

On the effectiveness of learning through the use of the web based Laboratories – the experience of using the solar e-lab

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Abstract

This paper elaborates on the experience from the operation of the solar energy e-learning laboratory (Solar e-lab) in Cyprus, and analyses the results of the online evaluation submitted by the e-lab users. The aim of solar energy e-learning laboratory is to use web-based technology as a tool to make the laboratory facilities accessible to engineering students and technicians, including handicapped, located outside the e-lab premises anywhere in the world. In this way, the laboratory, its equipment and experimental facilities are available and can be shared by many people, thus reducing costs and widening educational experiences.

Throughout its 5 years of operation, the solar e-lab has been accessed by users from over 400 locations from 75 countries spread all over the world. The total number of hits recorded on the site exceeded 1.2 million. Furthermore, a number of colleges and Universities are using the solar e-lab as part of their training programme. Judging from the online student evaluation reports sent to the solar e-lab administrator, it can be said that there is nearly excellent satisfaction by the users. The feedback provides useful information as to the students' satisfaction with the e-lab interaction, its course content, and organisation.

Introduction

The role that web-based learning undertakes within the teaching and learning environments has gained widespread acceptance over the last number of years as remote engineering is becoming an important element in engineering education (Auer et al 2003, Benmohamed et al 2005, Agrawal and Srivastava 2007, Helander and Emani 2008). The development of web-based remote engineering experimentation laboratories can significantly enhance the students' learning experience. A recent assessment study (Nickerson et al 2007) comparing versions of remote labs versus hands-on labs in a junior-level mechanical engineering course on machine dynamics and mechanisms, suggests 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.

Using remote laboratories has the potential to significantly reduce obstacles related of cost, time-inefficient use of facilities, inadequate technical support and limited access. The growing importance of sharing engineering resources through web-based laboratories can be attributed to the growing complexity of engineering tasks, the highly specialized and expensive equipment as well as software tools and simulators. It can also be attributed to the necessary use and application of high tech equipment and the need of high qualified staff to control such equipment. There is evidence that the distance educated students are more motivated than on-site students and that there is significant relationship between the student attends class and the motivation to do well (Bisciglia et al 2005).

As online education becomes an everyday part of engineering education in nowadays (Hutzel 2002, Lindsay and Good 2005, Aziz et al 2006, Machotka and Nedic 2006), 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 (Lindsay and Good 2006).

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 e-lab features: architecture and organisation

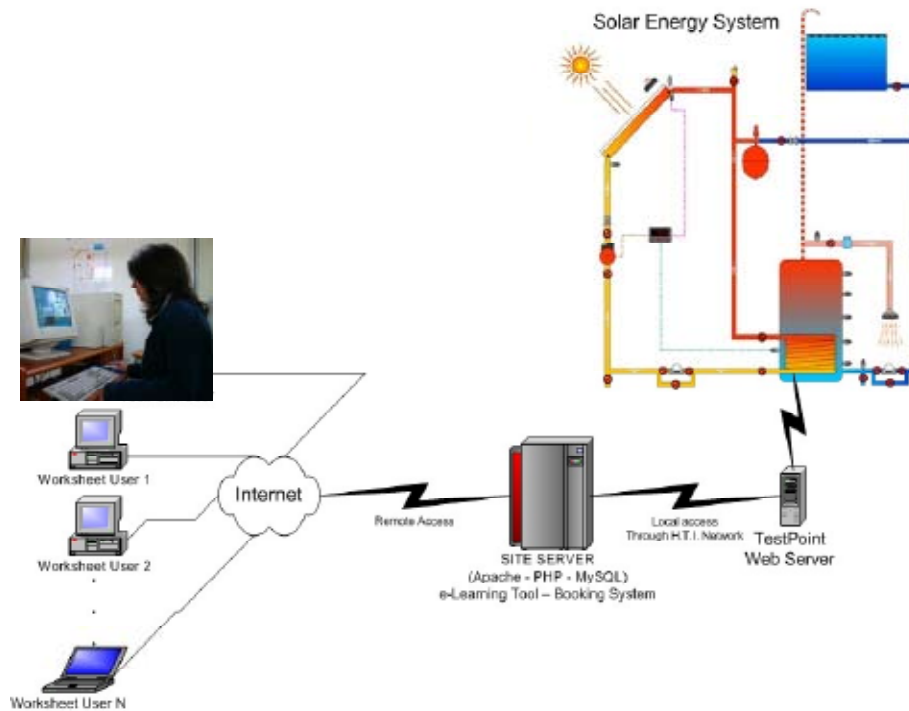
The solar energy e-learning laboratory is a good example of a web-based laboratory. It was developed within the MARVEL project of the Leonardo da Vinci programme (Müller and Ferreira 2003) and it focuses on experiential based learning arrangements allowing remote and distributed working with laboratories, workshops and real working-places to train students in remote engineering (Auer et al 2003). The solar e-lab comprises a pilot solar energy conversion plant which consists of two flat-plate 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.

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 increasing availability and reducing costs.

The system architecture used in the solar energy e-learning lab is illustrated in fig. 1. 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). 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.

Fig. 1. The solar e-lab system architecture



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 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 and control of the system. The "observer user" can, however, record the readings and use them for calculations if he/she wishes so.

The learning experience

The solar e-lab is designed for real time online live experiments in the field of solar engineering. The design of the learning scenarios comprises of a series of exercises of different degree of difficulty and complexity. The 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. The 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 he/she is successful to the pre-lab test.

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. One of the scenarios will be to elaborate on the stratification of temperatures in the vertical type storage tank and get a 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 more involved with the solar systems and the student has 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 (Duffie and Beckman 1991) he/she will 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. Should the student have more time available, he/she could use the data recorded in the Excel file downloaded at the logout or any time during the experiment, to plot graphs for the system thermal behaviour.

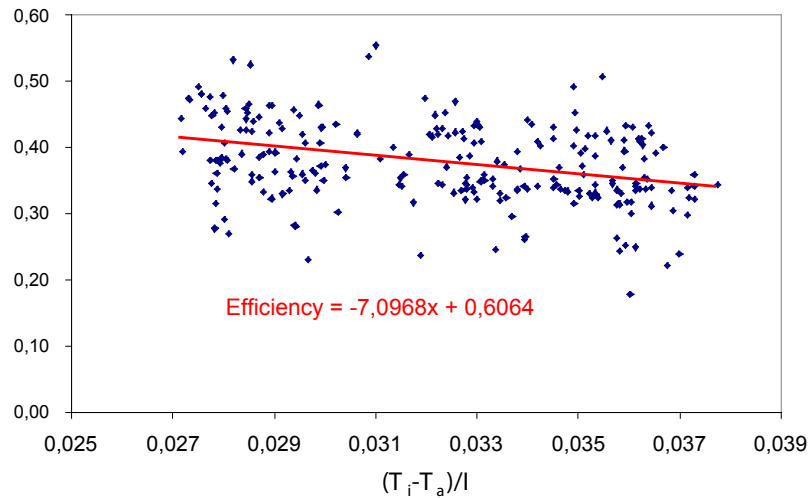
Below one may see an example from a real time online experiment conducted by a group of students in the Royal Institute of Technology in Stockholm. The test was carried out during a period where the weather in Stockholm was cloudy while in Nicosia there was plenty of sunshine. Following a booking, the students in the in Stockholm logged on the system and conducted the experiment for the two hour session. At the end of the lab session, the students downloaded the Excel file with all measurements recorded (see fig. 2).

Fig. 2. The downloadable EXCEL file with previously recorded data

Collector Temperatures (°C)		Water Temperatures (°C)		Storage Tank Temperatures (°C)			Ambient Temp (°C)	Solar Radiation (W/m ²)	Collector Flow Rate (%)
Outlet	Inlet	Hot Water out	Fresh water in	Bottom	Mid-point	Top			
60,7	58,5	40,8	20,6	37,0	52,8	56,8	13,3	1122,0	0,11
60,7	58,5	40,2	20,0	34,9	51,7	47,1	14,5	1119,6	0,11
61,3	58,5	40,8	20,6	35,5	52,8	47,1	13,3	1122,0	0,11
60,7	58,5	41,9	20,6	37,9	53,4	56,8	13,3	1126,7	0,12
61,3	58,5	39,6	19,4	33,8	51,1	48,8	13,3	1134,0	0,11
61,3	58,5	40,8	20,0	36,1	52,8	55,7	13,9	1134,0	0,11
61,3	58,5	41,4	20,6	37,3	53,4	51,7	13,9	1134,0	0,11
61,3	58,5	41,4	20,0	35,5	52,8	47,7	14,5	1119,6	0,11
61,3	58,5	41,9	20,6	38,4	53,4	57,3	13,9	1134,0	0,11
61,8	59,0	40,8	20,6	36,1	53,4	56,2	13,9	1143,6	0,11
61,8	59,0	41,9	20,6	37,9	53,4	48,3	13,9	1153,2	0,11
61,8	59,0	40,8	19,4	34,0	52,8	54,5	14,5	1153,2	0,11
61,3	59,0	41,4	20,6	39,0	54,0	55,1	13,9	1156,0	0,11
61,8	59,0	41,4	19,4	34,9	52,8	47,7	14,5	1153,2	0,11
61,8	59,0	40,8	20,0	36,1	52,3	56,2	13,9	1155,6	0,11
61,8	59,0	40,8	20,6	35,5	52,8	56,2	13,9	1155,6	0,11
62,4	59,0	40,8	20,0	36,7	53,4	57,3	13,9	1162,8	0,11
62,4	59,0	41,4	20,6	37,3	53,4	48,8	13,9	1165,2	0,11
62,4	59,0	40,8	19,4	34,3	52,6	52,6	13,9	1170,0	0,11

Using the downloaded data and the Excel facilities, they plotted the graph illustrated in fig. 3 which shows the variation of the instantaneous efficiency of the solar collector with $\frac{1}{I}$. Using the Excel capabilities; they also found the efficiency equation, as shown on the graph of fig. 3. The plotted graph and the efficiency equation were then compared with the theoretical ones, which are available on the website. This bi-institutional use of the system is a good demonstration of the flexibility and power of the web-based laboratories. Throughout the progress of the experiment, students from the northern part of Europe could control a system, perform an experimental exercise, and discuss their results with an instructor in the southern part of Europe.

Fig. 3. Investigation of the collector efficiency from data collected during an online real time experiment at the solar e-lab, through the internet.



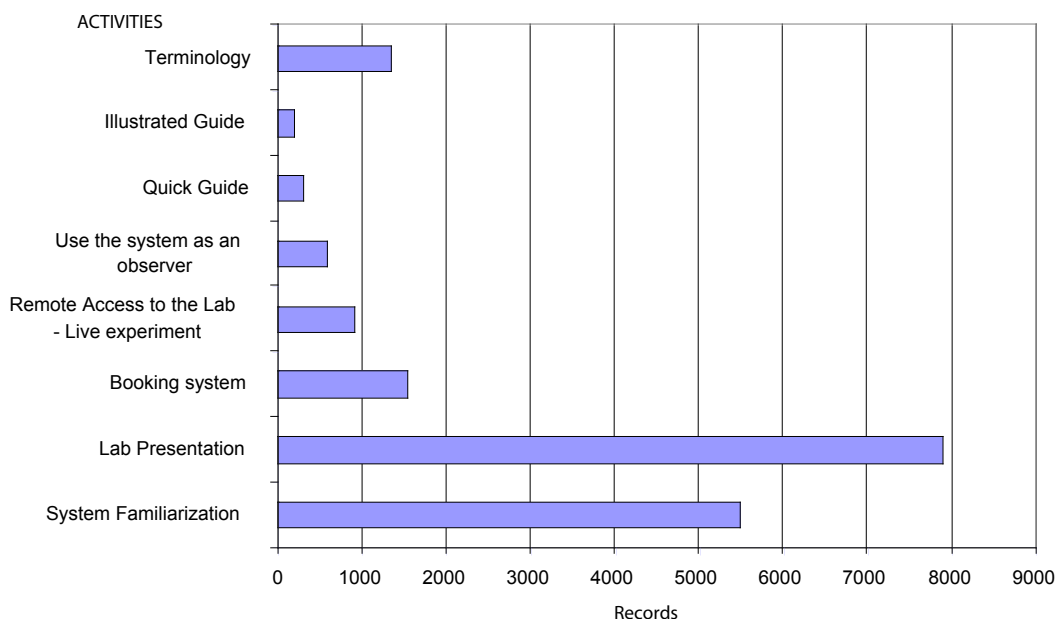
Feedback from remote users and overall impact

Several course trials were conducted to test the operation and reliability of the system, check for the consistency and reliability of the data acquisition and transfer, and also test for 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 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 from Thessalonica (Greece) to Stockholm (Sweden). 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. One of the main concerns was whether the data was transferred to the user in the appropriate format and in 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 works successfully. In addition to the validation tests, the solar e-lab gets feedback from its users on a continuous basis, through the "Online evaluation", which is taken into consideration for improvements.

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 400 locations from 75 countries spread all over the world and continents. Throughout the period of November 2004 to October 2008, a number of more than a million hits were recorded, out of which 25000 (Fig. 4) 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. 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.

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



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 the 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 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 continuous 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.

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. 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 them 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.

The results provide useful information as to the students’ satisfaction with the organization of the e-lab interaction and the course content and organization. The great majority of the students, especially those enrolled as distance learning students, 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. The great majority of the 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. 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 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

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.

Learning by experience and through experience in a real and social context is restricted in virtual environments. In this paper an alternative approach is presented 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 for him/her. In turn the learners use this to drive and determine their own continuous learning process. In this way learn-

ing 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.

The large number of people visiting the site, and the completed high score system evaluations by interested people, indicate the attractiveness of the system to people wishing to learn on the subject. The high scores in the evaluation process also indicate the success of the remote labs in promoting engineering education.

Acknowledgements

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