An inverted remote laboratory - makers and gamers

Andrew D. Maxwell[a]; Lindy Orwin[b], Alexander A. Kist[a], Ananda Maiti[a], Warren Midgley[c] and Wu Ting[c].
Faculty of Health, Engineering and Sciences[a], Australian Digital Futures Institute[b] , Faculty of Business, Education, Law, and Arts[c], University of Southern Queensland, Toowoomba, Australia
Corresponding Author Email: andrew.maxwell@usq.edu.au

Structured abstract

BACKGROUND
Not enough children develop and maintain an interest in Science, Technology, Engineering and Maths (STEM) and as a result, there is a skill shortage to meet Australia's needs in STEM careers. An effective method for developing a deep understanding of STEM concepts is through conducting experiments. A project is introduced that aims to create an innovative and unique online system for developing children's STEM concepts using a quest-based game that incorporates remotely accessed laboratories (RAL). With the support of online experts, plans and guides, learners will be making and assembling experiments locally and interfacing them to the Internet so others can use them remotely. Communication and collaboration will be fostered through game-style guilds where young people can safely tap into the expertise of their peers and experts as well as share their own knowledge.

PURPOSE
The research aims to improve the quality of the RAL experience by conducting technical research to optimise the online experience for users and pedagogical research to improve communication and collaboration around the use of remotely accessed laboratories.

DESIGN/METHOD
A design based research methodology is being employed to develop and test a prototype of a scalable technical and communication system that will be evaluated in field trials conducted in schools and informal learning contexts. Refinement of the design will involve an iterative process informed by observations, interviews, expert panel review and usability testing as well as mathematical modelling and test bed simulation. Technical and pedagogical peer-to-peer models will be developed.

RESULTS
It is anticipated that preliminary evaluation of this system will indicate the technical requirements for an end-to-end maker based system. Evaluation of user trials will identify ways maker communities supported by gamified systems for communication, collaboration and motivation can contribute to the learning experience of others. Expert review and participant feedback will indicate if user generated content in the RAL space offers a significant mechanism to not only engage children, but develop access to more experiments.

CONCLUSIONS
Through this research project we will demonstrate the potential for alternative delivery models for RAL that are not necessarily restricted to large institutions. Through a change in the delivery method and development of RAL experiments, maker communities have the potential to broaden engagement in the remote lab experience. Gamification of the RAL experience has the potential to increase communication and collaboration between RAL users.

KEYWORDS
RAL, Remote Access Laboratories, remote access, gamification

Introduction

Not enough children develop and maintain an interest in Science, Technology, Engineering and Maths (STEM) and as a result, there is a skill shortage to meet Australia's needs in STEM careers (Masters, 2009; Thompson et al., 2008). Schools have an important role in developing and maintaining interest in STEM subjects so that more students are retained in the pipeline to tertiary STEM studies. As well as positive attitudes to STEM, school education needs to develop deep knowledge and appropriate skills across the range of specialist areas within STEM.

Conducting experiments is an effective method for developing deep understanding of STEM concepts and engaging students in experiential learning (George, 2003; Feisel & Rosa, 2005). Practical laboratory experiences also form an integral part of tertiary engineering education programs and are often seen as a requirement for program accreditation within Australia (Kist & Gibbings, 2010; Lindsay et al., 2011).

In order to meet the learning needs of a growing online student cohort, focus often turns to online toolsets such as Learning Management Systems (LMS) and Remotely Accessible Laboratories (RAL). The development and use of RAL technology to provide greater access to experiments is not new and is well established in engineering disciplines (Aktan et al., 1996; Corter et al., 2007; Tuttas & Wagner, 2001; Ma & Nickerson, 2006). Within RAL systems, there has been a focus on replicating the on-site laboratory experience as accurately as possible to maintain an equivalent learning experience and outcome. Also typically the person in charge of the actual experimental lab determines the pedagogical design of the experiment. Any other educator wishing to use the lab must adhere to the given set of data recording options or existing constraints.

This paper introduces a multi-disciplinary research and innovation project aimed at creating a unique a peer-to-peer RAL environment designed to develop school-aged children's STEM concepts and exploring opportunities to transfer these methods to tertiary engineering education. The ***RALfie Project – Remote Access Labs for fun, innovation and education*** (RALfie) is a joint venture between the School of Mechanical and Electrical Engineering and the School of Linguistics, Adult and Specialist Education at the University of Southern Queensland in Australia (RALfie, 2013). The project 'inverts' the current RAL paradigm of experiments being delivered to students as a service. With the support of online experts, plans and guides, learners will be empowered to make and assemble experiments locally that can also be used remotely.

This project has two dimensions: the development of the RALfie learning environment and the research surrounding its design, implementation and performance. The former comprises a web portal; a quest-based game interface; an online community of practice (guild); a technical system that addresses access, authentication and mediation; support materials; open education resources; and user generated content. The latter consists of a suite of research activities investigating the components of the project from three perspectives: technical; communication and collaboration; and curriculum and pedagogy.

Background

Remote access systems

Experimentation plays a key role in engineering curricula. Remotely accessible laboratories have been proposed to share hardware by accessing it from a number of locations within and between and institutions; e.g. remotely controlled robots (Kondraske et al., 1993) or control laboratories (Aktan et al., 1996). One of the key motivations to sharing resources are the perceived economical benefits (Ma & Nickerson, 2006). It has also been shown that remote access can fulfil many learning objectives for experimentation. There is also the potential to of additional benefits, e.g. greater flexibility for student access (Lindsay, 2005; Trevelyan, 2004).

Until recently, considerable effort to increase students' understanding of phenomenon and provide experiential learning has been restricted to highly expensive rigs specifically designed for particular learning outcomes. Institutions such as universities have hosted these. Extensive setup complexity for both delivery systems and experiments are often seen as a fundamental barrier to the uptake of RAL (Dziabenko et al., 2012; Turtle 2011). Other barriers include an "understanding of RAL and what it can do in an educational context, understanding of pedagogy in these environments, rethinking of learning tasks, learning activity development and pedagogical design, technical expertise to implement RAL activities, (and) time and effort required" (Kist, 2012).

Maker movement/pedagogies

One disruptive engineering education field experiencing explosive growth is the "Maker Movement". This allows students to learn how to actually do things and be actively engaged (Honey & Kater, 2013), rather than simply learn facts about a topic (Skamp, 2008).

This project will investigate expanding the learning activity beyond students simply "using" remote activities to them becoming "makers" of activities and sharing "rigs". This is a key learning opportunity not available in traditional delivery-only RAL systems. Expanding RAL by creating a "maker" community permits construction and integration of activities by many participants thus increasing the number of available labs. Making experimental rigs, interfacing them to the network and designing activities offers opportunities for deep learning of STEM concepts; development of knowledge and skills related to interfacing labs; and applies existing knowledge and skills in novel contexts.

For instance, one of the professional standards for Queensland (Australia) teachers (QSA, 2006) formally requires teachers to design and implement "engaging and flexible" learning experiences, where teachers become a key enabler to the success of these initiatives.

Gamification

Social processes, peer collaboration, and student-to-instructor discussion have been shown to greatly influence science learning in RAL and simulated activities (Corter et al., 2011). Presently, online students who are using RAL, are commonly studying in isolation with little or no collaboration or communication (Lindsay, et al., 2007). This research will investigate the use of gamification methods as a strategy to provide meaningful collaboration among participants. A quest-based game interface that incorporates an achievement system aims to provide a highly engaging context for the experiments to support intrinsic motivation and a system of points and badges for extrinsic motivation. The study will investigate the use of, game-style 'guilds' to foster online communication so that young people can safely tap into the expertise of their peers and a community of experts as well as share their own knowledge.

ICT and STEM

There is also recognition that the integrated utility of Information and Communications Technologies (ICT) in learning and teaching is an important pedagogical approach at all levels of education (Fetherson, 2007). Developing a sophisticated understanding of ICT in STEM is recognised as important for young students' success in an increasingly information-intensive world (Tytler, 2007). Additionally research has demonstrated that it is most effective if these skills have been established and fostered before students reach high school (Nelson, 2012). In order to achieve this, students must be engaged in STEM from an early stage to provide grounding in required technical knowledge. Through this, progression and aspiration towards a STEM-related career can be fostered to encourage uptake of these related subjects at higher senior and university level education (Mathers et al., 2011). The RALfie project involves children using ICT to interface their STEM experiments to the system and to access other people's experiments.

The RALfie learning environment

In order to identify the core functional requirements of the learning environment, consideration of the typical user groups will be explored to identify their expected interaction. Three target audience groups have been identified: ***users (school aged children)****;* ***technology savvy*** members**;** and ***teachers and parents***.

To the ***users***, RALfie will need to be a fun, challenging game with engaging and stimulating quests that involve both making and using real experiments. This would be supported by having a 'Maker Space' with openly available plans and guides; yet allow the choice and freedom to explore and invent through extensible activities. This content would be both user-generated within this project, as well as sourced from publically available open education collections. Users would be able to showcase their achievements through game-style systems involving badges and awards.

The **technology-savvy** group would be encouraged to populate the game-style guilds forming a community of practice, providing technical and learning support for the young investigators. This would be required to allow users to safely tap into the expertise of the technology savvy group as well as share their own knowledge through forums, videos and photo galleries. The guilds would be used to provide access to this pool of authenticated adult expertise in a range of science and technology fields.

To ***teachers and parents***, RALfie would provide an Internet-based, digital classroom in the form of a highly engaging, game-based, learning environment with custom-made quests intended to motivate young learners to delve into the built and natural world to create experiments and share them with others. Children and youth would be able to use RALfie to engage in formal and informal learning at school and at home. Through expansion of plan libraries and guides young makers of experiments can be supported with re-useable content. Where a teacher or parent is unable to assist, it is expected that children would be able to access just-in-time assistance and support through guilds where learners will safely tap into a wide community of experts and enthusiasts of all ages. The RALfie Project intends to assist in building the digital confidence and technology literacy of youth that goes beyond merely accessing Wikipedia and social media. It will be revealed that through learning how to interface experiments to the Internet, learners will develop deeper technical skills and understanding meeting the requirements of the new national Technology curriculum.

Methodology

The main aim of this work is to demonstrate the pedagogical and practical advantages of RAL-based experimental learning as a means of preparing Australian children for the digital future. This will be done through the integration of three specific technologies and methods to support this experience.

- Infrastructure and technology;
- Collaboration model; and
- Maker community approach.

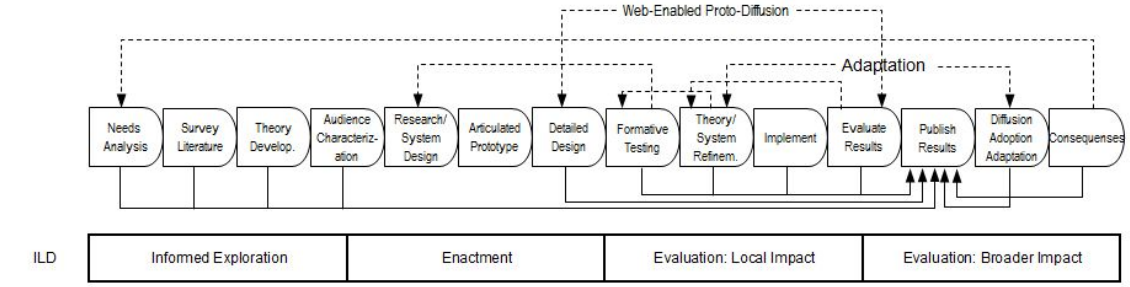
Specifically, whilst the project is research based, a supporting technological solution will be developed. In order to encourage the buy-in of relevant target audience groups, a model of collaboration will be developed using game-style guilds in which the expertise of the wider community of professionals, university academics and students, enthusiasts are safely brought together with the needs of learners.

The multidisciplinary project team will investigate three research strands simultaneously:

- A technical delivery platform and related network engineering research;
- Communications and collaboration through gamification; and
- A teacher professional development strategy.

For the overall project, design-based research is being used as it incorporates a range of processes into a single mixed methods approach allowing for various educational and

technical elements to be integrated and evaluated. The Integrative Learning Design Framework (ILDF) (Bannan-Ritland, 2003), see Figure 1, provides a comprehensive yet flexible framework for the overall project. The ILDF is a socially constructed, contextualized process incorporating field studies and experimental research for producing educationally effective interventions with a high likelihood of being used in practice. This method will be employed to develop and test a prototype of a scalable technical and communication system that will be evaluated in field trials conducted in schools and informal learning contexts. Refinement of the design will involve an iterative process informed by observations, interviews, expert panel review and usability testing as well as mathematical modelling and test bed simulation. Each of the three main research strands may also have additional specific methodologies to meet the needs of that particular strand's study.



ILD	Informed Exploration	Enactment	Evaluation: Local Impact	Evaluation: Broader Impact
Guiding Questions for Research	Questions: – What are identified gaps/problems in theory, practice and/or the marketplace? – What information can be gleaned from existing data or research? – How can we characterize the problem or leaner need? – What are the systemic social, cultural, and organizational influences or constraints on design? – What are characteristics of the audience?	Questions: – What are the learning targets for innovation? – What design principles or strategies may be applicable? – How to identify and operationalize cognitive and performance processes in design? – To what extent does the design embody the theoretical model?	Questions: – Is the enacted design usable, valid and relevant? – Is the design instance accessible and efficient in delivering instruction or supporting learning? – What is the local impact or effectiveness of the design instance? – How effective is the design solution in achieving learning targets at its highest fidelity in full context?	Questions: – What factors influence diffusion, adaption and adaption of innovation? – What are the pragmatic demands of the learning environment that influences adoption of design? – What policies and cultures shape participants use of innovation?
Applicable Research Methods	Methods: – Benchmarking – Performance/needs analysis – Interviews – Survey of Experts – Focus Groups – Observation/Role Modeling – Case Studies	Methods: – Task Analysis – Contextual Analysis – Designer Logs – Expert Review – Audience Review	Methods: – Usability Testing – Expert Review – Observation or Video records – Interviews – Formative Evaluation – Pre-post Comparative Studies – Quasi-experimental studies	Methods: – Analysis of computer log files – Multi-site interviews, surveys and Observations – Data mining – Correlational studies – Quasi-experimental studies

Figure 1: The integrative learning design framework

Peer-to-peer RAL system

A key aspect of the RALfie environment is that users can remotely access experiments that have been developed by makers. The purpose of the Peer to Peer (P2P) access system is to provide secure, authenticated, scheduled access to experiments via the Internet. Research that relates to this aspect of the project involves the overall system design, related performance modelling and evaluation and the investigation of specific technical issues such centralised versus peer-to-peer architecture.

This project will use a two-stage approach. Initially a technical trial system has been developed to allow for early testing with children as both makers and users; and to verify overall network design aspects and theoretical results. Later, a production system will be developed that will be opened to the wider community for use and extension.

P2P Architecture

The management system should allow users to join at their convenience. There are two kinds of interaction with the system - by learners (users) and providers (makers). Makers construct a rig and host them on local computers. Users are then able to use these experiments from a remote location.

In a move to a more decentralised model suitable for a “maker” community, a P2P overlay network architecture has been investigated. Prior work (Kist et al., 2013) has compared alternative overlay network architectures for real-time learning systems and was able to quantify how these impact on the average end-to-end delay. When examining Australia as an initial test case, this work showed that P2P style network design significantly reduced the impacts of delay (lag) compared to a centralised architecture.

User interface and instrumentation tool

The design and functions of the user interface (UI) and hardware has to be decided by the maker. Thus a UI design tool and instrumentation platform is required where the makers can create a static interface and may specify certain variable parameters for complex environments. For the initial trials, the native programming environment of kits will be used and control will be provided via authenticated remote desktop access.

Portal, repository for experiments and documentation

Although the learners and the providers interact directly, a centralised portal is the first point of contact. It allows users to search and book experiments, provides access to the gaming interface links to support tools and a repository to store experiment-related resources and documentation. It is planned that this portal will be developed using off-the-shelf software that is integrated and branded under a common theme. The design will be largely informed by usability and accessibility.

Technical research related to the peer-to-peer RAL system will employ traditional research methodologies including performance modelling, network simulation, test-bed implementations and usability tests with potential users. There is also a link to the educational research that occurs in other areas of the project.

Peer-to-Peer communication, collaboration and gamification

This research theme investigates the use of gamification of STEM learning with RAL to increase communication and collaboration between users, makers and their online community whilst also improving overall engagement with STEM. This approach builds upon existing quest-based learning approaches and guild-based communities of practice used in the games industry and increasingly in education (Haskell & Dawley, 2012). This will be achieved through the incorporation of a quest generation system that will integrate with other components of the technical delivery system for experiments. The game systems will be refined using iterative cycles with feedback from users, makers and guild members. The aim is to create a child-friendly system that not only contextualizes interfacing experiments to the Internet but also guides the creation of experiments that encourage users to group up, collaborate or share data and experiences.

Online community tools such as forums will be used to support the formation of guilds that provide the support community for makers of laboratories. Drawing heavily on the toolsets used by gamers, appropriate technology and service methods for asynchronous communication and collaboration will be integrated into the technical system to create a multi-functional environment with a focus on safe interaction within a community of practice.

Peer to peer pedagogy and curriculum

The project will research and deliver a support package to equip the participating teachers and parents with required technical and educational content and skills to use ‘RALfie’ experiments in their classrooms or at home. It will provide participants in the trial with clear methodologies and procedures for guiding primary and secondary school aged children in conceiving experimental activities and integrating them into the RALfie platform.

Ongoing Study (Results)

Trials and data gathering

In order to allow the development of the three strands of research, a multistep-tiered approach is being utilised. This will permit successive stages of both the technical and educational design to be refined and improve subsequent iterations.

A series of trials will focus on the technical specifications development; how to translate users through to makers; how to effectively deliver quest-based outcomes using these systems; and how to deliver teacher professional development and training to improve technical and pedagogical understanding of these systems and methods.

The trials design incorporates several stages, including:

- initial bench trials defining the technical specifications for experiment delivery;
- laboratory trial investigating laboratory users understanding of RALfie technical networking concepts, and of remote access methods;
- distributed technology trial involving home users, and home makers, introducing gamification strategies;
- distributed trials with education providers; and
- distributed open access trials with wider community outreach.

In addition to these trials, RALfie intends to explore the following:

- a model for online interaction to allow design and delivery of STEM based learning opportunities, across educational and technical themes to rural, remote and indigenous communities;
- creation of a bank of pilot RAL activity designs based on popular or open source platforms aligning to STEM curriculum relevant to the target audience (for instance LEGO Mindstorm (2013) NXT2 / EV3, Arduino (2013), Beaglebone (2013));
- creation of methods for linkage between gamification engine and real world experimental activities; and
- creation of a method for providing support through guilds and a knowledge base for all target audience members so as to provide a sustainable and scalable support experience.

Ethical considerations

In addition to the three research strands previously discussed, there are considerable complexities to be resolved where children interact with open online systems. A recent report on child safety on the Internet for the European child (Livingstone et al., 2010), indicated several key findings regarding online activity for children applicable to this project.

- 85% of 9-16 year olds use the Internet for schoolwork
- 83% of 9-16 year olds use the Internet for games
- 31% of 9-16 year olds use a webcam
- Children are going online at ever-younger ages
- 93% of 9-16 year old users go online at least weekly (60% every day)
- Risks and potential harm include experiencing something upsetting or harmful, or being bullied.
- 9% of children have met an online contact offline in the past year

These statistics clearly indicate an ever changing profile of online activity for young children, but also highlights the need for parental awareness and mediation. It also suggests that the target audience is capable of understanding key terminology and principles that will arise in this research. Whilst there is some evidence that children and parents receive advice on safe Internet behaviour and interaction, it is clear that a key philosophy of any system involving children is to create and sustain a child-safe environment and develop digital citizenship skills. This places an emphasis on the system invigilators to provide this as opposed to the end-user. This clearly raises key questions relating to:

- Ethical behaviour of system creators/administrators and publication methods regarding available content and appropriateness;
- Ethical requirements to maintain safe and secure environments; and
- Consequences of webcam and camera content streamed to online participants.

Findings/outcomes

It is clear that any system or research project involving the previously mentioned aspects demands a multi-disciplinary approach, where all facets of the project must intersect in order to be successful. STEM educational requirements for children will determine available quests. Authentication network modes will determine activity delivery models. The technical system has to integrate with the game and content system as well as deliver suitable performance to maintain user expectations. Teacher professional development will support teaching professionals in technical aspects, and curriculum integration.
Within typical RAL activities that have been pre-configured by an institution, skill sets tend to be restricted to observation, data collection, and relatively simplified actuation activities and experiences. It is expected that in moving towards a maker experience, children not only obtain experiential learning from the activity itself, but also very specific targeted learning, and competency in a wide range of additional topics, including but not limited to:

- information technology systems;
- mechanical and electrical construction methods;
- mechatronics, sensors and actuators;
- computer and systems interfacing;
- computer coding; and
- compliance with preset instructions, coding schemes, and standards.

The distributed system can allow many users to contribute to the learning aspects and number of experiments. But it poses potential problems:

1) The experiments are created by external users who may not be qualified to correctly develop scientifically accurate experiments.
2) There is direct interaction between the learners and the providers. A proper security measure must be in place to make sure data that originates during run time from the provider's end is legitimate and transferred to the learner's end without any manipulation.
3) There is an issue of quality of service in this distributed model as providers must specify and maintain time regulations and other constraints.

Conclusion

The authors have presented a methodology for the development of a longer-term 3 year study. This research project will investigate use of RAL technologies and game design in the development and testing of a technical system for teaching STEM curriculum concepts to children and youth in formal and importantly informal educational settings. The informal aspects of this project serve to provide the most significant impacts by providing a mechanism to access a wider target audience of both users and makers for the extension and expansion of online STEM curriculum activities. During the pilot stages of this project, a system will be built and tested to provide a prototype of an open, online, public education project that incorporates the use of Remote Access Laboratories for children who access them via the Internet. It will demonstrate to the formal and informal education sectors how communication and collaboration can be supported through gamification. It will also demonstrate an alternative, low-cost model for the development of remote access laboratories accessible by children in schools and at home.

Through this research, we demonstrate the potential for alternative delivery models for RAL that are not necessarily restricted to large institutions. Through a change in the delivery and methodology for RAL, maker communities have the potential to broaden engagement in the remote lab experience and increase communication and collaboration between RAL users.

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