Features, Trends and Characteristics of Remote Access Laboratory Management Systems

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***Abstract*— Remote Access Laboratories are being used around the globe to enable engineering students to practice practical skills and enhance their knowledge through hands-on experimentation. These facilities also increase access by allowing users to undertake experiments anywhere anytime thus offering more flexibility and mobility. Several RAL systems have successfully met these goals. However, the role of experiment designers has rarely being explored or expanded since the conception of RAL systems. Experiments are designed and put on internet by a small group of experts in their respective fields. While these systems have been successful for universities where experts and suitable environment are available, they have rarely been used in the schools; and Science, Technology, Engineering and Mathematics (STEM) education. As the pedagogical design is now seen as a critical development in the instigation of new experiments, any RAL for STEM education initiative must address pedagogical considerations from the onset. In this paper, the common attributes of the leading RAL systems are discussed and the basic denominators are identified to establish common feature that are widely implemented in RAL systems. Limitations for their use in STEM education are analysed. The paper concludes that RAL architectures need to incorporate new aspects such as the peer-to-peer access paradigm in order to become viable STEM-based education tools.**

***Index Terms*— remote laboratories; e-learning; computer networks; web technologies; instrumentation**

I. INTRODUCTION

The information and communication technology today has enabled fast and rich ways of exchanging information between people from different domains with a variety of applications. One such application is the Remote Access Laboratories (RAL) or Remote Laboratories, which are web-based interactive systems that gives students the ability to control and observe the characteristics and processes of remote equipment through the internet [1-5]. Teaching Science, Technology, Engineering and Mathematics at schools (known as STEM) is seen as an effective way of growing interest in science related fields [6]. Such education needs practical hands on experience in combination with theoretical knowledge of STEM concepts. Practical experience is acquired by physically building, observing and recording facts from different equipment setups and environments.

RALs can provide access to resources which are otherwise inaccessible to users. Typically all that is required is a web browser and an internet connection to enable rich educational experiences. Traditionally remote laboratories have been deployed by institutions for their own student cohorts or community members associated with the university. A 2010 survey advocated 'Virtual & Remote Labs' as the top choice for enhancing engineering education [4]. A number of collaborative projects have integrated experiments under a common infrastructure. Aims of these efforts typically include simple access by students and support of collaboration among students [7-8]. Research has mainly focused on integrating RAL experiments into higher education, including undergraduate courses [9-11]. Typically, because of large number students, limited hardware and defined sets of experimental setups.

The aim of this paper is to examine current trends and features of RAL systems and initiatives; and to contrast those with requirements and constraints of a K12 curriculum oriented STEM education. To do this, a model is created of what key components comprise a "good" RAL system and what are common characteristics of all RAL systems. It is observed that various components of RAL are implemented in different ways; however, common properties are retained and similar services are exposed. The general features of remote laboratories are compared to establish the common standards being followed for creating RALs, and how their designers use them for teaching. This is found to be as too complex and designer oriented i.e. specialized to particular domains of laboratory experience. This is stated as a reason for a relatively slow adoption of RAL as a regular tool, especially within K12 education. This paper extends [12] by analysing RAL system features in the context of STEM education.

In Section 2 expected features of remote laboratories are outlined in the context of laboratory learning in engineering followed by a program logic model to explain the origin and development of remote laboratory architectures. In Section 3, common characteristics are formulated followed by detailed examination of different RALs systems in Section 4. Technical criteria and features are evaluated. Common features and tends are discussed in Section 5. Limitations and drawbacks of RAL systems in the context of their adoption for K12 education; and potential solutions are presented in Section 6.

II. RESEARCH METHODOLOGY

A. RAL requirements for K12 education

STEM education in schools is very important for students to develop interests in further studies in these fields. A major problem of practical STEM education is that expert expertise is required to develop and operate (remotely accessible) experiments in home or schools environments. One of the main challenges of STEM education is to finding new and creative ways to express ideas with aids of physical means and understand each aspect of the entity being studied. STEM based education also encourages the use of enquiry based learning which requires hands-on experience, including building of the experimental setup and collaborating between students [13, 6]. Existing RAL architectures fall short in these criteria as discussed in the next sections.

B. Research Framework

Laboratory and practical activities form an integral part of Engineering Education. At an ABET Colloquy [14], a set of thirteen common learning outcomes for engineering laboratory activities were identified. Traditionally practice classes are taught face-to-face; however, Remote Access Laboratories have been widely discussed as potential alternatives for online delivery. Drivers to develop remote laboratories differ and include the ability to share hardware between physical locations within and between and institutions e.g. remotely controlled robots [15] and control laboratories [16], economic benefits [17] and access for distance education students [18]. RAL literature largely focuses on technical system implementation details; questions regarding learning outcomes and pedagogy are often not addressed.

Another common deficiency with laboratory work in science and engineering curricular is that objectives for practical activities are not explicitly addressed [14]. This makes it difficult to judge the educational effectiveness of RAL activities. In particular since "the pedagogical effectiveness of any educational activity is judged by whether or not the intended learning outcomes are achieved" [19]. As this paper focuses on the system design, it addresses this question by considering the factors that lead to the creation of a RAL, as well as the sub components that make up the final system with respect to both technical requirements, as well as educational and pedagogy considerations.

C. Research Methodology

To evaluate and compare different RAL systems and establish whether individual approaches have major advantages over others, a Program Logic method [20] is used. This method maps inputs, activities, outputs, outcomes and impacts. As this paper addresses the overall system design, the evaluation is limited only to aspects that are relevant in this context. Fig. 1 summarizes the program logic used for a generic RAL system.

The situation is depicted on the left-hand side and includes the technical advances that have been possible with the developments in computing and communication, i.e. the Internet. This also includes generally underutilized laboratory spaces and student access to practical experiments. In the context of distance education, for example, this issue is dominant. The next box depicts the inputs. Most RAL systems have originated from academics with a keen interest in technology. Additionally, funding, institutional support and other resources play a vital role.

Another consideration is that of isolated development, or development based on other published system designs. Outputs include the actually developed RAL system that solve the access problem and the experiment or 'rig' design. Students using the systems and dissemination of novel results are also important outputs. The impact of these activities is arrived at by improved access for students (temporal and geographical) and collaborative opportunities; improved pedagogies and wider use; as well as changes to learning and teaching paradigms. To complete the methodology, the following aspects of these systems where evaluated: Initial Problem, Pedagogy, Web Interface Design, Innovative Features, Users, Scheduling, Programming Languages, impact and major academic fields.

III. REMOTE LABORATORY – BASIC COMPONENTS

Within a RAL system there are traditionally two nodes, the server and the client (see Fig. 2). The users' side consists of the students engaging and learning from use of the experiment, with the server side providing the experiment 'rig', as well as the experiment designers responsible for designing, creating and maintaining the experiment designed to allow experiential learning of concepts and learning materials. RLMS are responsible for arbitrated interaction between all components and interfaces in the system. Typically RLMSs have certain common components:

- Scheduling
- Rig operations
- Transport layer

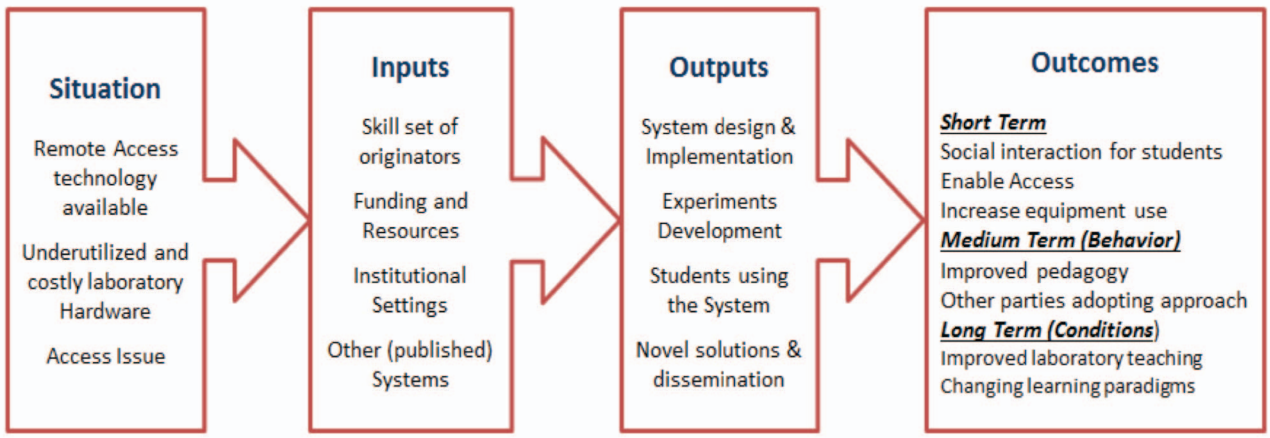

Fig 1. Program Logic for RAL evaluation.

- Multimedia tools/data about experiments
- Experiment user interface
- Accepting and processing user requests
- Storing and maintaining user details

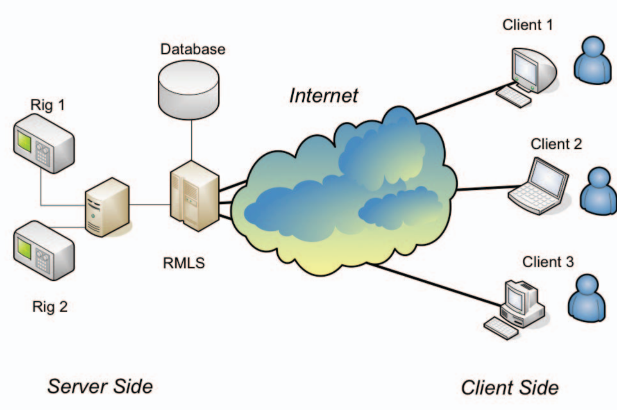

Figure 2. Typical RLMS System Architecture.

IV. STUDY OF DIFFERENT RAL SYSTEMS

Some of the largest and most widely used RLMSs are chosen for comparison because these have been developed and used for several years namely iLab [1, 11], SAHARA [7] and VISIR [21].

A. System architecture

The iLab has a three layered architecture called the iLab Shared Architecture (ISA). Users connect with a service broker server, which in turn makes a connection with the actual laboratory server. The system architecture is heavily dependent on web services [1]. iLab has also been used to implement extensions such as iLab-MIT-Africa [22] in African nations and some universities in Australia. Experiments in iLab have been categorized into three different delivery methods: batched, interactive and sensor. iLab is based on the Microsoft platforms including Visual C#, .NET framework tools and Microsoft SQL Server. This makes the system very platform dependent, consequently it is difficult to implement on open source platforms. Recent attempts are being made to re-implement the ISA in Java in an attempt to make it platform independent [23].

SAHARA originally followed a client-server architecture, where all experiments were hosted at the UTS laboratories, and accessed upon request by remote users. In this design, the lists of experiments are stored by the central server, which is also responsible for other operational aspects including running the RAL, scheduling, and operating the rig. Recent developments in SAHARA have moved towards grid architecture, but mostly within partner institutions. VISIR implementations also follow client server architecture, where all the experiment lists are stored in centralized databases along with user details, and connection to the same server is used for booking and operating the experiment. Both iLab and VISIR use LabVIEW as the main platform and language to write programs to operate instruments.

B. Experiment scheduling

iLab follows a queuing method for scheduling experiments with users. All requests are placed in a queue and processed successively one after another. Users of VISIR follow a time-slot booking method by assigning a particular time period in the future to a particular student [9]. Only the student allocated that time-slot can control the instruments and measure data. The SAHARA software release is available freely with the following modules [7]:

- Scheduling scheme – Both Queuing and Reservation Systems
- Rig Management and Alarming

This can be used by developers to implement their own laboratory management systems although it is still useful only for people who already have a laboratory rather than individuals or small groups of users. Teachers can also make requests to the laboratory manager for a rig, upon which it is shared with the interested group.

C. Deploying new experiments

In all cases new experiments are chosen by the administrators based on the university curriculum and educational needs according to the subjects being taught. The instruments used are typically of high cost featuring complex functions. Due to the nature of the experiments, these systems have to be developed within the laboratories of participating universities. The experiment configurations are generally composed of several experimental apparatus operated by a high level language, and typically involve a PC computer based controller. The user interface for the remote laboratory is also typically created by the laboratory staff. The scheduling aspect is easy to implement for instance as in the SAHARA software. These features allow developers to implement their own laboratory management systems.

VISIR, which provides workbench environment and set of experiments, is flexible but still limited to the number of experiments that can be performed with the given restricted component set [24]. In this instance there is no scope of deploying any new module extensions, except for where VISIR developers extend the features and components of the hardware.

D. Nature of experiments

Within iLab the experiments are varied in nature and maintained by different laboratories at MIT with different experiment focus. The micro-electronics laboratory for instance is the most used experiment. In addition to this, there are other laboratories for control theory, circuits' laboratory, micro-electronics and physics. All laboratories are built with a key focus on the required laboratory experience for undergraduate and graduate courses. For Labshare, the experiments are also from varied fields such as physics and electronics. Some of the typical experiments available as of now are:

- Beam Deflection
- Fluid Mechanics
- FPGA Experiment
- Microcontroller design

VISIR is restricted for use with the analog electronics basic experiments [25]. The UI for VISIR features considerable flexibility and intelligence. The users can assemble and measure currents, voltage and other properties of serial and parallel circuits. The environment can detect and immediately inform users making incorrect connections such as short circuits. This increases the students understanding about what can go wrong while designing a circuit. Although VISIR provides more definite sets of experiments, it is restricted to core electrical and electronics education for undergraduate students [26]. VISIR has been used by several universities such as Carinthia Technical Institute Austria, UNED Madrid Spain, Univ. of Duesto Bilbao Spain and ISEP for their undergraduate curriculum.

E. Notable Features of WebLab@Duesto

Univ. of Duesto, Bilbao Spain developed the WebLab-Deusto remote laboratories [3-4] in the early 2000s. This system uses the client-server mechanism, utilizing mostly time reservation with priority queuing based scheduling [27], although the nature of scheduling can change if connecting to other systems. Within this particular system, there is a wide variety of experiments ranging from basics of physics to FPGA [28], although the main focus is on electronics and electrical experiments. But like all RLMSs, new experiments are designed by laboratory experts based on educational needs of their undergraduate students.

The most notable features of WebLab are

i. Integration with other RLMSs such as VISIR [29] to use their experiments

ii. 3D user interface in second-life called the ‘SecondLab’ [30]. SecondLab merges all the RAL components and allows students to program a micro-bot from Second Life with visual feedback. However the experiments portal is highly dependent on the type of experiment being implemented.

F. USQ RAL

The University of Southern Queensland is distance education provider and in engineering typically 75% are external students who are located off-campus. RAL has become a viable option to improve the learning experience of external students. In most cases the RAL activities are undertaken in addition to face-to-face residential school, in some cases students work remotely instead of visiting the university periodically [31]. Remote access laboratories have been successfully used at the USQ in teaching fields from education [32, 33], nursing [34, 35], and geographic information systems [36] to hydraulics and power engineering. This has been possible through extending the traditional definition of remote laboratories from controlling hardware remotely to conceptual space of conducting experiments remotely [18].

The experiments are all hosted at the university site and have been designed by academics. This RAL system uses the remote desktop sharing as an experiment access paradigm. Sessions are authenticated via a booking system that integrates with the institutional LMS. It allows users to view the experiments and the interface by directly transmitting the desktop image from the university servers to the user’s desktop. A lot of different equipment can be run out-of-the-box using this approach making it very easy to implement any experiment quickly without much expertise. This system follows a time-scheduling approach and uses native programs of the rigs to operate them.

G. Other RAL Examples

In 2011, the project ‘LiLa’ (Library of Labs) was

TABLE I
COMPARISON BETWEEN LABS

	Netlab (UniSA)	***iLab, MIT, USA***	***VISIR, Sweden***	***Labshare, Australia***	***WebLab , Duesto***	***USQ RAL***
Initial Problem	Accessibility	Accessibility	Accessibility, User Experience	Resource Sharing	Accessibility	Distant Education
Pedagogy	Investigated Implemented	Investigated	Investigated	Investigated	-	Investigated
Web Interface Design	Similar to classroom	Mimic Interface & LabVIEW interface	Similar to classroom	LabVIEW interface, Mimic Interface	Mimic Interface	Desktop Sharing
Notable System Features	Co-operative Activities	iLab Shared Architecture (ISA) & service broker	Flexible electronics circuit hardware	Collaboration	3D Interaction	Easy Out-of-box implementation
Users	Undergraduate	Undergraduate	Undergraduate	Undergraduate	Undergraduate	Undergraduate
Scheduling	Time-Booking	Queuing (batched expts.) & Time-Booking (interactive expts.)	Time-Reservation	Time- Booking Queuing Hybrid	Time-Reservation (with priority Queuing)	Time Booking
Programming Language(s) - Rigs	JAVA	LabVIEW	LabVIEW	LabVIEW	-	Native
Programming Language(s) - UI	JAVA	JAVA	Flash	LabVIEW Interface	HTML, Flash	Native
Major Academic Fields	Electrical Circuits	Control theory, circuits laboratory, micro-electronics and physics	Analogue electronics	Physics, Electronics, Electrical	Physics, Electronics (FPGA)	Hydraulics, Nursing, Geographic information system, Networking
Impact	Initiated Co-operative Experiments	Used in Africa and Australia	Collaboration with others	Used by school students	Collaboration with others	Collaboration with non-technical disciplines

started as a collaborative venture between several RAL installations throughout Europe. Many virtual and remote experiments were shared by partner institutions through a Learning Management Systems (LMS) and the 'LiLa Internet Portal'. The learning aspects of LiLa were managed using SCORM, a learning object creation and management tool [8]. Actual operating and related costs of the laboratories however were still borne by the participating universities.

REXLab (Brazil) was created in Brazil. It has RAL experiments that could be accessed via the mobile devices. An experimental 3D Augmented Reality activity using LabVIEW has been reported [37]. RemoteElectlab [38] was developed at FEUP, Porto, Portugal targeting Mechanical, Physics Electronics and Meteorological experiments. eMersion and SMARTLAB have been used at EPFL, Switzerland which uses the 'Graaasp' social media platform [4]. This also is for higher education students in the fields of Control Theory, Physics, etc.

V. FEATURES AND TRENDS OF RLMS

To establish the difference between the systems the following criteria were examined:

A. Why were these Laboratories rolled out?

Most laboratories have their origins addressing problem of inaccessibility of equipment (i.e. more students and limited instruments) including iLab, Netlab (UniSA) and WebLab-Duesto. The UTS laboratories were developed to offer more expensive and hence higher performance instruments than the ones being used in the regular laboratories. Later Labshare and LiLa were initiated to share resources among different institutions in Australia and Europe. VISIR was initiated to provide knowledge of the difference between simulated data and real experimental data on a computer.

B. Advanced and Innovative Applications

As with the original concepts of RAL, each system started by providing access to the instruments over the internet, i.e. that users be able to access the instruments from their computers. Later, several innovative steps were introduced that could be used to enhance the student learning such as:

i. *Virtual 3D Environment:* Several RAL systems have used 3D interactive and immersive environments to simulate the real world experience in the virtual world. The RemoteElectlab (Porto) has preseted a case study for accessing a digital multi-meter through a 3D immersive environment [38]. iLab have created the TEALsim system to provide interactive physics experiments on magnetism [39]. REXLab has implemented a young's modulus experiment in a 3D virtual laboratory environment [37]. WebLab also introduced the most significant of these 3D systems, SecondLab, which is based on the SecondLife virtual world environment [30].

ii. *Co-operation between students in experiments:* Operating experiments via the internet also allows for co-operation and collaboration between different students interacting, watching or lurking within the same experiment simultaneously. All of the 3D environments stated above already allow multiple users to access the experiment at a given time. In these instances, the users are represented by their avatars. Netlab was one of the earliest systems to implement interstudent collaboration [40]. Should it be desired, a multiuser interactive collaborative environment is required to allow concurrent users to have control over the entire experiment simultaneously.

iii. *Dynamic Components Assembly:* VISIR created a relay based dynamic circuit assembly system to allow students to build and test circuits during sessions by using micro controllers through a computer server. The Netlab system also follows a similar approach to connect several instruments together dynamically to form the experiment. Other systems have implemented this technology [41].

iv. *Reconfigurable Laboratory Kit:* One general drawback of RAL systems are they provide only a static set of experiemtns and the users never actually set them up. There have been some efforts to create low-cost reconfigurable laboratory devices that may be used by individuals to create and test experiemtns. An adaptable model of remote laboratory platform that can be easily re-assembles/configured for electronics laboratories allows large number of reconfigurations has been reported [42]. The WebLab@Duesto has also created one such device.

v. *Scheduling schemes:* Remote laboratories pose a very unique scheduling prolem. It's a major technical difference in implementatio of on-site and the remote laboratories. All RLMS have implemented some innovative solution to it [43] with two fundamental strategies used - queuing and time-slotted booking [27]. In some RAL systems where only brief interactions between users and rigs are required, a reservation mechanism is used where users are presented with links to the experiment on a first-come-first-serve basis.

vi. *Lab on Mobile Platforms:* Several RAL systems have tried and tested experiments from Mobile Devices [44] like smartphones. Mobile Devices pose a problem of being too compact and short on resources like internet speed and computational power. So it is difficult to recreate the same effects as that of a PC. Several technologies like SMS, HTML5, Java and Adobe Flash have been used to implement different prototype of experiments, but this method of distribution is still not very popular and majority of experiments are done through the PCs.

vii. *Pedagogy:* RALs has been traditionally seen as replicas of on-site laboratories and every effort has been made to make these activites look exactly like traditional laboratory experiments. Some RAL accurately replicate the actual instrument panels on the web pages [40] while others use simplified interfaces and in some cases an enhanced version of the experiemtn for e.g. in a 3D experiemnt interface that shows the experiment action with additional simulated elements (the magnetic fields) otherwise not possible in real laboratories [39] as a form of augmented laboratory reality. However, as mentioned in [4], "It's probably a safe bet that few, if any, engineering programs implement remote labs for pedagogical reasons…" RAL usually do not carry any additional pedagogical values. iLab and Labshare developers have studied the factors affecting the convertability of laboratories and experiments to RAL [1, 45, 46]. Students learning outcomes [47-48] with RAL has also been studied and found to be adequate.

C. Common Advantages of Centralized RAL Systems

All traditional RAL systems have been successful in their truest objectives of providing access to resources along with additional services. The advantages of all these systems are:

i. The experiments are designed keeping a particular course and curriculum in mind. In other words, the lists of experiments are equivalent to that of an on-site laboratory. Since they are hosted by universities, there are qualified personnel to maintain update, modify or add new experiments.

ii. All of the leading RLMSs have been used for teaching at in several courses. Each one has been used by more than thousand students over several years. This suggests that these laboratories have been successful in providing an alternative platform [3-4, 45].

iii. Centralized RLMSs have good technical support and are available as and when needed.

VI. CHARACTERICTICS OF RLMS AND THEIR SUITABILTY FOR STEM

While several developers have improved and worked on different aspects of the RALs such as user interface and experiment pedagogy, the core architecture has remained the same. Some of the similarities can be summarized as follows:

i. The current trends for developing RALs allow only experienced and expert developers to create an experiment. The experiment variety is hence limited and concentrated on particular fields of higher education.

ii. The instruments and devices used are mostly costly and complex to build and operate [49]. They use industrial standards such as GPIB, LXI [50] and PXI to connect the hardware to the computer servers. High performance software for engineering such as LabVIEW, VEE and MATLAB are also widely used to implement these experiment setups. Thus ‘Rig Operation’ remains a matter of high complexity in all RLMSs.

iii. The laboratory management systems are predominantly client-server in nature. All users need to log into a web address and provide user credentials to authorize access, select an experiment before utilising it. Any grid technology implemented is essentially limited to the server side of the architecture. The experiment configuration is also centralized and maintained under high-end laboratory conditions. All laboratories are designed to be operated for long periods and available to students all the time.

iv. There is very limited scope for collaboration among students in different geographic locations, and not typically available in RLMSs except for forums [7], although this issue has been given importance in some systems [40, 51-53]. There is also a trend to incorporate 3D user interfaces for collaborative learning purposes [37-39]. There have been multiple reports of 3D UI in various laboratories using different platforms, but it is not clear how many students have used these systems, although the positive effects on learning outcome have been reported [37].

v. The experiments are mostly concentrated on providing for engineering courses in undergraduate and graduate degrees. There appears to be little attention directed towards school level science education (STEM), which is rapidly becoming an important area for development using enquiry based learning methods.

The enquiry based learning methodology [54] in STEM requires students to analyse problems and find solutions by practical knowledge and implementation to understand the concepts. As such there can be an infinite number of different setups of rigs and devices that may be used for designing different concepts. Moreover with the school systems, it is the teachers and students who are more close to designing an experiment setup than experts who are already providing pre-setup rigs. But, with the above stated features for creating new laboratories is difficult for them.

There have been recent concerns on the slow adaption of remote laboratories with teachers [55] for their students. Faculty resistance to incorporate new technology in teaching and technical support issues have been cited as main reason behind underutilization of remote laboratory technologies. These reasons become more prominent if the rigs that are supposed to be used by teachers are actually designed by some other than themselves. Another study in Europe concludes that schools and teachers are very interested in remote laboratories, but are unsure how to integrate them into school curriculum [56]. This is mostly because they are incapable of fulfilling computational requirements in RAL implementations and the relevant pedagogical and technical concepts.

Since RALs are considered extended on-site laboratories, there curriculum and structure closely resembles the onsite laboratory. This is perfect of higher education where experiment have fixed nature and done with specific equipment and there is less room to 'play around' with the setup. On the other hand, in STEM education, while the list of objective may be static, the physical system on tends to be very flexible. The same kind of activity may be done with various setups to understand the STEM concepts behind it. These setups need to be built and used by students for effective learning.

In terms of RAL, a peer-to-peer system can address the problems of traditional RAL. Users may be both creators of experiments or share them with others and be user of other's experiments. Once individuals are enabled to develop and host an experiment it can create more flexibility on the laboratory providers’ side. The students using these laboratories may collaborate with each other on running the setup thus giving the users fresh views of the same problem that may be different from their own. These way new and interesting ideas about practical learning and enquiry-based learning methodology may be implemented.

School level children are capable of participating in this kind of activity as evident from recent initiatives taken to incorporate RAL activities into schools such as the robot-

RALly project [32]. A project with RAL at University of Southern Queensland was used to create enquiry-based learning activities and facilitated collaborative learning in the K-12 demography between elementary school children from Japan and Australia [33]. The study indicated that such technology can thrive in school environment also but will need transition from the client server to a peer to peer architecture where students can directly interact with others and their experiments.

CONCLUSIONS

RAL technologies so far have been confined to replicating the experience of on-site laboratories with great accuracy within a remote online environment to maintain equivalent learning outcomes. These laboratories consistently focus on the fields of higher education, but lack the capability of infrastructure support for STEM education and related physical activities. The resulting online learning tools mainly aim to resolve the resource constraints of universities. STEM education has other needs. Collaboration and hands-on experience of creating and running experiments are key requirements. The current features of RAL systems are complex and mark a barrier for individuals in schools with little experience in networking, computer systems and instrumentation. By using newer web technologies and the peer-to-peer access paradigm, RAL could provide much richer environments and experience for students remotely interacting with experiments and collaborating in joint activities in the context of STEM education.

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