Institutional Factors Governing the Deployment of Remote Experiments: Lessons from the REXNET Project

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Abstract—**Remote labs offer many unique advantages to students as they provide opportunities to access experiments and learning scenarios that would be otherwise unavailable. At the same time, however, these opportunities introduce real challenges to the institutions hosting the remote labs. This paper draws on the experiences of the REXNET project consortium to expose a number of these issues as a means of furthering the debate on the value of remote labs and the best practices in deploying them. The paper presents a brief outline of the various types of remote lab scenarios that might be deployed. It then describes the key human and technological actors that have an interest in or are intrinsic to a remote lab instance, with a description of the role of each actor and their interest. Some relationships between these various actors are then discussed with some factors that might influence those relationships. Finally some general issues are briefly described.**

Index Terms—**Remote Labs, Remote Experimentation, Stakeholders, Remote Monitoring and controlling.**

I. INTRODUCTION

The growth of Internet has brought new paradigms and possibilities in technology mediated education. In particular, it allows the remote use of experimental facilities that can be used to illustrate concepts handled in classroom and serves as an enabling and powerful technology for distance teaching. Through its world wide connectivity, the Internet also allows to have learning materials available to a much larger audience of students. The use of laboratories supports students' activities both in terms of active learning [1, 2], distributed learning [3] and team learning [4]. Web accessible laboratories with remote experiments have become an attractive economical solution for the increasing number of students [5]. They represent a "second best to being there" (SBBT) [6] solution for students and laboratories with expensive equipments. Remote experiments increase accessibility to laboratory equipment and also provide, theoretically at least, space and time flexibility, i.e. students can be anywhere anytime performing their experiments via Internet [5]. Following this trend, many institutions around the world have been engaged in the development of Web based experiments. Systems aiming at teaching and research in several different areas have been implemented, such as digital process control [8], [7], aerospace applications [8], PID control [9], predictive control, embedded communication systems [18], and real-time video and voice applications [10]. Mostly, these experiments utilize customized devices and software to make small-scale textbook-like experiments remotely available.

Although remote laboratories or remote access to experimental equipment have proved valuable for a more efficient exploitation of laboratory resources and can enable access to students in different places, there has been less research on collaborative lab applications. We maintain that remote laboratories are ideal tools for teaching distributive collaborative work skills, because they offer perspectives of shaping teaching scenarios which are close to real distributed engineering team work. Likewise, because remote labs can be shared by many institutions and students worldwide, they may promote the interaction of faculty and students across laboratory-based and technology oriented subjects in different countries.

It is widely believed that collaborative experiences are powerful drivers of cognitive processes and can significantly enhance learning efficiency, particularly where the collaboration promotes communities of common interest. Regardless of the varying theoretical emphasis in different approaches on collaborative learning (e.g. social constructivism), research clearly indicates that in many (not all) cases students learn more effectively through collaborative interaction with others. This is a motivator to prepare remote labs for collaborative learning and to use them in distributed teaching scenarios together with simulation tools, hands-on laboratories and practical workshops.

Consequently there is a strong demand for research that seeks to create such a mix, where collaborative remote labs can play a significant role. This emphasis on collaboration adds new technical requirements to the

design of remote laboratories. In additional, however, it poses new challenges on institutions that are attempting to host such labs. The REXNET project has deployed a variety of remote labs, and from this experience, and from the record of remote labs reported in the literature, it has attempted to understand and address the institutional issues.

This work has been developed with the context of the REXNET Consortium [9]. This Alfa project, funded by the European Community, had three principle goals: to share (1), harmonize (2), and spread (3) current skills on remote experimentation. The first goal directly addresses the essence of the ALFA program (financial support), namely it calls for the cooperation among the consortium partners: those having already available a remote experiment (or lab) grant access to the all consortium, and those not having it should make all efforts to set up at least one remote experiment useful to the consortium. Harmonization is a direct consequence of having universities from distinct countries with different languages and cultures. Among other items it includes interface harmonization, with support to different languages, and curricula harmonization, i.e., defining a common set of practical experiments for a given course already served by a remote lab (or set of remote experiments). Each university participating in the REXNET project must act as a disseminating party within its own country, i.e., spread the access to remote experiments to other surrounding universities. Some results of the REXNET project can be seen in [11, 12, 13, 14, 15, 16, 17, 18]."

II. SCOPE OF REMOTE EXPERIMENTS

Remote experiments are attractive in a number of different situations. In order to consider the feasibility of a generic approach to deployment of remote experiment technologies, it is important to understand these different situations of access and use.

A. Access to "Real" Equipment:

Some operational characteristics of real equipment are difficult to simulate. For this reason, a remote experiment may be constructed that provides ``"hands on" access to equipment that students should have experience of using but is often not available to them.

B. Access to Research Facilities:

Scientists gathering data in unusual locations (e.g. glaciers or ocean beds) may make the facility available to students or other scientists.

C. Access to Expertise/Community:

Experts on a particular topic can work together or with students collaboratively even if they are physically not co-located.

D. Access to Scarce Resources:

It may be difficult to equip a lab with sufficient sets of experiment equipment for the entire cohort to access. In this case complementary labs in different locations can be made available for remote access.

E. Access to Expensive Resources:

Some experiment equipment might be too expensive for most educational institutions to have on-site (e.g. an electron microscope, small scale industrial process equipment or a telescope). In this case, access to this equipment can be made available to students from other educational institutions.

F. Access to Live Events:

Students can become involved in events such as exploring natural phenomena (e.g. counting numbers of animals involved in annual migration or breeding event) not just as observers but also as co-investigators.

These different situations differ in many ways, including location, real time characteristics, number of collaborators, number of simultaneous experiments etc. These will all need to be considered when attempting to propose a generic architectural framework or technology platform for remote experiments.

III. ACTORS AND THEIR INTERESTS

The starting point for considering the institutional issues involved in the deployment of remote labs is to consider the set of actors (humans and technical components) that are involved in a remote lab instance. An initial set of actors and the relationships between them are outlined in Figure 1. As can be seen from Figure 1, the network of actors and the relationships between them are quite complex. This is an important observation. No single academic or teacher can propose or attempt to set up a remote lab without carefully considering the spectrum of interests of the various stakeholders, particularly where those interests might conflict or introduce tensions in the deployment decisions associated with the remote lab.

These include:

A. Subject Teachers

The role of the teacher in the context of remote labs is to provide the theoretical and practical framework needed by the students to be able to do the experiment supported by the lab. In the context of collaborative labs, this will mean providing tuition to students in different locations. Where appropriate, pedagogic support in the form of a virtual assistant/tutor could be provided in addition to any online learning materials delivered via a Virtual Learning Environment or live tutor "presence".

This is a relatively new teaching paradigm, and one that is unlikely to part of the teacher training provided to teachers, either in their initial teacher training or in the ongoing professional development programmes. In principle, however, teachers will still need to have a blended approach to lab work, with some aspects being explicit and carefully choreographed, and other parts being exploratory, allowing students the opportunity to discover knowledge for themselves and to reflect on the results of the lab activities. Teachers may be apprehensive about the practical aspects of interacting with students who are remote and may be geographically distributed. They may have difficultly imagining strategies for monitoring and intervening in a lab that in progress, the virtual equivalent of moving through a lab and watching

students working. Training in conducting remote labs is essential for teachers so that they can develop their individualised competencies in the techniques that they will need.

Intrinsic to the practice of remote labs is the booking and timetabling of access. It is implied that a lab that can be accessed remotely, that has the appropriate support and administration infrastructure in place, should be in use whenever it can be. This puts a burden on the teachers to ensure that the experiments that they provide to students are doable in the time allocated for the lab. Thorough testing of the experiment should take place in the expectation that the author of the experiment will not always be available to students when they are actually doing the lab. Support to the students may be provided through tutors providing local time support, even if they are not actually collocated with the students.
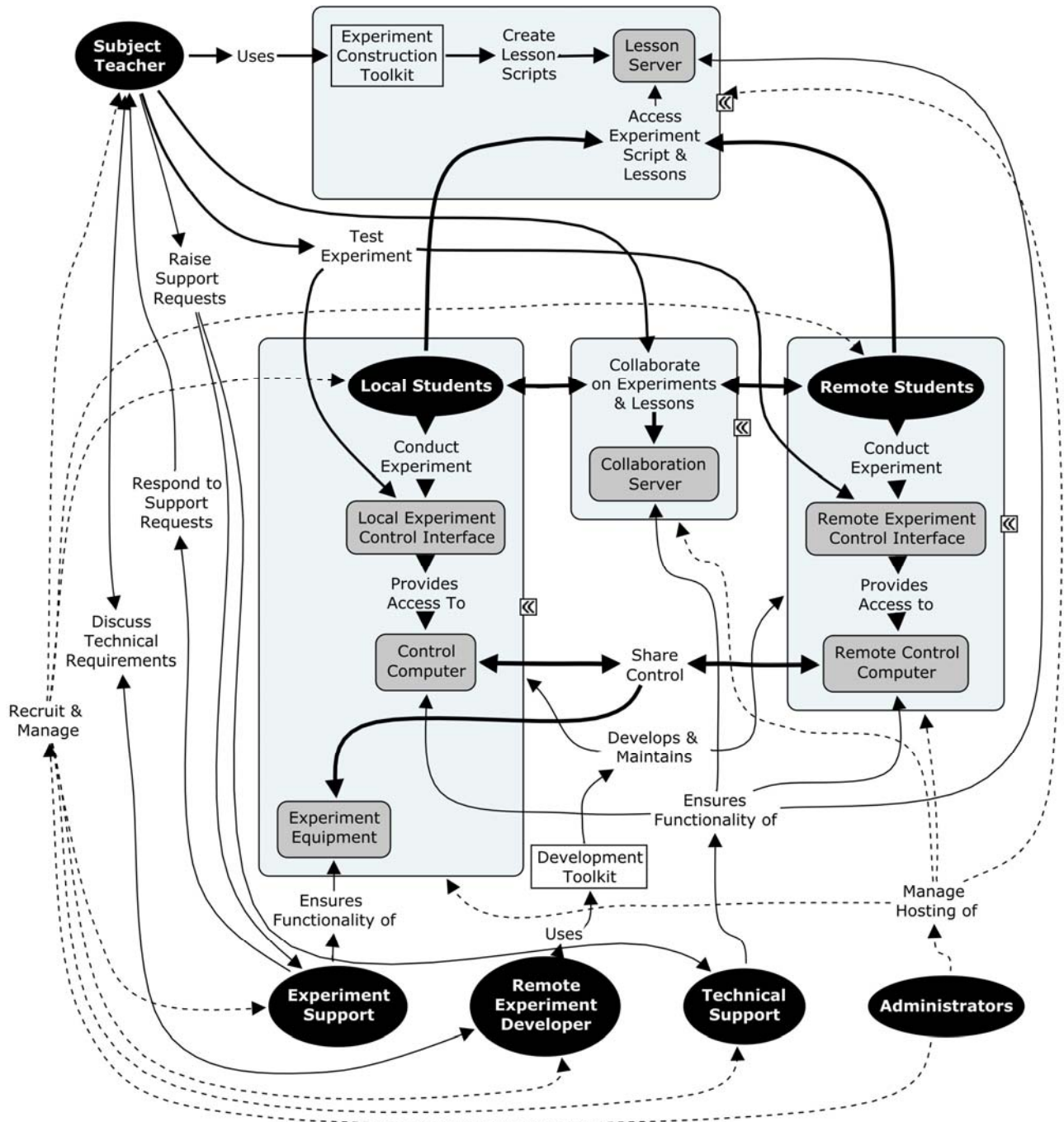

Figure 1. Actors involved in the deployment of Remote Experiments

It would also be of significant benefit for the teachers if a toolkit is available that provides teachers with a assistance in the compilation of remote lab lessons and activities, as there are some unique attributes that need to be considered, such as explicit direction to students on a mechanism for agreeing amongst a remote collaborating team times to meet on-line.

B. Students

The purpose of the remote lab is to enable students who cannot be in the same physical location as the experimental equipment, to use it at a distance. The set of students that are using the remote lab could include a mix of local, remote and even geographically distributed teams. On the one hand, this may provide students with opportunities that might simply not be available locally. On the other hand students may need to be assured that all the pedagogic goals can be achieved using the remote lab rather than interacting directly with the "real thing". These goals will include validation of the theory through practice, experience of operational procedures and real behaviours of the experimental systems, exposure to good and bad data gathered during the experiment etc. Poorly designed or implemented remote labs and the associated collaborative environments might result in students who, as a result of their experience of using a remote lab, give an illusion of competence that is too shallow to be credible as a vocational or practical skill.

C. Technical Support Staff

Remote labs are technically demanding to develop and deliver, as they depend on a chain of interactions mediated by as yet potentially unreliable or unpredictable network infrastructures. Support, therefore, needs to be provided at two levels.

The first level is "experiment support", where the requirement is to ensure that the experiment is ready to be used by the student. This includes such aspects as ensuring that consumables are sufficient for the experiment, that the equipment is serviceable and that it is in the "starting state". The importance of this role should not be under-estimated. Depending on the access regime in operation and the nature of the experimental equipment and experiment, this may require human support to be on hand at the location of the experimental equipment, even at times that are locally unsociable but fit the timetable of the remote students.

The second level of support is in the provision of the tools that support the remote experiments, such as the collaborative learning tools and the learning support environments. Management of local infrastructures can operate within rules and procedures that can be readily agreed and communicated locally, taking prevailing practices and expectations into account. For example, down times and maintenance schedules can be negotiated and agreed to take place during known quite periods (e.g. times of the day when few students need access, or avoiding local exam or assignment submission times). If a facility is being used by students in other locations, however, these issues become significantly more complex, and good communication between central support and distributed users and their advocates needs to be put in place before the system is widely deployed and used.

D. Remote Experiment Developers

The technical complexities of deploying a remote lab that accurately carries the operational experience to the users are not trivial. Issues such as response times, resetting systems after the experiment etc. change the experience for the remote users compared with that experienced when using the system locally. Some aspects, such as the ability to smell when experimental equipment is running too hot are currently impossible to convey directly, but must be conveyed by sensoring for the effect or phenomenon (hot equipment) rather than the symptom (smell of hot components). Although this example illustrates that a technical solution is generally possible to convey facts about the experiment, the skill of smelling hot components is an important practical one for an engineer to develop and is not possible to teach in an entirely remote lab. So whilst it may be possible to teach the limits if operating equipment based on the effect that it has on it, the practical skills of detecting these effects may not be possible.

The challenge for the developer, therefore, is to work with the teacher to understand the comprehensive learning outcomes that would normally be expected from participation in an experiment locally, and then to seek technical solutions to ensure that the maximum number of those outcomes can also be achieved remotely. Having demonstrated the technically feasibility of providing a solution, this will need to be demonstrated to work as designed when the realities of distance access are taken into account. In general this will focus on the influence of the network and the operational realities that exist between the experiment and the remote users, particularly if it is expected that several benches or examples of experiments will be available from a lab, and all could be used simultaneously.

In practice, many remote experiments tend to be unique, "one off" developments. Few people have experience of deploying many different experiments, or even of having deployed the same remote experiment many times. This suggests that there is a learning curve involved in each deployment of a remote experiment that far exceeds that associated with deploying a local experiment. Teachers themselves will take the lead role in deploying local experiments. It is unlikely that many teachers will have the necessary computing skills to undertake the deployment of a remote experiment. In practice, however, the team that is put together a given experiment may not stay together to tackle subsequent experiments.

Other more mature domains of applied computing (database integration, user interface design, web site deployment etc) have standardized methods and an array of tools and toolkits available to ensure that best practice and experience can be carried from earlier experiences into subsequent. In this way, each deployment is not a unique event, but builds on standardized best practice. The domain of remote experiments has demonstrated technical feasibility in a wide variety of examples. Unfortunately, the

appropriate technical platforms are still evolving rapidly, particularly in the areas of middleware and networking technologies. Systems developed in the past cease working when new security mechanisms and firewalls are deployed. The base level technologies available in schools, colleges and universities are however improving. It is appropriate, therefore that developers of remote experiments should seek to evolve the tools and practices that streamline the deployment of remote experiments.

E. Technology

Remote labs depend on technology to run the experiment, to connect the remote student to the experiment and provide the collaboration tools between the students. The role of technology is central to all that happens in a remote lab, so it has a relationship with all the other actors in the provision of remote labs.

Technology is constantly evolving, so the technology employed in remote labs is constantly evolving. This means that the relationships that other actors have with the technology is constantly changing. There is a tendency to attempt to deploy a particular technology just because it is now available, or because another factor has changed, rather than to perform a gradual evolution in response to demonstrated pedagogic needs. This is seen most clearly in the response to changes in security risk associated with technology in education. Widespread deployment of firewalls and other security measures has resulting many early examples of remote lab technologies ceasing to function. For remote labs to achieve more widespread deployment, more technological stability is required so that the other actors can "catch up" with the issues associated with the deployment of remote labs, and some mature best practices emerge.

F. Institution Administrators

Remote experiments are hosted by institutions. Students' access involves a mediated access via one or more institutions. Institutional policies inevitably have a profound impact on the practicalities of deploying remote labs for wide access.

Remote labs might be seen as a potential source of financial income for educational institutions although the overhead costs of providing and staffing such a service might be considered too high. The institutions first responsibility might be considered to be to its local students, so there might be little motivation to provide services to external students without a clear profit being guaranteed.

Where access is to be provided to students from different institutions, there are significant overheads associated with administering this access. Many institutions use incompatible virtual learning environments, with no possibility of moving enrollment details between them. Students would therefore need to be administered separately in their home institution and the remote institution. Credit and curriculum systems are different in different places, even within the same country.

If institutions see remote labs as a way of increasing income from student fees, they will be concerned to have a recruitment infrastructure in place that means

there is some predictability about numbers and educational standards of students. This will require networks of cooperation to be established.

Administrators will also be concerned to balance the income from providing remote access with the cost of providing this access at locally unsociable times.

IV. RELATIONSHIPS IN THE PROVISION OF REMOTE LABS

Figure 1 shows the key actors involved in a remote lab scenario. It also shows some of the relationships that exist between the actors. It is important to explore these relationships in order to understand the various issues that will need to be addressed when deploying remote labs. Experiences from REXNET and other remote lab deployments can be generalized in the following observations.

A. Teacher-Student

This relationship between the teachers and the students is mediated by the collaboration services, and is an extension of the traditional and evolving relationship between teachers and students. Although this relationship builds on a long tradition of education practices, the practicalities of running a remote lab and teaching in this way at a distance is a new paradigm. Some "early adopters" will have valuable experiences of success and mistakes, but few teacher-training courses will address these issues at all.

B. Teacher-Technical Support

This relationship is difficult to model, because it is currently ambiguous for this application in many institutions. Whilst technical support staff are willing and effective in supporting pilot deployments, the long term relationship between teachers and technical support is often governed by bureaucracy and by complex or time delayed processes. Teachers often feel out of touch with technical support personnel, and technical support personnel often feel overwhelmed by the call on their services. This is, however, a fundamental relationship in the provision of remote labs.

C. Teacher-Technology

Early adopters, or those from technical backgrounds will be ready to embrace or promote the use of remote labs and even get involved in the development and deployment processes. Many teachers in non-technical subjects do not have a good relationship with technology, and do not receive the training and ongoing skills reinforcement to maintain confidence in the technology. For them it is often seen as simply too unreliable, and they are unconvinced of the pedagogic value. Both these issues will need to be addressed. Good toolkits will need to be provided to teachers to help them to construct the lessons that use the remote labs.

This relationship also often mediates the relationship between the teacher and the student. It is important to recognize that the relationship is mediated. The channel is different to that that exists when the student and the teacher are face to face. Technology should provide a

rich and appropriate set of tools to facilitate the communication.

D. Teacher-Administrator

This relationship is fundamental to the adoption of remote labs as a service within an institution beyond a teacher or researcher led pilot phase. Administrators run institutions and they balance policies from policy makers such as governments and regulators. They seek to balance and maximize the value of resource usage against cost within the entire institution. Any venture will have parameters such as cost, profit, pedagogic value, kudos, popularity amongst students, vocational worth etc. The provision of remote labs will need to be seen to add value beyond the resource costs for it to be acceptable and be supported by the administrators of an institution. This relationship is barely explored in the literature covering remote labs, and yet is invariably the reason for remote labs not moving from pilot phase to long-term provision.

E. Teacher-Developer

Teachers are rarely appropriately skilled to develop their own remote labs without some element of cooperation with developers. Whilst, ideally the developer should work directly with all the users, including students, it may be that that relationship is mediated through the teacher. It is crucial that the developer understand the subtleties of the operation of the experimental equipment, and that the behaviours are modeled as accurately as possible. In some cases, for example, operational procedures are not completely intuitive but are standard (e.g the use of a standard instrument and it's behaviour and operational procedures). The developers and the teachers need to foster a strong and understanding dialogue so that all the various pedagogic, usability (including access for disabled students) and vocational learning outcomes can be achieved.

It is a characteristic of this domain that the technological building blocks, particularly the middleware and communication services are evolving rapidly. Developers should attempt not to innovate in a way that is going to require a regular rebuild of the experiment because inappropriate technical choices were made. Tried and tested technologies, even if they are not absolutely "state-of-the-art" should be used if that ensures that the deployment costs can be reduced and the lifetime of the experiment extended.

F. Administrator-Developer

There is a perennial tension between those responsible for the management of development and deployment projects and those responsible for doing the development. This tension tends to be centered on the developers desire for excellence and the administrators desire for increased efficiency and productivity. This dialogue needs to be well informed, therefore, with the additional factors such vocational and academic competencies enabled by the approach, so that both administrators and developers become facilitators of the learning process rather than significant determiners of it.

G. Administrators-Technology

The administrators manage the hosting of the technology and the contracts that govern the access to it. It would be unusual for them to be practical users of remote experiments. But they have significant influence in its use. This is clearly a potential point of tension, so it is important for their role to be recognized, and those with an interest in the remote experiments to ensure that appropriately weighted arguments and evidence are presented to the administrators to ensure that they are equipped understand the implications of decisions made about technology, and how those decisions impact pedagogy and the balance of institutional imperatives.

H. Administrator-Student

Each technology based learning system needs to be administered. Factors that influence this administration include access to increasingly complex functions of instruments based on demonstration of competence and the need to ensure that experiments are secure and not open to abuse by non-authorised or competent people. It is unrealistic that each learning support system (Virtual Learning Environment., Lab Server, Videoconferencing Servcer, E-Mail Server etc.) can be administered individually, so the ability to integrate the students through a centralized administration system is important. Because of this, students and administrators may communicate directly in addition to any student-teacher relationship. It's not always easy, however, for students to understand the role of administrators and the systems that they operate. It's important, therefore, for the visibility of administrators and their processes to be as transparent as possible, from initial contact and recruitment through to access to the experiments themselves. Duplication and complication in the system inevitably leads to errors, so it is in the institution's interest to appropriately support other actors rather than be seen to visibly mediate the relationships between them.

I. Administrator-Technical Support

Remote labs will depend on technical support, in a way that will be different to other polices governing the other learning technologies in use institution. New working policies will need to be negotiated between the administrators and the technical support staff, who may well need to be reskilled in order to provide support to a new set of collaborative and experiment tools.

J. Student-Technology

The technology is the enabler of the learning that the students are expecting to occur. The learning may be concerned with the technology itself, or it may be about a completely different subject that is mediated by the technology. In principle, the technology should be as transparent as possible so that the attention of the student is on the experiment, not the role of the technology in the experiment. This relationship depends, therefore on the teacher and the developer properly understanding the place of the student and technology in the experiment, and learning outcomes that are expected, and the initial competencies of the student. The teachers and developers should therefore work together to ensure that this relationship is appropriate and in the best interest of the learning.

K. Technical Support-Technology

The technologies involved in remote experiments add a layer of complexity to what has previously been supported in labs. Experiments have traditionally been supported by subject specialist technical support staff. In the case of remote labs, however, they now have a layer of technology to contend with. Technology specialists now have to comprehend the support issues of specialist subjects. This suggests two types of technical support skills, experiment specific and technological. It also suggests a training overhead for technical support beyond that currently provided for any exisiting technical support staff.

L. Technology-Technology

Remote experiments imply a suite of technologies, bundled in some way as a single user experience. The technologies may co-exist and have no explicit relationship, or they may communicate, or at least influence each other. These relationships must be well understood before a remote experiment is deployed, and no assumptions made about the ability of technologies to provide a single seamless experience.

This analysis demonstrates the complexity associated with deploying remote experiments. It should be stressed that this is an overview of the issues involved. Other third party actors such as external developers (commercial or open source), policy makers, even wider society could influence the relationships between the actors that have not been predicted here.

V. PRACTICAL IMPLICATIONS INHERENT IN REMOTE LABS

As well as specific issues faced by the various stakeholders and actors concerned with the deployment of remote experiments, there are some generic issues that are faced by those seeking to get involved in deploying or using remote experiments. These include:

A. Time

Institutions, students and educators will need to face the realities of providing and participating in remote labs across times zones. Equipment can be utilised more efficiently but issues such as technical support 24 hrs a day, 7 days a week may present serious challenges to the viability of this facility. This is true both at the technical support level, but also at the level of pedagogic support. Institutional directives will need to take these realities into account..

B. Technical Constraints

Moving from pilot demonstrations of technical feasibility with the goodwill support of technical support services to widespread deployment will have impact on the technical infrastructure of institutions. The services supporting remote experiments imply at least telemetry with minimum delay. Feedback of the response of the experiment following intervention by the student will often depend on video and audio in addition to data telemetry. Collaboration between students depends on unbroken reliable audio and video services as the operation of critical and valuable equipment (e.g. an on-line electron microscope) cannot be done simply through text chatting services.

C. Language

Students in different countries will need to find a common language in order to collaborate effectively. This becomes especially important when the experiment equipment is expensive and potentially delicate (e.g. an electron microscope). This is potentially sensitive as language is a precious attribute of a culture, and it should not be assumed that education depends on a particular language. Students should be able to reach their potential in different domains without having to mediate that education through a different language than their mother tongue, even in a world that is increasingly globalised and homogeneous.

D. Culturally Specific Pedagogy

Different cultures have different pedagogies that reflect the different traditions within the cultures. Some cultures teach science in ways that are more didactic, some that are more exploratory. Some have a more oral expressive tradition, some a more visual. These differences mean that different learning styles that work in different cultures may be unsuitable in another culture. This has implications for the teaching and learning, but also the way that different cultures will subsequently express their competencies in the workplace. Cooperative learning needs to recognize this, and make efforts to reflect this by tailoring the way that learning is provided and managed to different students in different contexts.

VI. CONCLUSIONS

The REXNET project piloted a number of different remote experiments that demonstrated technical feasibility of the approach, both at the local level, but also at the level of transatlantic remote access. The project showed that technology is moving in a way that removes doubt about the technical feasibility of the approach, irrespective of distance. The approach works across global distances.

It recognized however, that increasingly, the issues governing the deployment of remote experiments have as much to do with the variety of practical constraints on the various stakeholders and actors as they have to do with technology. This paper has sought to gather a number of those issues together. The complexity and importance of the issues raised suggest that it is necessary to develop a set of guidelines of best practice and standardized toolkits and methods for both the technical and the pedagogic elements of remote experiments. Such guidelines and toolkits will facilitate wider interest, deployment and use of this valuable educational facility.

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