Web-based Education 2006*, (2006) pp. 264–269.
10. W. Hutzel, A remotely Accesses HVAC Laboratory for Distance Education, *Int. J. Eng. Educ.* **18**(6), 2002, pp. 711–716.
11. J. Bourne, D. Harris, F. Mayadas, Online Engineering Education: Learning anywhere, Anytime. *J. Eng. Educ*. **94**(1), 2005, pp 131–146.
12. E. Scanlon, C. Colwell, M. Cooper, T. Di Paolo, Remote experiments, re-versioning and re-thinking science learning, *Comp. Educ.* **43**(1-2 SPEC ISS.), (2004), pp. 153–163.
13. P. Fox, W. Worley, S. Hundley, K. Wilding, Enchancing Student Learning Through International University—Industry Cooperation; The GO GREEN Course, *Int. J. Eng. Educ.,* **24**(1), 2008, pp. 175–184.
14. J. Lee, H. Qiu, J. Ni, D. Djurdjanovi, Infotronics Technologies and Predictive Tools for Next-Generation Maintenance Systems, *11th IFAC Symposium on Information Control Problems in Manufacturing.* Salvador, Brasil April 5–7th (2004).
15. T. Graupner, E. Westkämper, E-maintenance web-based services for production systems, in Qu, *Proceedings of International Conference on Intelligent Maintenance Systems*, China: National University of Defence Technology Press, (2003), pp. 637–645.
16. L. Motiwalla, S. Tello, Distance Learning on the Internet: An Exploratory Study, *Internet and Higher Education* **2**(4), 1999, pp. 253–264.
17. C. Tzafestas, N. Palaiologou, M. Alifragis, Virtual and remote robotic laboratory: Comparative experimental evaluation, *IEEE Transact. Educ*. **49**(3), 2006, pp. 360–369.
18. T. Kikuchi, S. Fukuda, A. Fukuzaki, K. Nagaoka, K. Tanaka, T. Kenjo, D. Harris, DVTS-Based Remote Laboratory Across the Pacific Over the Gigabit Network, *IEEE Transact. Educ.* **47**(1), 2004, pp. 26–32.
19. M. Callaghan, J. Harkin, T. McGinnity, L. Maguire, Cost effectiveness issues in remote experimentation, Conference Proceedings—IEEE International Conference on Systems, *Man and Cybernetics* **5**, 2004, pp. 4700–4704.
20. H. Erbe, F. Bruns, *Didactical Aspects of Mechatronics Education*, 5th IFAC International Symposium on Intelligent Components and Instruments for Control Applications (SISACA). Aveiro, Portugal (2003).
21. D. Kolb, *Experiential Learning: Experience as the source of learning and development*, New Jersey: Prentice-Hall, (1984).
22. V. Burr, An Introduction to Social Constructivism, London: Routledge, (1995).
23. The solar energy e-learning laboratory, http://e-ab.hti.ac.cy/mod/resource/view.php?id=34
24. TestPoint—Keithley Solutions for Data acquisition. http://www.test-point.com/gen_tp.html
25. Moodle—A free, Open Source Course Management System for Online Learning, http//moodle.org/.
26. The world's most popular open source database, http://www.mysql.com/
27. Matt Riordan, Moodle—An electronic classroom, Teacher Manual, http//moodle.org/
28. J. Duffie, W. Beckman, Solar Engineering of Thermal Processes. John Wiley, New York, (1991), pp. 301–307.
29. The solar energy e-learning laboratory, http://e-lab.hti.ac.cy/mod/resource/view.php?id=55

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