Lessons Taught and Learned from the Operation of the Solar Energy E-learning Laboratory

doi:10.3991/ijoe.v5s1.955

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Abstract—**The solar energy e-learning laboratory (solar e-lab) in Cyprus is a good example of a web-based, remote engineering laboratory. It 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 impact that the solar e-lab had during its nearly 5 years of operation is indeed high. Throughout this period, the solar e-lab has been accessed by users from over 500 locations from 79 countries spread all over the world. In the period of November 2004 to October 2008, more than a million visits were recorded, out of which 25000 have registered on the site and surfed through studying the supplied material. Around 1000 hits concerned registered users that passed the pre-lab test and performed the experimentation part.

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 technicians located outside the laboratory, including overseas. In this way, the solar energy e-learning lab, its equipment and experimental facilities were made available and shared by a number of interested people, thus widening educational experiences. Judging from the online evaluation reports that were received from the solar e-lab users during the last 2 years of operation, it can be concluded that there is nearly excellent satisfaction by the users.

Index Terms—**Remote laboratories, solar energy, solar collector, e-learning, real world experiments, e-lab.**

I. INTRODUCTION

Engineering work is undergoing significant changes worldwide. As online education becomes an everyday part of education, online methods in tertiary and especially engineering education will increase the breadth and scale of engineering, thus extending the reach of institutions and the delivery of education to broader audiences [1]. Various studies give evidence for the increasing use of the internet-based work environment and its importance in the context of geographically distributed commissioning, installation, maintenance and repair of plant and machinery [2]. Remote engineering, remote maintenance, teleservice or e-maintenance are all terms for these novel engineering and management concepts whereby construction and maintenance of plants and machinery are monitored and managed over the Internet [2, 3].

Remote engineering is becoming an important element in engineering education. The role that distance learning now undertakes within the teaching and learning environments has gained widespread acceptance over the last few of years. Subsequently, there is a growing need for new educational concepts, learning media and tools to accommodate for these new advancements in technology. The development of internet based remote engineering experimentation laboratories can and does enhance the students' learning experience. A recent assessment study [4] comparing versions of remote labs versus hands-on labs in a junior-level mechanical engineering course on machine dynamics and mechanisms, the results suggest that students learned lab content information equally well from both types of laboratories, and that they have a realistic understanding and appreciation of the practical advantages of remote laboratories.

In contrast to "traditional" engineering, experts in remote engineering are deployed in a relatively broad range of activities that span to 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. 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.

The solar energy e-learning laboratory (solar e-lab) developed within the MARVEL project of the Leonardo da Vinci programme focuses on experiential based learning arrangements allowing remote and distributed working with laboratories, workshops and real working-places to train students in remote engineering [5]. This paper is an overview of the lessons taught and learned throughout its nearly 5 years of operation.

II. THE SOLAR E-LAB ARCHITECTURE AND ORGANISATION

The solar energy e-learning laboratory comprises a pilot solar energy conversion plant which consists of two flatplate solar collectors having a surface area of 3 m2 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. 1.

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) 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 be shared by many people, thus reducing costs.

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.

The system architecture used in the solar energy e-learning lab is illustrated in Fig. 2. 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) [6].

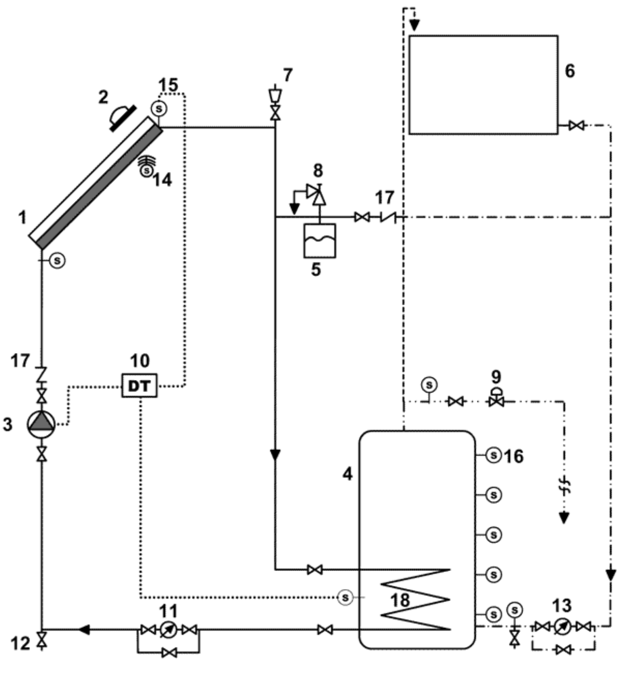

Figure 1. System schematic diagram of the experimental setup: (1) solar collector; (2) pyranometer; (3) pump; (4) storage tank; (5) expansion tank; (6) feed water; (7) and (17) check valves; (8) pressure relief valve; (9) motorised valve; (10) differential temperature controller; (11) and (13) water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

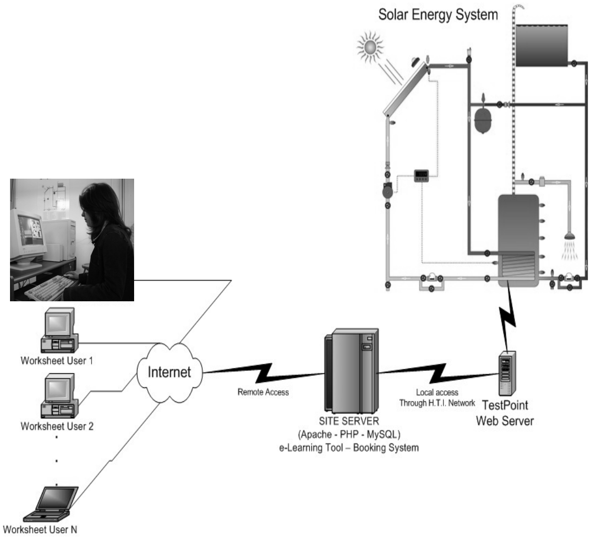

Figure 2. The solar e-lab system architecture

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 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 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.

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 the pre-lab test and get a passing grade. If he/she fails to score the passing mark, he/she can try again, unlimited times. The user can make use of the notes available as well as the “Glossary of Terminology” available in the website.

The selected e-learning platform at the web server is Moodle. In this particular case, Moodle is used for the first time ever as a demonstration, a quiz and an experimental tool all tight up together. 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.

III. THE ONLINE LAB EXPERIMENTS

A number of laboratory experiments and learning tasks were 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" [7]. The user is advised to start by downloading the "User Guide" which is available in three languages, English, German and Greek. There is also an "Illustrated User Guide" which guides the user, step by step, through screenshots and illustrations.

The design of the learning scenarios comprises of a series of exercises of different degree of difficulty and complexity [8]. 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 exercises, the student becomes familiar with the solar energy e-learning lab; these excercises make the student conversant with the components of the pilot solar energy conversion plant. Upon completion of these exercises the student is able to identify the various components needed to construct a solar 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 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.

In case 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. The system will open a new window and he/she 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 system or to control the system. He/she can, however, record the readings and use them for calculations if he/she wishes so. There is no limitation to the number of "passive" participants.

IV. LESSONS LEARNED

The solar e-lab has been accessed by users from over 400 locations from 79 countries spread all over the world and continents [10]. Furthermore, a number of colleges and Universities used the solar e-lab as part of their training programme. By October 2008, 1.2 million visits have been recorded. Most of them concerned logging in as "guests" and surfing through the various parts of the solar e-lab site and its courses. Almost 25000 hits from registered users, thus provided their identity and details, and went through the various steps and system facilities (Fig. 3). Around 1000 hits concerned registered users that passed the pre-lab test and performed the experimentation part. Some of them communicated their experiences to the e-lab administrator with comments and suggestions for improvements which have been seriously considered. Furthermore, a smaller number of users (around 250) gave their feedback from the e-lab "Online evaluation".

Fig. 4 shows the record distribution of registered users to the solar e-lab activities. It is worth noting that the solar e-lab presentation activity was the most popular, while a smaller percentage of users proceeded to more specialized activities. Regarding the guides uploaded from the site, it appears that the Quick Guide has attracted more users as compared to the Illustrated Guide, showing that the first one was sufficiently explanatory for most of the users. The terminology activity has also attracted the interest of many users.

Fig. 5 shows the record distribution of all the users that actually went through the experimentation thus used the complete facilities the solar e-lab had to offer. It is worth noting that only a very small number of non registered users (guests) went through this procedure.

It is however worth mentioning that in addition to individual users, the e-lab is used on an organized basis by a number of Institutions, as part of their curricula, especially by Institutions offering distance learning. This is the case of The Royal Institute of Technology (KTH) in Stockholm, where for 3 consecutive years the solar e-lab is used by the students of 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.

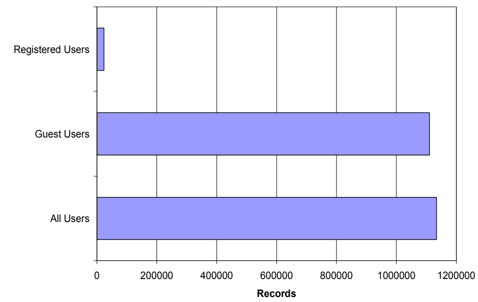

Figure 3. The distribution of all records in the period October 2004 – October 2008

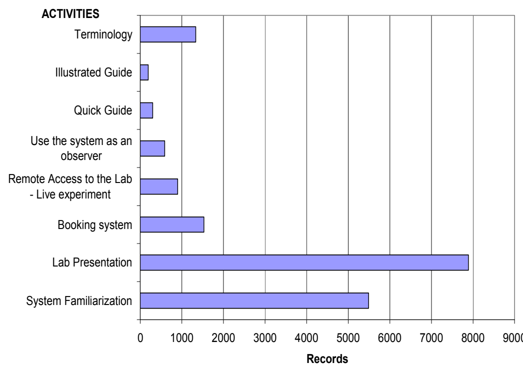

Figure 4. The distribution of the records of registered users to the solar e-lab activities

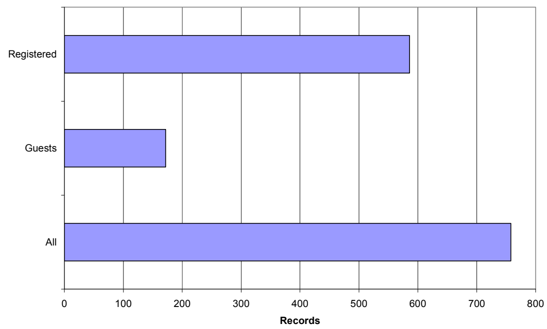

Figure 5. The distribution of the records of registered and non registered users that went through the experimentation

Judging from the online evaluation reports it can be concluded 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 of the course. Five of these students were enrolled as distant learning students. Some of the surveys were sent directly to the e-lab administrator via e-mail while some others were sent through their local supervisor. 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. Students suggested that the booking slots of 2 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 4 per day, owing to the fact that the actual sunshine duration is limited to a number of hours ranging from 5 to 12 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.

TABLE I.
RESULTS FROM THE ONLINE EVALUATION

Item	Mean score	SD
The resources in the course (quizzes, notes, glossary, etc.) were straightforward and easy to use	4,54	0,64
The e-learning course was interesting and enjoyable	3,32	0,48
The content was clear and easy to understand	4,50	0,75
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
The material was explained in a clear and understandable manner	3,75	0,84
The pre-lab test as a condition for the live access to the system was reasonable	4,00	0,61
The booking system was well organized	3,64	0,78
I would recommend this course to others	4,57	0,57

1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good, 5 = Excellent
Course level: MSc. Number of students: 28 (5 of them distance learning)

V. 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 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.

The large number of people visiting the site, and its use by other schools of higher learning, provide a good motive for its sustainability. 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 technicians located anywhere in the world. In this way, the solar e-lab and its experimental facilities are made available free of charge and are shared by many people and Institutions, thus reducing costs and widening educational experiences.

REFERENCES

[1] 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.

[2] 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

[3] 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.

[4] J. V. Nickerson, J. E. Corter, S. K. Esche, C. Chassapis. A model for evaluating the effectiveness of remote engineering laboratories and simulations in education. *Computers & Education*, Vol. 49, 3, pp. 708-725, November 2007. (doi:10.1016/j.compedu.2005.11.019)

[5] 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.

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

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

[8] I. Michaelides, P. Eleftheriou, and D. Müller. A remotely accessible solar energy laboratory - A distributed learning experience. Proceedings *1st International Conference on Remote Engineering and Virtual Instrumentation (REV2004)*, Villach, Austria, 28-29 September 2004, ISBN 3-89958-090-7, (2004).

[9] Duffie J. A. and Beckman W. A.: *Solar Engineering of Thermal Processes*. John Wiley, New York, 1991, pp. 301-307.

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

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This article was modified from a presentation at the REV2009 conference in Bridgeport, CT, USA June 2009. Submitted, May 20, 2009. Published as resubmitted by the authors on July 20, 2009.