Sustainable Management of Industrial Collaborations in E-Lab Learning

R.J. Watson[1], A. Braumann[1], A.R. Coble[2], T.A. Hennis[3] and M. Kraft[1,2]
[1] University of Cambridge, Department of Chemical Engineering & Biotechnology, Cambridge, United Kingdom
[2] cmcl innovations Ltd, Cambridge, United Kingdom
[3] Delft University of Technology, Delft, The Netherlands

***Abstract*—We describe a wide range of issues relating to industrial collaborations that can help to sustain and improve virtual and remote experiments, which are used in online learning. The discussion focuses on the benefits of collaboration for the key stakeholders, methods for establishing and sustaining collaborations and techniques for enhancing didactics. Current trends and future opportunities for industry-driven e-Labs are also discussed. We conclude with three case studies which illustrate the recent past, the state-of-the-art and the imminent future of e-Lab learning, and advocate the position that the e-Labs concept can be advanced dramatically with the help of industrial partners.**

***Index Terms*— sustainability, remote experiments, virtual laboratories, pedagogy.**

I. INTRODUCTION

Over the last 10-15 years, remote and virtual laboratories have become a common feature in universities throughout the world. In many cases, the full potential of these learning resources has not been realised for a wide range of reasons; typically inadequate communication, scepticism from potential user groups and a lack of continuity in the didactical preferences of changing teaching staff. Most of these problems can be solved if sufficient resources are allocated; therefore one way to increase the success and the sustainability of a remote or virtual laboratory is to obtain backing from an industrial collaborator. There are many ways in which each of the stakeholder groups can benefit from such collaboration, but there are also challenges to overcome. One of these challenges concerns the level of use and usefulness of the resource. Industrial and academic partners can sustain an initiative, but when it does not improve end-users' learning or professional life, then there can be no sustainability [1]. Furthermore, a failure to make good use of the resources provided is likely to result in withdrawal of support.

Universities that participate in collaborative e-learning initiatives with industry can benefit from a new source of funding, increased status, publicity, additional skills and experience for staff, improved relationships with the company and new technologies which may be applied in their research. The main challenge for universities is in addressing long-term sustainability issues. These include production costs (human resources, workflow processes, technology), dissemination costs (bandwidth, media inventory), and costs of using and reusing/adapting resources. Reuse or adaptation also means that the materials must be localised to make them pedagogically effective in specific contexts.

By using authentic industrial e-learning resources, students can gain convenient access to relevant training, which will improve their awareness of industry, give them the skills companies require, and improve their overall employability. At the same time, special effort is required on the part of the content provider to ensure that the students find the resources interesting and immersive, given that the user is not physically present in the lab. Industrial tools must also be adapted to suit the educational level of the student and the limited training time available during a university course. Sustainability can be promoted using peer-collaboration in online environments that enable trust relationships and motivate end-users to participate and even contribute to further development of the teaching resources.

Collaboration with the educational sector provides an opportunity for companies to increase exposure, experience, and brand recognition with the next generation of scientists and engineers. A major challenge for many industrial e-learning resource-providers is achieving a balance in the exposure of the underlying intellectual property (IP). Enough access to the company's proprietary tools must be allowed in order to provide an authentic and useful learning environment; at the same time, providing unrestricted access must not compromise the value of these tools. For established market leaders, the resources invested provide major benefits with very few negative impacts.

II. STRATEGIES FOR ESTABLISHING REMOTE AND VIRTUAL LABORATORIES IN COLLABORATION WITH INDUSTRY

A. Nature of the Collaboration

Most large companies engage in some form of sponsorship of not-for-profit organisations or events. Some businesses support internal organisations with interests in specific areas, including education. In some cases these organisations exist primarily to improve brand image, a good example in the UK being 'Tesco for Schools and Clubs' [2], where the sponsor is a supermarket chain. In other cases, for example 'Siemens Cooperates with Education' (SCE) [3] at Siemens plc., an important goal is to promote product awareness so that the sponsoring company becomes the supplier of choice for as much of the next generation of scientists and engineers as possible. In the context of remote and virtual experiment design, a large industrial sponsor is likely to want to reach a broad target audience. This means that it is desirable to design the experiment for high scalability and cross-disciplinary appeal. Because the educational institution acts as the intermediary between the student and the company, it is likely that they would need to take the initiative in setting up the collaboration, although the company might provide substantial technical support later on.

Smaller businesses, such as University spin-off companies, usually survive by providing specialist products to small market niches. Their brand will not be well known outside the circles in which they operate and it does not need to be. It is nevertheless very important to achieve a position as a market leader by ensuring that their name is well known amongst potential customers. By working with a limited number of selected universities that specialise in the area of interest, small companies can gain a major competitive edge by ensuring that most of the fresh recruits in the target industry will use their product by preference. In this case, scalability of virtual or remote experiments will not usually need to be very high and cross-disciplinary appeal will not be necessary; the collaboration should instead focus on providing high quality, in-depth learning resources for final year or postgraduate students.

Another interesting type of collaboration is inspired by online open innovation platforms such as Innocentive [4] or Hypios [5]. These so-called 'ideagoras' host a large number of industry challenges, within a scientific context. By undertaking challenges, the person who suggests the best solution is able to earn a monetary reward [6]. Such industry challenges have higher degrees of attraction than regular assignments. This paradigm can be adopted in online learning by encouraging staff and students to provide feedback and ideas which could improve the product represented in the virtual or remote experiment. The best suggestions could attract a cash prize from the sponsoring company. This approach is also an excellent way of engaging students with the commercial world.

B. Design Considerations

Although the design of REs or VLs will inevitably be influenced by the requirements of all stakeholders, meeting the demands of the end-user must always be the main objective. In particular, a validated set of design criteria, a functional analysis/design and specification of vocabularies needed to structure and search the content are especially important. Processes central to an initiative, such as planning time slots for remote experiments, need to be well thought out, described, and designed in the context of a system. Also, if a project depends heavily on end-user collaboration and online interaction, design should focus on tools and incentives to support such processes. Furthermore, the design should include process steps and a strategy about how and when to involve various stakeholders.

When designing a remote experiment or virtual laboratory, it is important to take a flexible and modular approach. This makes the resources more adaptable to a variety of educational goals, pedagogical strategies, and curriculum structures, thereby ensuring maximum usage and return on the initial investment. By maintaining modularity, e-learning resources can be reused and composed together in a form that best suits a particular application.

Factors which might need to be taken into consideration when designing a remote or virtual experiment include:

- Is it scalable enough to meet the needs of the target audience? Can it be designed for simultaneously operation by multiple users, e.g. by incorporating multiple functionalities which can be used independently of each other? Is there enough space and computing capacity to support more than one user at a time?
- Does it need cross-disciplinary appeal?
- Can other users groups such as industrial or academic researchers or commercial training courses be engaged to help sustain the experiment? If so, can the capacity of the experiment be increased to meet the needs of additional users?
- Given the high staff turnover in academia, is it possible to carry out day-to-day operation of the experiment with minimal training?
- Are there any other benefits that the experiment can provide, e.g. applications in academic research, or any commercial income sources which could contribute to sustainability. For example the MIT Nuclear Reactor iLab [7] is sustained by its other research activities and by manufacturing chemicals containing radioactive isotopes which can be sold for medical research.

C. Technological Considerations

When considering the technological requirements for an online learning environment or an individual remote or virtual laboratory, one must strike a balance between ease-of-use and an enriching user-experience. Particularly in the case of an industry-supported virtual or remote experiment, attractive presentation is important and a means of engaging with the sponsoring organisation may be desirable. Whilst providing the most engaging and immersive learning environment possible to the end-users is important, this ambition must be tempered by the realisation that difficult installations, or in fact any installation requirement at all, may deter many users. Furthermore, system requirements should not prove a limitation for end-users and the software for remote and virtual laboratories should be accessible on as many platforms as possible, including emerging technologies such as netbooks and smartphones. Ultimately, the technological solutions used should provide an enriching experience whilst encouraging as wide a user-base as possible.

D. Scalability

The scalability restrictions for simulation-based e-learning tools are minimal; as user demand increases, the simulation server can be incrementally upgraded to meet demand. Remote laboratories are also scalable, but tend to reach their capacity much more quickly because parallel usage is not usually possible, although technical solutions can be developed, such as installation of additional diagnostics which allow multiple users to take measurements simultaneously. Both types of experiment can be considered as common pool resources. Institutional frameworks and process rules are needed to offer sustained access and avoid overexploitation and conflicts [8], but can also be used to take full advantage of the scalability of an experiment by maximising usage.

III. MANAGING THE COLLABORATION

A. General Considerations

As discussed in section II, there are a number of different strategies and scenarios for collaboration and cooperation. Collaboration happens on different levels, and the involved stakeholders have different objectives. In any collaboration, these objectives must be central. Important aspects of collaboration include ongoing management, sustainability and contribution/delivery of content.

B. Ongoing Management

Day-to-day management of e-learning simulations is usually straightforward, unless they are exceptionally computationally expensive. Remote experiments tend to be much more difficult to manage due to the labour needed to maintain and set up the equipment, provide technical support and where necessary, to supervise the students using them. Because of the number of different individuals involved in running a remote experiment, it is also more difficult to organise a session, meaning that careful scheduling is required. Consumables, such as chemicals, can potentially increase the cost still further. The risk of session cancellation due to technical problems is much higher for a remote experiment than a simulation, if appropriate design features are not incorporated. Having an industrial backer can alleviate many of the problems associated with remote experiments through the immense technical, material and financial resources which they can often provide.

An alternative scenario for sustainable e-learning could be conceived based on the activities of the so-called 'biohacker' community. Biohackers are hobbyist, mainly biochemistry scholars, who share information about building labs at home. They get their equipment from 7-11 and chemistry shops and are able to rebuild experiments themselves. Clearly, even though this relieves pressure on ongoing maintenance, it requires higher levels of peer-support for setting up and maintaining labs at home (or school). In the long run, it may result in an active user community, and new or improved (open source) software and information. Companies which do not have enough sponsorship resources to finance a remote or virtual experiment indefinitely might in some circumstances be able to benefit from the assistance of an amateur user community.

In order to decrease pressure on centralised management (universities, industry), processes (such as quality control and supervision) may be externalised to the end-user community. The more people involved, the more likely it will be that the project becomes sustainable. This requires both tooling and strong (built-in) incentives for people to be engaged in these processes. In some cases, 'outsourcing' of remote experiments may not even be possible or is not within the scope of the project as a whole.

C. Contribution and Delivery of Content

By acting unilaterally and engaging directly with the user, sponsors of online learning resources may find that their credibility is open to question, as their efforts may be perceived to be a pure marketing exercise with limited educational value. The credibility issue can potentially be resolved by delivering the educational content via a neutral online portal. Currently, such portals only exist in the USA (iLabs) [9] and Australia (Labshare) [10], however a European portal (LiLa – the Library of Labs) [11] is currently under construction and a global organisation (GOLC - Global Online Laboratory Consortium) [12] is in its early stages. It is important that these portals incorporate features that allow for peer and user review of online learning resources otherwise they cannot effectively fulfil the role of the neutral broker. Ultimately it is possible that the portals could facilitate competition between sponsors of rival products. Provided that it remains free and fair, competition is likely to be a positive force in ensuring high quality of content, and may even lead to 'Formula 1'-style sponsorship of rival apparatus by key industrial players. For example the Cambridge Weblabs (See section V) are operated by the Siemens PCS7 control system. One of the main competing products, Emerson Process's 'Delta V', is used to control apparatus at Manchester University, and although this has not yet been used remotely, the potential to do so exists.

A second important reason for joining an online portal is that it makes dissemination of content much easier and allows access for a much wider variety of target groups. Schools, industry and interested individuals will be able to find out about the product via the portal, significantly increasing the marketing potential of the online resource.

D. Sustainability

Sustainability is concerned with the ongoing ability to meet the goals of a project [13]. Hence, sustainability depends strongly on the objectives of the different stakeholders. Within the context of online experiments or remote experiments, these objectives include reputation/branding (personal and institutional), improving quality, lowering costs of maintenance, networking, learning, improving pedagogy, and retention of leading-edge status.

Whilst sustaining a simulation usually incurs minimal costs and difficulties, remote experiments require a careful sustainability strategy. Next to the creation, associated publishing, management and development of remote experiments and online simulations, sustainability also means the ability to continually provide value in terms of learning and professional development. Each project must have an idea on how to deliver value to its end-users. A simple example would be the offering of pedagogical guidance for teachers on how to use certain experiments.

High staff turnover in higher education sometimes means that the remote experiment stops working when the technical expertise required to maintain it is lost. Simulations will still need some overall sustainability strategy as the high pace of development in the IT sector means that ongoing evaluation and improvements will be required to keep pace with user expectations. Ultimately it must be acknowledged that most e-learning resources become obsolete over time, but that certain steps can be taken to maximise their lifetime. These steps might include development of an easily adaptable design and selection of technology that is likely to remain relevant for the foreseeable future.

As well as seeking funding and industry backing, initiatives can grow faster and more sustainably by looking for opportunities to decentralise processes. Decentralisation is not limited to the level of institutions and teachers and requires engagement with the end-user and individual contributors. Even though in many cases the initial setup and management of remote experiments require some centralised effort, projects must strive for decentralisation of other processes, such as online support, support for pedagogy, feedback, and arrangement of materials.

Arranging usage charges for remote experiments is difficult due to the legal obligations on the provider and a possible lack of funding available to the user; sponsorship by an industrial backer is a possible alternative. If objectives include research, grants may be a possible source of funding. Additionally, projects may be sustained through value added services or commercial offerings on the platform hosting remote experiments. For example, the experiment could be used for commercial training.

IV. Didactics of Online Learning with Support from an Industrial Collaborator

A. *Contextualisation of Learning Resources*

Involving industrial partners in online learning potentially has the advantage of contextualizing theory and offering real life examples and applications. It must nevertheless be remembered that educational institutions have widely varying teaching styles and sharing of e-learning resources means that they will have to be adaptable. Furthermore, academics can only devote limited time to adapting these resources, so they will need access to a community that can provide the support they require. The learning infrastructure should on the one hand be flexible enough to accommodate existing educational scenarios, but also, offer opportunities for collaborative knowledge creation in a community framework.

Learning objects always face the challenge of contextualisation. Dry, theoretical resources, not contextualised within a pedagogical, cultural and societal context, have less pedagogical effectiveness than highly contextualised ones. On the other hand, these resources are easier to contextualise and reuse, because they need no “de-contextualisation” and can be adapted directly for a specific purpose [14].

With industry collaboration, there are opportunities to offer direct, societal contextualisation of resources and learning activities. Even though public institutions should have a degree of independence, this offers great benefits to all involved stakeholders. Industry can bring context to resources with real life challenges, case studies, video materials, et cetera.

Another way to contextualise online resources is to offer the basic, dry, de-contextualised resource together with tools and information that support for contextualisation by end-users. These may include teacher ideas and pedagogical guidelines. Some theoretical courses might be less open to the possibility of using industry-developed e-learning resources, meaning that careful presentation may be required. For example, for in-house usage the Cambridge Weblabs [15] require the students to complete an extensive theoretical pre-preparation exercise before they can use the equipment. This approach makes the experiment, which in itself is essentially a vocational training exercise, well suited to an highly academic course.

B. *Integration into Curricula*

There are many different ways in which e-learning resources can be used. Scenarios for applying pedagogical concepts to e-learning include:

1) Teachers refer to remote experiments or simulations during class, and give specific assignments that can be done with the experiments: Evaluation processes and discussions happen mainly in class, because that is where students usually see each other. There is little to no online interaction, because teachers and students have no need to engage in online activity.

2) Opportunities are given for teachers to evaluate the output of students based on their online interaction and collaboration: Analytical tools, best practices, and online support can be offered to implement such collaborations. These are particularly interesting to industry, because of the skills involved in processes of problem solving and team-work, and the potential for the company to engage directly with the students.

3) Use of online and blended collaborations that do not necessarily involve pedagogical institutions: Resources and tools are used by students to get acquainted with theory in an engaging way, to discuss problems, and to make themselves visible to industrial partners. This involves higher levels of involvement from industrial partners, in terms of supplying assignments, giving feedback, and offering internships to motivate and engage students.

Clearly, there are a range of possibilities which exist between the scenarios described, even within one specific course.

V. Case Studies

A. *Cambridge Weblabs*

The Cambridge Weblabs (see Figure 1) were inspired by the work which took place during the iLabs project [16] and were developed through a collaboration between the Chemical Engineering Department’s CoMo (Computational Modelling) group and ‘Siemens Co-operates with Education’ (SCE), an organisation which develops relationships between Siemens plc and educational institutions. The collaboration has brought to light many strengths and weaknesses of the ‘remote experiment’ concept. The narrow focus on Chemical Engineering has generally proved disadvantageous as this has limited the external user base, however the Weblabs have proved surprisingly adaptable. They also constitute one of the most technically advanced experimental setups of their kind in the world, which has led to their adoption as a flagship experiment during the initial stage of the ‘Library of Labs’ [11].

The Weblabs were designed to provide essential training to students of chemical engineering and related subjects without the need to go to the laboratory. Possible software setups and the experience with remote experiments in Chemical Engineering were discussed by [17]. However, for a thorough training of the students the experimental setup must allow for teaching units that are both challenging and rewarding. The Cambridge Weblab is built around a small reactor, one of the core elements in the chemical industry. The reactor can be stirred and fed with three different liquids. In addition, it is fitted with a heating jacket and a temperature sensor. Removal of

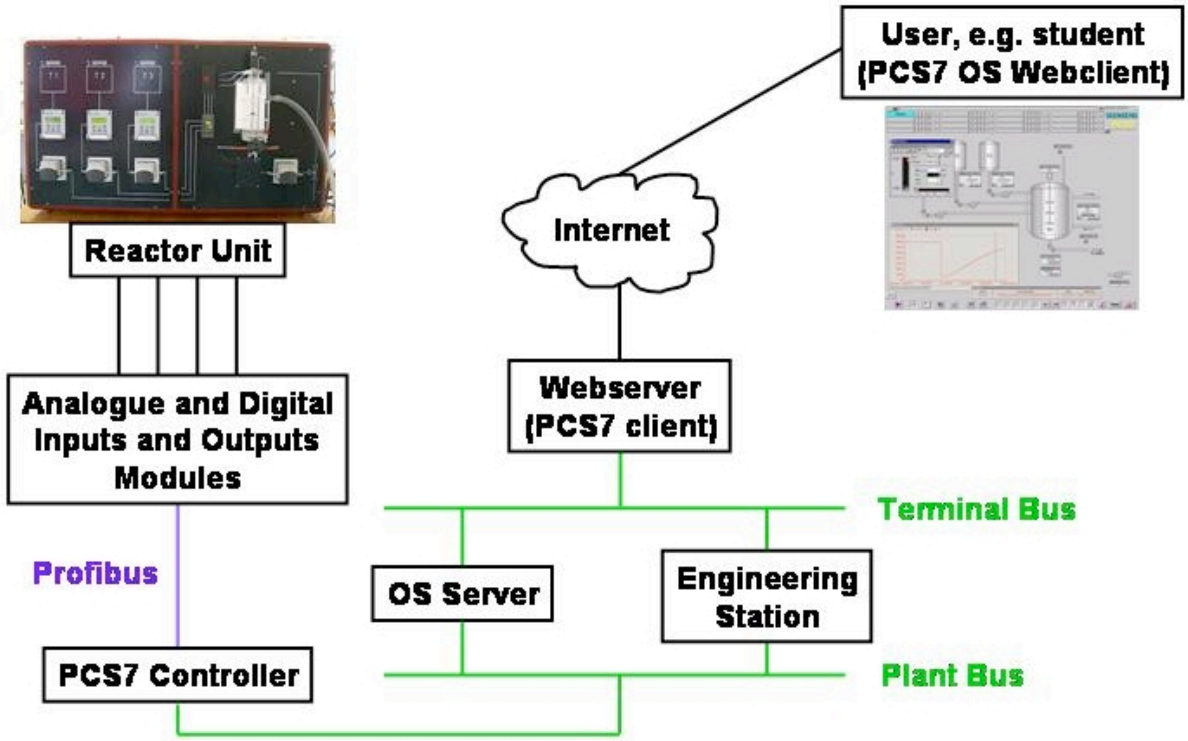

Figure 1. Technical setup of Cambridge Reactor Weblab using SIMATIC PCS7

product from the reactor is possible through multiple exits and variable positions. Upon leaving the reactor, the (liquid) product passes a spectrophotometer, which can monitor the progress of the reaction through colourimetry, provided that enough of the outlet stream components absorb in or near the visible spectrum.

The Cambridge Reactor Weblab is operated using industrial state-of-the-art hard- and software (Figure 1); the SIMATIC PSC7 interface provides the users with an authentic experience of industrial operation. The students observe and manipulate the equipment through a graphical interface; a view which is typical of what an operator sees in an industrial plant. By using the web option for the PCS7 system, a webserver has been set up, so that the Cambridge Reactor Weblab can be operated via the internet from anywhere in the world. Since its inception in February 2006, the Cambridge Reactor Weblab has not only been continuously used in undergraduate teaching at the University of Cambridge, but has also attracted use in undergraduate and postgraduate courses at MIT, Imperial College London, the University of Birmingham, the University of Surrey, the University of Newcastle and Loughborough University. A number of other UK universities have also expressed an interest in using the Weblab apparatus.

B. srm websuite

The srm (stochastic reactor model) websuite is a platform for generating virtual laboratories, which was developed by cmcl innovations Ltd in conjunction with the Lila project. Its primary aim is to model combustion in automotive engines, enabling insight into state-of-the-art combustion processes and futuristic fuels. The key innovation of the cmcl methodology for virtual laboratories is its basis of virtual labs for education using industry-standard research and development (R&D) tools. The simulations in the srm websuite use the same technology as cmcl's srm suite, which has been adopted by R&D teams at engine manufacturers in order to improve engine performance and emissions and streamline the development process by reducing the number of costly experiments performed. By using the srm websuite, students gain an authentic experience of how simulations are used in industry. The srm websuite uses cutting-edge Web 2.0 methodology to deliver engaging virtual laboratories in a modular and flexible design (see Figure 3). The web-interface to the remote laboratory is a Rich Internet Application (RIA) built using AJAX compiled from Java by Google Web Toolkit

Figure 2. Screenshot of the srm websuite

Figure 3. 3D visualisation of a possible design for the CREAM apparatus

(GWT). This lightweight interface can be run on nearly any device including mobile phones and since the simulations are run on cmcl's servers, there are minimal hardware requirements for the end-users system or device. The virtual experiments are supported by "Mash-ups" of supporting materials including videos, animations, articles, and other internet resources, ensuring users receive an engaging and up-to-date experience. The srm websuite is a very recent development and rapid uptake by the potential user community is desired. In order to facilitate this, cmcl has established a robust collaboration within the LiLa project so that it can make use of the portal as soon as possible.

C. *CREAM*

CREAM (Combustion Reaction Experimental and Modelling) is a new initiative by the CoMo group at the University of Cambridge, which aims to maintain and develop the existing collaboration with Siemens. The lessons learnt from the Weblabs have been applied by choosing an experiment which is simple, interdisciplinary in nature and relevant to CoMo group research: the ASTM D1322 smoke point test. The test itself closely resembles a candle flame, except that it uses liquid fuels (e.g. diesel) rather than wax. By augmenting the ASTM D1322 procedure with a wide variety of additional diagnostics, the apparatus will be given the capability to deliver experiments which are useful to teaching of mechanical and chemical engineering and most of the physical sciences at all educational levels; ranging from school to postgraduate. The test can be used to characterise any automotive fuel, making it particularly useful for measurements of the sooting tendencies of futuristic fuels, meaning that the justifiable lifetime of the project is likely to be high.

Although the ASTM D1322 test itself has limited scope for further research, it is possible to incorporate extra diagnostics to study the flame chemistry and soot

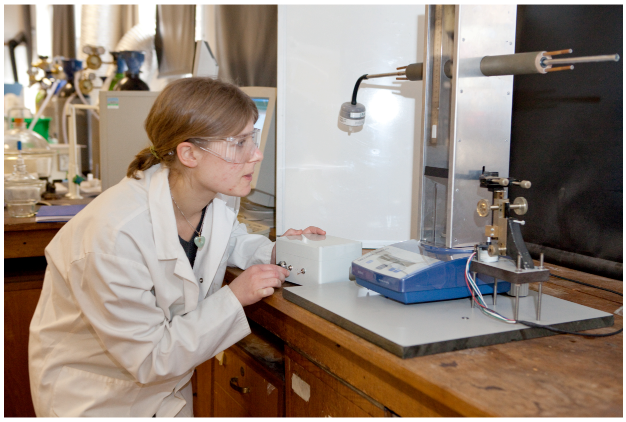

Figure 4. Preliminary testing of CREAM apparatus components

formation in greater depth; this approach is likely to lead to real long-term benefits to the research community. Furthermore, individual diagnostics can be operated by separate users, making the experiment much more scalable. By fully automating the equipment it will be possible to put the experiment to use in research whenever it is not being used for educational purposes. The ultimate goal is to build intelligent communication between the experiment and combustion models that are under development. A possible final design for the apparatus is shown in Figure 4. and its status in early 2010 can be seen in Figure 5.

Additional diagnostics to be incorporated include a DMS500 fast particle analyser, a schlieren imaging system, a fuel uptake rate measurement system, a conventional imaging system and an atmospheric control housing. In particular the schlieren imaging system will be a visually impressive feature of the experiment. As well as utilising the existing PCS7 capabilities developed by the CoMo group during the construction of the Weblabs, the apparatus contains features which could justify the incorporation of other technologies such as Siemens 'Step 7' machine control systems.

Overall, the design conforms well to the likely requirements of a large company interested in publicising its products to a wide audience; it is scalable, relevant to a wide audience, visually impressive and can demonstrate a wide variety of features. It is also likely to be sustainable due to the potential for combined resourcing from both industry and research.

VI. CONCLUSIONS

Collaboration with industrial partners in online learning initiatives which involve virtual or remote experiments opens up significant potential for educational institutions. Possible benefits include improved sustainability, easier management, higher quality teaching resources, more authentic learning, better engagement of students with industry and introduction of a healthy competitive element. Industry can benefit from good publicity for the brand, good publicity for a product, useful training resources for its own staff, useful and easily accessible research facilities, improved links with universities and better training for its graduate recruits. Including the experiment in a virtual portal has the potential to increase usage and support ongoing improvement of the resource.

Acknowledgment

We thank the staff at Siemens Cooperates with education for their continued advice and support, both technically and financially. We also thank the technical support staff at the University of Cambridge's Department of Chemical Engineering for their ongoing help in maintaining and developing our remote experimentation capabilities.

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Authors

R.J. Watson (rw406@cam.ac.uk), **A. Braumann** (ab589@cam.ac.uk), **M. Kraft** (mk306@cam.ac.uk), Department of Chemical Engineering and Biotechnology, University of Cambridge, Pembroke Street, Cambridge, CB2 3RA, United Kingdom

A.R. Coble, cmcl innovations, Sheraton House, Castle Park, Cambridge, CB3 0AX, United Kingdom (e-mail: arcoble@cmclinnovations.com)

T.A. Hennis, Delft University of Technology, Jaffalaan 5, 2628 BX, Delft (e-mail: t.a.hennis@tudelft.nl).

This work was supported in part by the EU e-Content Plus Programme via the Library of Labs (LiLa) project and in part by Siemens plc via 'Siemens Cooperates with Education' (SCE) .