Online engineering education - A new approach in using physical laboratories to enhance student learning

I. M. Michaelides[1] and P. C. Eleftheriou

Department of Mechanical Engineering and Materials Science and Engineering,
Cyprus University of Technology, P.O. Box 50329, 3603 Limassol, Cyprus

Index Terms: Remote engineering, e-learning, solar energy.

This paper presents the experience from the operation of the solar energy e-learning laboratory in Cyprus and demonstrates the benefits of online engineering education in the field of solar energy. The solar energy e-learning laboratory (Solar e-lab) provides online experimentation, thus allowing students from anywhere to operate remote instruments at any time.

The Solar e-lab comprises a pilot solar energy conversion plant which is equipped with all necessary instrumentation, data acquisition, and communication devices needed for remote access, control, data collection and processing. The installed hardware and software include features for controlling external devices, responding to events, processing data, creating report files, and exchanging information with other applications.

The Solar e-lab has so far been accessed by users from over 400 locations from 75 countries spread all over the world and continents [1]. Furthermore, a number of colleges and Universities use the solar e-lab as part of their training programmes, like for example the Royal Institute of Technology in Sweden, the Delmenhorst College in Germany, and the Higher Technical Institute in Cyprus. There is an interactive communication between the students of the above institutions and the solar e-lab helping them to accomplish the assigned work in due time.

I. Introduction

As remote engineering is becoming an import element in engineering, a growing need for new educational concepts, learning media, and tools to accommodate for these new advancements in technology are in greater demand. The solar energy e-learning laboratory, presented here, was developed within the MARVEL project of the Leonardo da Vinci programme and focuses on experiential based learning arrangements allowing remote and distributed working with laboratories, workshops and real working-places to train students in remote engineering [2].

The solar energy e-learning laboratory (Solar e-lab), is been on the air for the last four years, and comprises of a pilot solar energy conversion plant which is equipped with all necessary 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 which includes colleges, industry partners, and national bodies dealing with certification and standardisation issues.

This paper presents the experience of using such technology for teaching, but also some of the learning scenarios developed as well as the forthcoming trends in the training of futures' engineering. The solar energy e-learning laboratory and its features is then presented, followed by a presentation of a number of laboratory tasks in the field of solar energy conversion that can be remotely conducted through the Internet.

II. Needs in today's engineering education

Nowadays, engineering work is undergoing significant structural changes worldwide. As online education becomes an everyday part of education, 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

[1] E-mail: ioannis.michaelides@cut.ac.cy

broader audiences [3]. Various studies give evidence for the increasing telematic-based work environment important in the context of geographically distributed commissioning, installation, maintenance and repair of plant and machinery [4, 5]. 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.

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 require 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 know-how 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.

With the above requirements in mind, the solar e-lab was designed with the aim to produce evaluated working examples of remotely accessible laboratory exercises, to train engineering students in remote engineering, e-maintenance, remote process control and supervision. Thus, the pedagogical approach was 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 play a fundamental role in the experimental learning settings. Teamwork on the other hand 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 itself are 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 [6] 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 [7], who proposes a learning theory comprising four main stages, as illustrated in fig.1: active experimentation, concrete experiences, reflective observation and abstract conceptualization. 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; and use of feedback to change practices and theories.

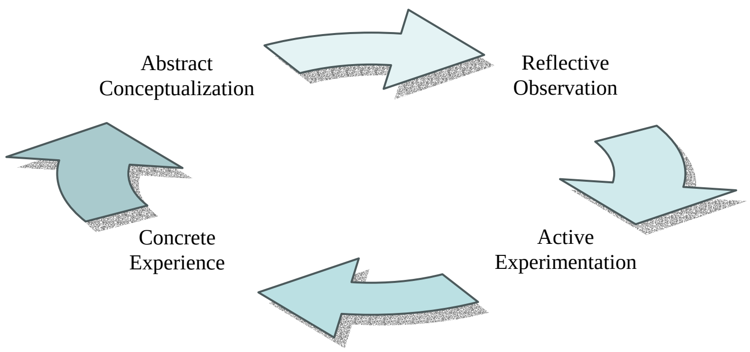

Fig. 1. Experiential learning cycle, adapted from Kolb [7]

[1] E-mail: ioannis.michaelides@cut.ac.cy

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 [8]. 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 supporting students how 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 concerning the provision of various Internet based services associated with complex systems and networked machinery.

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

III. The laboratory setup

The solar energy e-learning laboratory comprises a pilot solar energy conversion plant consisting 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 fig. 2.

The installed hard- 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 during an experimental session and can be stored on the users´ PC for various calculations and/or documentation.

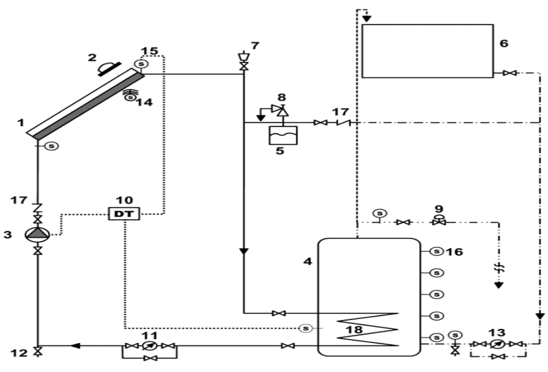

Fig. 2. System schematic diagram of the experimental setup: (1) Solar collector; (2) pyranometer; (3) pump; (4) storage tank; (5) expansion tank; (6) feed water; (7) and (17) check valves; (8) pressure relief valve; (9) motorised valve; (10) differential temperature controller; (11) and (13) water flow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

[1] E-mail: ioannis.michaelides@cut.ac.cy

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. Its aim is to use the Internet as a tool to make the laboratory facilities accessible to engineering students (especially handicapped). In this way, the solar energy e-learning lab and its equipment and experimental facility will be available and be shared by many people, thus 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 ‘virtual books’ [9].

IV. Runtime booking and learning platform

A booking tool is available to control the access time to the system. In order 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 and he/she can get into the e-lab as an observer. The system will open a new window and the remote user will be able to have a view of the system in operation and get the readings but he/she will not be allowed to intervene into the operation of the system. The “observer user” can, however, record the readings and use them for calculations if he/she wishes so.

The selected e-learning platform at the web server is Moodle [10], which is a course management system which is provided freely as Open Source software (under the GNU Public License). Moodle will run on any computer that can run PHP, and can support many types of database, particularly MySQL [11]. This choice allows for flexibility in the learning tools and provides various learning environments to suit the requirements of the various courses [12]. In this particular case Moodle is used as a demonstration, a quiz and an experimental tool. The Moodle capabilities were enhanced so that the running of the actual experimental set-up is only allowed after the successful completion of the preliminary exercises.

V. Hardware architecture and runtime

The system architecture used in the solar energy e-learning lab is illustrated in fig. 3. The user can access the solar e-lab through 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) [13]. 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.

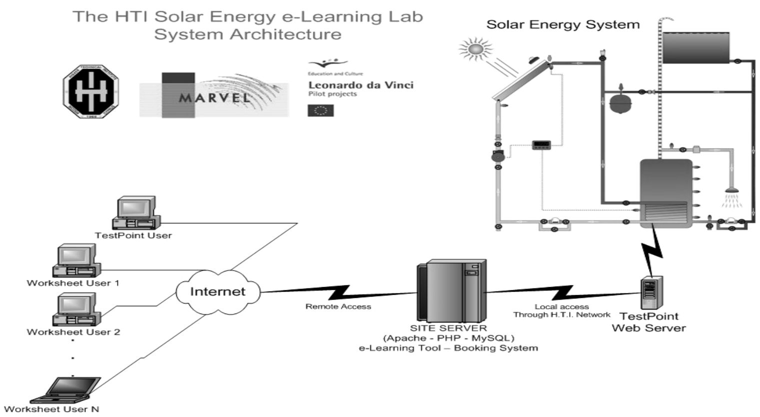

Fig. 3. The solar e-lab system architecture

The actual running of the set-up 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, and processing and handling the data in a meaningful manner. This particular software consists of two parts, the programming and the

[1] E-mail: ioannis.michaelides@cut.ac.cy

runtime parts. The programming is needed only to 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 programme formats (Word, Excel, etc.) allowing the user to print his own report formats and hand in a report of his 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 little interest in solar energy to read and study on the subject with no requirements or registration or testing. So, not all of the pages require login. As a matter of fact, one can see most of the pages without the need of creating an account. Login, and 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 Fig. 4.

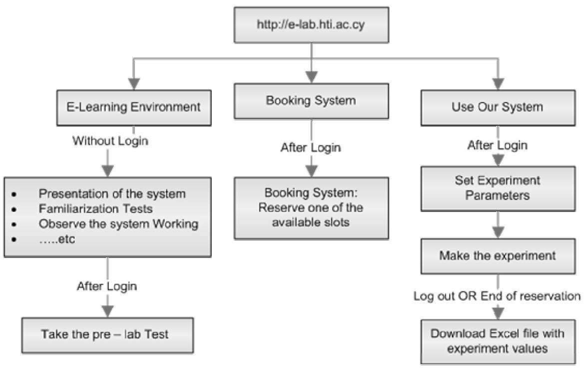

Fig. 4: Activities in the solar e-lab

VI. Applying the learning concept

The design of the learning scenarios comprises of a series of exercises of different degree of difficulty and complexity [14]. For each exercise, the student undergoes an online assessment and is allowed to proceed to a real experiment only if he/she is successful to the pre-lab test. It also comprises an indexed glossary which includes a good number of terms and definitions related to the solar energy laboratory. The introductory exercises start with the familiarization of the student with the solar plant.

During these introductory exersises the student becomes familiar with the solar energy e-learning lab; these exercises make the student 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.

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 and appreciate its role in the system as well as introduce him into 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 get acquaint 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.

VII. System accesses and validation

The solar e-lab has been accessed by users from over 75 countries spread all over the five continents. Fig. 5 shows the World map showing the locations of the accesses to the solar e-lab. Furthermore, a number of

[1] E-mail: ioannis.michaelides@cut.ac.cy

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 the remote access to the online live experiments; some of them communicated their experiences to the lab administrator.

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

The aspect of remote experimentation through the Internet was tried and validated from a number of academic institutions (Greece in 2004, Germany in 2005, Belgium in 2006, and Sweden in 2007). The validation tests included navigation through the e-learning part but emphasis was given on the reliability of the booking system and the live connection and remote experimentation aspect. Furthermore, there is a continuous feedback from the e-lab users through the “Online evaluation” which is seriously taken into consideration for improvements.

Fig. 5 The World map showing the locations of the accesses to the solar e-lab

VIII. 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 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 the laboratory facilities accessible to engineering students and other interested parties outside the laboratory, including overseas. In this way, the solar e-lab its equipment and experimental facilities are made available and are shared by many people, thus reducing costs and widening educational experiences. The Solar e-lab has so far been accessed by users from over 400 locations from 75 countries spread all over the five continents. In addition, a number of colleges and Universities use the solar e-lab as part of their scheduled programmes. Such examples are the Royal Institute of Technology in Sweden, the Delmenhorst College in Germany, and the Higher Technical Institute in Cyprus.

The laboratory has proved that laboratories can be shared among educational establishments, thus reducing equipment cost, and that learning by experience and through experience in a real and social context is restricted in virtual environments. As experimentation is understood as the process of acquiring information and processing experience in which the learner selects and constructs knowledge, it is an ideal situation of applying the above approach. 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.

[1] E-mail: ioannis.michaelides@cut.ac.cy

IX. 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] The solar energy e-learning laboratory, http://e-lab.hti.ac.cy/mod/resource/view.php?id=55.

[2] Müller, D., Ferreira, J. M, "MARVEL: A mixed-reality learning environment for vocational training in mechatronics," Proceedings of the Technology Enhanced Learning International Conference, (TEL'03), Milan, Italy, November 2003.

[3] Bourne J., Harris D., and Mayadas F. Online Engineering Education: Learning anywhere, Anytime. *Journal of Engineering Education*, pp 131-146, Vol. 94, No. 1; January 2005.

[4] Lee, J., Qiu, H., Ni, J., Djurdjanovi, D: 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

[5] Graupner, Tom-David; Westkämper, Engelbert: E-maintenance web-based services for production systems. In: Qu, Liangsheng (Ed.) et al.: *Proceedings of International Conference on Intelligent Maintenance Systems*. October 30 - November 1, 2003, Xi'an, China. Changsha, China: National University of Defence Technology Press, 2003, pp. 637-645.

[6] Erbe, H.-H., Bruns, F. W.: Didactical Aspects of Mechatronics Education. 5th IFAC International Symposium on Intelligent Components and Instruments for Control Applications (SISACA). Aveiro - Portugal 2003.

[7] Kolb, D.A.: *Experiential Learning: Experience as the source of learning and development*. New Jersey: Prentice-Hall, 1984.

[8] Burr, V.: *An Introduction to Social Constructivism*, London: Routledge, 1995.

[9] The solar energy e-learning laboratory, http://e-lab.hti.ac.cy/mod/resource/view.php?id=34

[10] Moodle – A free, Open Source Course Management System for Online Learning, http//moodle.org/.

[11] The world's most popular open source database, http://www.mysql.com/

[12] Matt Riordan, Moodle – An electronic classroom, Teacher Manual, http//moodle.org/.

[13] TestPoint - Keithley Solutions for Data acquisition. http://www.test-point.com/gen_tp.html.

[14] Michaelides I., Eleftheriou P., and Economides K. HTI e-learning Laboratory - Remote Experimentation over the Internet. Proceedings 2nd International Conference on Remote Engineering and Virtual Instrumentation (REV2005), Brasov, Romania, 30 June - 1 July 2005, ISBN 3-89958-137-7, (2005).

[1] E-mail: ioannis.michaelides@cut.ac.cy