Weblabs in Chemical Engineering Education

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Abstract

The idea for this paper resulted from a workshop on the use of remotely operated experiments (weblabs) in chemical engineering education held in Cambridge, UK, in July 2005 (http://como.cheng.cam.ac.uk/conf.workshop.html). At the workshop people using weblabs met to discuss experiences and different approaches on how to make the most out of remote experiments in undergraduate chemical engineering teaching.

We describe the technology involved in making educational experiments available on the internet and how they are motivated and used in teaching at MIT, the University of Cambridge and the University of Leipzig. Experiences are discussed and we give our view of the strengths and weaknesses of weblabs in chemical engineering education.
1 Introduction

Information technology has had an enormous impact on engineering, providing new tools across the range of engineering disciplines. It facilitates the development of additional teaching strategies, including new ways to use them for illustration, simulation, demonstration, experimentation, operation, communication, etc.

Hands-on laboratory experiments have enormous educational value, but traditional teaching laboratories are expensive and have complex logistics regarding space, staff, scheduling and safety. Compared to these, experiments that are operated remotely over the internet offer many advantages. The internet gives the option to include laboratory experiments in teaching at any time and the experiments can be performed from any place with internet access. The ability to share experiments between different institutions drastically changes the economics of providing laboratory experiments and, potentially, a huge number of experiments could be available for use, including experiments on expensive equipment, rare materials and in remote locations. These experiments are called weblabs.

Weblabs have been around since the late nineties and projects using both in-house developed solutions for remote operation [1] and commercially available software [11, 6, 14, 12, 7] have been reported as well as review articles [3, 2].

Weblabs cannot provide hands-on laboratory experience, however they can provide access to experimental equipment and data using up-to-date technologies for remote operation. Remote operation is widespread in industry, both in research and production. Hence, weblabs can offer students essential training for what they are likely to encounter in their professional life. Weblabs also provide students with the opportunity to learn communication skills and to experience working in a team.

In July 2005 a workshop to discuss the use of weblabs in the education of chemical engineers was held in Cambridge, UK [15]. Speakers from the USA, Germany, the UK, Brazil and Mexico came to share their experiences, not only trying, but continuously using weblabs in undergraduate teaching. In this paper the aims are to describe:

- different ways of using weblabs in chemical engineering education;
- different technical approaches;
- sharing of experiences;
- report on future strategies.

2 Case Studies

2.1 Massachusetts Institute of Technology (MIT), USA

MIT is a private technical university with 10,000 students. Professor Clark Colton at the Department of Chemical Engineering has developed a suite of experiments for online use in his course “Transport Processes”. The first experiment was used by students in 2001.
2.1.1 Weblabs in Teaching

“Transport Processes” is taught in the third (junior) year to around 100 students each year and covers principles of heat and mass transfer, steady and transient conduction and diffusion, radiative heat transfer and convective transport of heat and mass in both laminar and turbulent flows. Emphasis is on the development of a physical understanding of the underlying phenomena and upon the ability to solve heat and mass transfer problems of practical relevance. To support the lectures in this subject, remotely operated experiments have been developed for use as class demonstrations, expanded homework, and small projects.

One of the heat exchanger experiments used on this course has also been used by the University of Texas, USA, in 2002 and by the University of Cambridge, UK, since 2004.

2.1.2 Experimental Hardware

The equipment for the suite of experiments has been supplied by Armfield Ltd. (Ringwood, UK). This includes a set of three heat exchanger experiments, two radiation/convection experiments and three conduction experiments. A detailed description of all the equipment with images can be found online. A description of the heat exchanger experiments is given here. The heat exchanger experiments include a flat plate heat exchanger experiment, a shell and tube heat exchanger experiment and a tubular heat exchanger experiment. One of the three different heat exchangers is mounted on the service unit which has been adapted for remote use. The service unit provides cold water from the mains tap and the flow is controlled with a pressure regulator. Hot water is also provided via the service unit and is circulated through a heater bath by a two way-gear pump, which allows the heat exchangers to be run in either co- or countercurrent mode and at different hot water flow rates. Two flow meters measure the flow rates of the hot and cold water and four standard k-type (chromel/alumel) thermocouples measure the hot and cold water inlet and outlet temperatures. The small volumes and low mass of the system allow it to respond and reach steady state quickly after a change has been made to the operating conditions.

The service unit is connected to a computer via a USB (Universal Serial Bus) port. USB is a standard allowing several devices to be connected to a computer without the need of separate extension cards.

2.1.3 Software Architecture

The laboratory equipment from Armfield Ltd. comes with software that allows it to be controlled via a USB interface from a computer. Included with this software is a DLL (Dynamic Link Library), which provides a means to access the input and output parameters of the experiment. A DLL is a module used in Microsoft Windows which contains functions and data that can be used by other modules. Dynamic linking allows a module to include only the information needed to locate an exported DLL function when required. Dynamic linking differs from static linking, in which the linker copies a library function’s
Function calls to the DLL file are made using LabVIEW 7.0. Analogue channels are used for transmitting temperature and flow rate data whereas digital channels are used to turn the experiment on and off. The LabVIEW 7.0 software (National Instruments, Austin, USA) is at the core of the architecture and makes data accessible to users of the system. LabVIEW uses a graphical programming interface and is designed to handle signal acquisition, measurement analysis and data presentation.

The experiment has two web-accessible interfaces, one for instructors only, and one for students. To give remote instructor control, VNC (Virtual Network Computing) software is used (AT&T Laboratories, Cambridge, UK). The VNC software makes it possible to view and fully interact with one computer from any other computer or mobile device anywhere on the internet. The VNC software is cross-platform, allowing remote control between different types of computers. It also contains a Java viewer, so that any desktop can be controlled remotely from within a browser without having to install software. This allows the instructor to have the same control as if seated at the server. For remote student control a LabVIEW 7.0 interface is used which permits remote control of the Graphical User Interface (GUI) on the web. On the same page as the LabVIEW GUI is a chat window for communication between the students and the instructor. The chat window is programmed in Java (Sun Microsystems, Santa Clara, USA), which allows it to update dynamically without reloading the page. The architecture also performs user registration,
authentication, and scheduling and allows students to work in teams on an experiment.

2.1.4 User Management, Authentication and Scheduling

On the experiment website, Microsoft .NET architecture for web services is used. Web services is a platform independent open standard used to exchange information between web applications using XML (eXtensible Markup Language). XML is a W3C (World Wide Web Consortium) initiative that encodes information structurally and semantically for interpretation by computers and humans.

The individual web pages and the user management (login, authentication, teams, courses, scheduling, etc.) were created using ASP.NET, which is Microsoft’s visual programming tool for building dynamic web applications. Programming has been done using C#, which is Microsoft’s object oriented language derived from C and C++ and includes a lot of concepts from Java. The database server is a Microsoft SQL Server 2000, a database system based on the Standard Query Language (SQL). The database server resides on the same machine as the web server. To access the SQL server database ADO.NET (ActiveX Data Objects), the data-access component of the Microsoft .NET framework is used.

Users must register before they are allowed to perform an experiment. At the time of registration, the user is prompted to choose a Login ID and password, and to supply an e-mail address and phone number. Users can then join a team and select an available time slot on the schedule page which shows all the time slots, if they are occupied and by whom. This information is stored in the SQL database.

2.1.5 Performing an Experiment

The experiment can be accessed from any computer connected to the internet after installing Java and LabVIEW plug-ins. All the information the students need to perform the experiments (assignments, theory and instructions), is available at the course website (<http://heatex.mit.edu>).

The LabVIEW interface, shown in figure 2, allows the user to change experimental parameters by entering numbers into boxes, using arrow buttons or by turning knobs on the screen. It also displays values in real time as numbers, scrolling graphs or in tabular form. All the generated data can be recorded to a file for later retrieval. The charts can be re-scaled by double clicking and entering new extreme values on an axis.

The interface looks and operates in exactly the same way if used over the internet or if used on a computer directly connected to the experiment. When performing remote experiments there is a disadvantage of not being able to see and hear the equipment. This problem has been overcome by the use of a webcam with a microphone.

2.1.6 Experiences

The students’ opinion of the weblab has been evaluated using web based questionnaires developed by Dr Rudolph Mitchell from the MIT Teaching and Learning Laboratory
Figure 2: Screen shot of LabVIEW Graphical User Interface
The results show that students are generally positive towards weblabs, but have a low opinion of imperfections in the interface and of hard- and software problems. The educational value offered by weblabs can be gained in different ways. In addition to supporting a lecture class without a laboratory component, weblabs are sometimes successful in a laboratory class consisting of mostly hands-on experiments, for example, for generating data used for data analysis and/or report writing.

Weblabs in chemical engineering at MIT provide a pedagogically rich experience when used as a project, expanded homework or class demonstration. They can provide an experience of collecting data from experimental equipment without having to physically be in the laboratory. The collected data can then be used for analysis and written and oral presentations. If performed in a group, the students will also gain teamwork experience. Weblabs provide a richer experience than simulations, since real equipment usually provides surprises and non-idealities. What weblabs can not do is provide, or substitute for, hands-on experience that is uniquely valuable in an engineering curriculum.

2.2 University of Cambridge, United Kingdom

The University of Cambridge is one of the oldest universities in the world and one of the largest in the United Kingdom with around 18,000 students. Dr Markus Kraft is a Reader in chemical engineering at the University of Cambridge with an interest in new teaching methods and has, for example, developed a web module to teach stochastic modelling [8]. A common interest in web based teaching between Dr Kraft and Professor Clark Colton, from MIT, led to a collaboration between the University of Cambridge and MIT, funded by the Cambridge-MIT Institute (CMI), enabling the research associate Anders Selmer to use the MIT iLabs heat exchanger to teach Process Dynamics and Control (PD&C) to students from the University of Cambridge.

2.2.1 Weblabs in Teaching

At the University of Cambridge, the third year chemical engineering students perform a number of exercises that are designed to be an intermediate step between idealized, exam-style questions and long-term, large-scale projects. These are based on the theory taught in lectures and are intended to challenge the students.

The exercises have previously been theoretical pen and paper activities with numerical simulations. The opportunity to use the MIT iLabs heat exchanger weblab presented the possibility to add an experimental exercise without altering the syllabus and without costly changes to facilities and staffing. The MIT iLabs heat exchanger experiment was originally developed to study the principles of heat transfer, but for use at the University of Cambridge, a new exercise in PD&C was developed. In this exercise the heat exchanger is treated as a black box and the focus is on the controller for the hot water inlet temperature. For a detailed description of the exercise please refer to [13].
2.2.2 Experimental Hardware, Software Architecture and User Management, Authentication and Scheduling

The PD&C exercise uses the MIT iLabs heat exchanger experiment with a shell and tube (HT33) heat exchanger, operated in counter current mode, mounted on the service unit. Please refer to section 2.1 for a detailed description.

2.2.3 Performing an Experiment

All of the information that the students need to perform the exercise is available on the internet [16]. The students from the University of Cambridge chose to perform the experimental part of the exercise from the computer room in the department (figure 3). Most groups decided to sit together in front of two computers with the experiment running on one of them and the chat window on the other. This meant that most discussions within the groups took place face to face whereas all conversations with the demonstrator were facilitated through the chat window.
2.2.4 Experiences

The students' opinion of the new exercise has been evaluated by issuing questionnaires developed together with Dr Rudolph Mitchell from the MIT Teaching and Learning Laboratory (TLL), who also evaluated the responses. The questionnaires assessed different aspects of the learning experience: the usability of the experiment and interface, group work experience, meeting educational objectives, and experience in comparison to exercises in other subjects.

The students were satisfied with the web based instructions and managed to use the LabVIEW interface and chat window successfully. They were also able to download their experimental data after the experiment. Some students commented on a lack of sense of reality when performing the experiment but most agreed that it provided an experience of measurement and analysis and the qualitative behaviour of a controlled system. When compared to other exercises, which were purely theoretical and performed individually, most students preferred the exercise containing the weblab and were positive towards the hands-on feel, the non-ideal behaviour and the opportunity to work with experimental data. The students enjoyed participating in a group exercise and all felt that they could contribute to the team. The experiments were performed in groups of four but the reports were written individually. The students’ opinion of the group size was split, with some students seeing no reason to change the size and some wanting smaller groups. When the exercise was repeated the following academic year, the group size was reduced to three people to address this.

It was found that by using the weblab, the experience of an experiment can be added to a course unaccompanied by a lab component. This experience could be extremely valuable to the students’ professional future, as remote operation and LabVIEW are now commonplace in industry and academic research laboratories.

2.3 Institute of Technical Chemistry, University of Leipzig (ITCL), Germany

The eLearning Group at the Institute of Technical Chemistry, University of Leipzig (ITCL), is one of the 15 groups at chemical institutes in Germany which took part in the “Vernetztes Studium Chemie” (VSC) project. Within the VSC project a learning unit is named a “VLU” (Valid Learning Unit). Through the VSC portal [17] it is possible to access more than a hundred VLUs. The VLUs can be used for lectures, seminars and practical courses. VLUs have been developed at ITCL which feature online laboratory courses containing remotely controlled experiments [18]. At ITCL, Ralf Moros is a senior soft-and hardware developer and the project coordinator, responsible for the development of the remotely controlled experiments: hardware, remote control software and VLU design.

2.3.1 Weblabs in Teaching

Chemical engineering education at the University of Leipzig is taught in three ways: lectures, seminars and practical laboratory courses. Online learning units can be developed
for all parts of these studies. Ideally the development of online laboratory courses should aim towards providing remotely controlled experiments.

A laboratory course in Chemical Engineering and Unit Operations normally consists of several hands-on experiments. To prepare for an experiment a student has to study the experiment’s manual. The manual contains a description of experimental objectives, theoretical background, procedures, equipment and also information concerning evaluation and discussion of measured data. Online laboratory courses can contain a web-based version of the manuals, as well as including animations and simulations. This is what the experimental VLU structure is based on as can be seen in figure 4.

The introduction describes the theoretical background of the experiment. This section is followed by the experiment objectives and then a description of the used hardware (equipment). Interactive pictures are integrated to help the student/user understand the hardware of the experiment. In the procedure section the student can learn how the control software is used in order to control the experiment online. This is followed by an offline version of the experiment (offline experiment).

A user who has completed all previous sections will then be able to carry out the online experiment. Once the experiment has been completed, valuable help for evaluation of received data can then be found in the evaluation/discussion section. An interactive simulation and a section for self-controlling complete the VLU.
2.3.2 Experimental Hardware

The experimental hardware (pumps, valves, stirrers, etc.) used in the VLUs was acquired by the project team and then assembled with the help of the mechanical and electronic workshops at ITCL. For the data acquisition, a TCP/IP-based (Transmission Control Protocol/Internet Protocol) hardware, called EDAS (Intelligent Instrumentation GmbH, Germany), is used. The EDAS is an industrial Ethernet I/O (Input/Output) system designed with an open architecture standard allowing for easy development and deployment. The EDAS can be shared between several experiments whereas sensors and signal conditioning amplifiers are experiment specific.

2.3.3 Software Architecture

All that a user requires to take part in a remote controlled experiment is a standard web browser that supports Java. With that, the user is able to observe and control a remote experiment from any location with internet access at any time.

Access to remote experiments is based on a client/server architecture for data acquisition and control written in Java as shown in figure 5.

The data acquisition and control server is named MIFFY-server. User data (user ID, password, etc.), reservations and data from experiments (broadcast interval, IP addresses, number of hardware units, etc.) are stored in the MIFFY-database. The MIFFY-server is easy to configure by using a Java application. The server can normally be configured in less than an hour. One MIFFY-server can control one online experiment. Each experiment
may consist of one or more hardware units (units for collecting and sending analogue and
digital signals to/from the experimental setup).

In addition to the data acquisition and control it is also possible to observe the experiment
in real time using video and audio. This is done by using a video/audio server and an
additional Java applet which is started from the main controlling applet. One camera
server is needed for each experiment.

From a developer’s perspective, applet clients for new remote experiments are easily as-
sembled using a library of Java Bean components (VJBL: VIPRATECH (Virtuelles Prak-
tikum Technische Chemie) Java Bean Library). By using this tool the developer can create
the graphical user interface (GUI) for observation and control using drag and drop tech-
niques. All libraries and the Java code for the server will be released on an open source
licence.

2.3.4 User Management, Authentication and Scheduling

The user management is implemented using Java servlets. These are not part of the VJBL,
but are also freely available for use. The servlets have been developed in Leipzig and
combined to produce a simple user-management and scheduling software that provides a
complete practical laboratory course over the internet. The user who has booked the time
in the booking system can control the experiment and is called the active user. Up to 20
users can observe but not control the experiment and are called passive users. If an active
user wants to carry out the experiment in privacy, it is possible for him/her to block passive
users from observing the experiment. The system has a user hierarchy where users from
a higher level can always watch and take control from users at a lower level. The system
administrator decides how the user rights are assigned.

Servlets have also been developed for group management of users but this has not yet
been fully implemented.

2.3.5 Performing an Experiment

Before performing an experiment the user must request an ID and password from the
administrator via e-mail. Using this identification the user can login to the MIFFY-server
and make a time reservation for the chosen experiment. At the reserved time, the user
may login and access the experiment. Figure 6 shows a typical web page for the remote
control of an experiment.

The user is able to change the parameters in the experiment, start and stop the experi-
ment, print out graphs, send the acquired data via e-mail and view the experiment live.
The remotely controlled experiments have been developed for slow processes so that the
response time is sufficient to observe and control the parameters.

The experiment is normally finished by closing the web page. In this case the MIFFY-
server terminates the experiment automatically.
2.3.6 Experiences

Based on these concepts of remote control, seven experiments situated at two different German universities (Leipzig and Oldenburg) have been developed:

- heat transfer experiment;
- adsorption experiment;
- residence time distribution experiment;
- hydrolysis/saponification experiment;
- dehydration experiment;
- temperature control experiment;
- remote control experiment.

At both universities, the experiments are included in the normal laboratory courses for Bachelor and Master studies in chemistry (Laboratory Course in Chemical Engineering and Unit Operations) as well being relevant to lectures. Experiments are also included into a practical course for further education. Access to the experiments has been tested from different locations in Germany, the UK, South Korea, New Zealand and the USA, under different conditions (high speed internet access, internet cafés and Wireless Local Area Networks (WLANs)). Access to the experiments was successful from every location and under every condition.

The users at the universities in Leipzig and Oldenburg have pointed out the following advantages:

- access to the experiments via internet from any location at any time;
• access to the experiments from within an experiment learning unit;
• the possibility to carry out an experiment without being observed by an assistant.

From the institutions’ point of view there are additional advantages:

• developing and sharing of high value lab resources between several institutions;
• bringing lab experiences into the lecture hall;
• enabling more flexible timetabling of labs.

3 The Future

Weblabs are a very powerful tool in chemical engineering education, offering students an experimental experience in courses not accompanied by a laboratory component. The experimental equipment is designed to be intrinsically safe and to require little maintenance so that no one is required to be in the laboratory at the time of experiment. This enables both students and faculty members to perform and use experiments independent of time and location.

Experimental equipment is usually only used for a few weeks every year but by sharing equipment via the internet this can be increased. This drastically changes the economics of providing experiments in education. To facilitate sharing of experiments between institutions it is helpful to use a common platform to handle user IDs, passwords, authentication, scheduling and storage of experimental data. If the same platform is used at the broadcasting and receiving institutions, the responsibility to register and manage users can be transferred from the provider to the user. An effort to develop such a system is the MIT iLabs Shared Architecture [9], in which a Service Broker (a server running the shared architecture software) is placed at institutions broadcasting or receiving experiments. All traffic to or from a weblab would go through the Service Broker. Efforts to interface experiments to the MIT iLabs Service Broker are ongoing in all three institutions.

At MIT new experiments and new assignments within the field of heat transfer are being developed. These will be available through the MIT iLab Heat Transfer Project website (<http://heatex.mit.edu>).

At the University of Cambridge a weblab using an industrial operating system has recently been set up through a partnership with Siemens Automation & Drives. By using industrial equipment, the experiment features all of the important elements of an industrial plant, from measuring devices to control hard- and software. As a consequence, this weblab not only offers the advantages which have already been discussed, but provides hands-on experience of industrial equipment, not only on a chemical plant level but also on the control level. Partnerships are actively sought to co-develop new assignments and make more use of the weblab. This has already happened to some extent with other UK universities, such as Imperial College London (Dr Charles Immanuel) and the University of Birmingham (Dr Phillip Robbins) and also with MIT.
At the University of Leipzig more experiments and VLUs are being developed within all areas of chemical engineering. The VLUs are also being translated into English and other languages to increase the number of potential users of the experiments. Partners are being sought to create a network of remotely controlled chemical engineering experiments.

4 Summary

The use of weblabs to teach undergraduate chemical engineers at MIT, the University of Cambridge and the University of Leipzig has been reported. Though weblabs cannot replace hands-on experiments, we conclude that they are a very useful tool to give students training in working with experimental equipment and measured data by using technologies commonplace in industry. They provide a means to share an experiment between different institutions, drastically reducing the economics of providing new equipment. Weblabs also stimulate transferable skills such as teamwork, communication and presentation. In addition to this, the possibility to include an experimental experience in courses not accompanied by a laboratory component, the use of experiments out of the lab (from home or as demonstrations in lectures) and the freedom of where to place the equipment and how to schedule the sessions are the main advantages.

All the involved institutions are continuously developing their weblab activities, updating and adding experiments and assignments and encouraging other universities to use their facilities.

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References


