Remote laboratories: enhancing accredited engineering degree programs

Euan Lindsay
Curtin University, Perth, Australia
e.lindsay@curtin.edu.au

Ben Stumpers
Curtin University, Perth, Australia
b.stumpers@curtin.edu.au

***Abstract**: Remote laboratories have been subjected to considerable scrutiny, as to their place in educational programs, since their original use in the early 90's. Since this time they have been the focus of academic research, and subsequent reviews, which show that they have potential advantages over traditional laboratories when correctly used. While these advantages are generally understood and agreed on, there is still some concern as to the impact they might have on the accreditation of existing programs. The body responsible for accreditation in Australia, Engineers Australia, takes a holistic approach to the accreditation of academic programs. In order to receive accreditation a program must satisfy all criteria within Engineers Australia's categorical assessment. This paper uses a criterion-by-criterion analysis to show that remote laboratories have no negative impact on any of these criteria and in some cases actually have a positive impact. Therefore the accreditation of academic programs containing remote laboratories are just as likely to have a positive outcome, assuming the laboratory is designed to embody the guiding pedagogical principles of the program in question.*

Introduction

Since their introduction, remote laboratories have become an increasingly credible addition to modern engineering education programs. The logistical and pedagogical advantages of providing remote laboratory access to students have been extensively documented and reviewed, leading to a general consensus regarding their role as educational tools. (Hanson et al. 2008; Nickerson et al. 2007). The advantages include spatial and time independence, the relative inexpensiveness of operation and the ability to easily reproduce experiments.

While originally slated as the "second best" option to a hands-on experience (Aktan et al. 1996), remote laboratories have since been found to provide considerable advantages compared to traditional hands-on laboratories. It has been argued that the time required to setup and teardown experiments commonly used in a traditional laboratory setup causes them to be particularly inefficient in terms of pedagogical outcomes. Alternatively, "it is pedagogically advantageous to conduct open laboratories where students can return later at their personal discretion and convenience to repeat and refine their experiments as required" as is the case with remote access laboratories (Esche 2002).

These include convenient access independent of time and space, the potential for resource sharing between educational institutions and the mitigation of safety issues for hazardous experiments.

Despite the considerable potential advantages of remote laboratories, concerns remain in the minds of many academics regarding their impact on students' learning outcomes, due to not having direct (unmediated) contact with the equipment(Nickerson et al. 2007). These concerns manifest at both the individual unit level as well as more broadly at the overall program level.

The learning outcomes exhibited by students exposed to a remote learning environment have since been investigated and it is now acknowledged that different access modes provide a different learning experience (Lindsay and Good 2005). It has therefore become common to offer multiple access modes over the course of an academic program.

The concerns regarding remote laboratories largely parallel the concerns regarding distance-mode delivery of engineering programs identified by Webster (2000), with the key challenge being that "careful consideration must be given to implementing rigorous quality assurance systems to ensure that the claimed equivalence of internal and external programs is matched".

Accreditation by Engineers Australia (EA) is one of these quality assurance systems, and it is a legitimate concern for academics and faculties considering the introduction of remote laboratories. It is possible for remote laboratories to be used to satisfy the EA accreditation criteria; this paper will highlight which aspects of the accreditation process are most impacted by the transition to the remote operation mode.

Engineers Australia Accreditation

Engineers Australia (EA) is responsible for assessing the competency of engineers throughout Australia, with the required graduate skills referred to as the Stage One Competencies. The analysis which forms the focus for this paper concerns the effect of remote laboratories on stage one competency.

For the graduates of Australian engineering degrees, assessment of the stage one competencies is handled through the accreditation of degree programs. Individual engineers who have not trained in Australia can apply to EA to have their qualifications recognised, with EA using their designated Stage one competencies as "a tool for direct assessment, in a generic sense, of the preparedness of a candidate not holding an accredited or recommended qualification for entry to the profession" (Bradley 2011).

EA uses 22 accreditation criteria to determine whether a degree program will lead to the acquisition of the stage one competencies. The criteria are divided into three categories: the operating environment, the academic programs and quality systems (Bradley 2011).

Each criterion has several performance indicators that are predefined by EA, which are used as an indication of the implementation of the criteria in an institution's educational program. These performance indicators give a key insight into the evidence EA expects for its criteria, without confining the approach that programs must take to achieve them. This 'guiding principle' theme EA forms in its accrediting process is reinforced by their holistic perspective of engineering programs.

Accreditation decisions are made based on how the criteria combine together to form an overall engineering degree, and how this degree eventually leads to an engineering graduate. In order to consider how remote laboratories can impact upon accreditation, it is necessary to first consider how they can impact upon each of the accreditation criteria, and then on how these combine to form an overall degree program.

Category One: The operating environment

The foundation upon which any academic program is based is arguably the biggest indication of its success. It is therefore not surprising that EA's first category of accreditation criteria concerns the institutions operating environment. The six criteria comprising the operating environment category are:

- Organisational structure and commitment to engineering education
- Academic and support staff profile
- Academic leadership and educational culture
- Facilities and physical resources
- Funding
- Strategic management of the student profile

Three of these criteria have either no direct relevance, or only marginal relevance, to remote laboratories. They include organisational structure and commitment to engineering education, academic and support staff profile and strategic management of student profile. The three remaining criteria have stronger links.

"Academic leadership and educational culture" includes the composition and quality of the teaching team, as well as the learning environment they try to foster. It has a key performance indicator directly relevant to remote laboratories, namely "*Progressive learning environment, based on a sound pedagogical framework and adoption of best practice*". Remote laboratories are a superior way of delivering learning outcomes such as exception handling (Lindsay and Good 2005), and as such their adoption is supported by this criterion.

The quality and appropriateness of facilities provided, as well as the provided access to modern resources is covered under "Facilities and physical resources" criterion. The performance indicators for this criterion include *"Appropriate experimental and project based facilities to support both structured and investigatory learning within the specified field of practice and specialisation."* The key is the interpretation of the word appropriate – well designed facilities will support these outcomes, regardless of mode. Remote laboratories being better suited to deliver specific projects, such as the exceptionally hazardous or expensive, enhance the academic program by providing students with the most appropriate facilities available.

The final criterion, "Funding", covers the planning, viability and budgeting of the program. While funding has often been used as a driver for motivating the deployment of remote access laboratories (Alves et al. 2005), it does not intrinsically support or prevent remote laboratories. The critical nature of funding and remote laboratories potential for alleviating funding pressures was also evident in a national survey of Australian universities (Kostulski and Murray 2010).

Category Two: Academic Programs

The second category of criteria, academic programs, scrutinises the learning outcomes, program structure and exposure to engineering practice provided by an accredited program. Academic programs is comprised of the following criteria:

- Specification of educational outcomes.
- Title of Program and award.
- Program structure and implementation framework.
- Curriculum.
- Exposure to engineering practice.

Of these five criteria "Titles of Program and award" has either no direct relevance, or only marginal relevance, to remote laboratories. The remaining four criteria have stronger links.

The "Specification of educational outcomes" criterion ensures that an engineering course has an intentional focus on a specific area of application and that this is reflected in the educational outcomes of a student completing the course. As part of the development of any good remote laboratory class it is necessary to make explicit the learning objectives of the experiment; this assists in ensuring that educational outcomes can be specified. Given the digital nature of a remote laboratories interface, the process of monitoring the progression of learning and acquisition of learning outcomes is potentially enhanced. In cases where this potential is realised the experimental setup can be reworked or refined, enhancing the ability of educators to focus student's efforts on the educational outcomes.

The ability of a program to cater to individual students learning abilities by providing alternate paths of course completion, while simultaneously assuring the quality of specified outcomes is covered under the "Program structure and implementation framework" criteria. One of the performance indicators for this criterion includes "*Flexible structure adaptable to student backgrounds and individual learning abilities*". Remote laboratories certainly allow for a more flexible delivery for students, and allows for the differing non-academic commitments that come from a wide variety of backgrounds to be worked around.

Remote laboratories provide exposure to new technology, that students wouldn't otherwise receive, and therefore can be viewed as relevant to the "Exposure to engineering practice" category. While remote access technology is not necessary or an integral part of all professional engineering practice, it is central to some. An example of this is shown in the development of Australia's mining industry (Duff et al. 2007). Given the large distances and potential for hazards inherent in mining, there has been increasing dependence on remote access technologies. Therefore given that a large pool of engineering students spends at least some time in this field, exposure to this technology as part of their education is beneficial, as well as relevant to EA accreditation.

"Curriculum" is the final relevant criterion in the academic programs category. The performance indicators for the curriculum are divided into three sections: knowledge base, engineering ability and professional attributes. Remote laboratories provide a significantly different learning experience compared to hands on or virtual access modes. Giving students the opportunity to operate equipment remotely effectively expands their knowledge base, enabling them to adapt more easily to future tasks involving remote operation. Enhancing an engineering student's knowledge base of relevant equipment and access modes also potentially expands their engineering ability.

Category Three: Quality Systems

The "Quality Systems" of a course are the process by which it is reviewed. The criteria for this category are:

- Formal processes for new program approval, development and amendment.
- Key external stakeholder input to continuous improvement processes.
- Student input to continuous improvement processes.
- Processes for setting and reviewing the educational outcomes specification.
- Approach to educational design and review.
- Approach to assessment and performance evaluation.
- Management of alternative implementation pathways and delivery modes.
- Dissemination of educational philosophy.
- Benchmarking.
- Formal processes for review and revision of an existing program.
- Student administration and support.

Of these criteria "approach to educational design and review" is marginally relevant to remote laboratories, while "processes for setting and reviewing the educational outcomes specification" and "management of alternative implementation pathways and delivery modes" have a stronger link:.

The educational design and review of a laboratory setup is required for the continual refinement and improvement of desired learning outcomes. Thorough review requires an investment of time and resources, and as such these are often only triggered when there is a change in hardware or in teaching staff. This opportunity is conveniently provided when designing a remote laboratory to enhance an existing program. Care must be taken to ensure that thorough reviews are appropriately executed, rather than the remote laboratory equipment simply being substituted for previous hands-on equipment in established lessons. The requirement of designing both appropriate laboratory equipment and lesson plans is stressed by remote laboratory sharing organisations such as Labshare, who provide detailed guidelines as to what newly developed experiments should include (Lindsay et al. 2011).

As part of the development of any good remote laboratory class it is necessary to make explicit the learning objectives of the experiment; a move to remote laboratories will make this explication part of the normal operating procedures.

The performance indicators for the "management of alternative implementation pathways and delivery modes" criterion include "*Adequate processes for analysing, monitoring and ensuring the equivalence of alternative implementation pathways and delivery modes.*" By their nature remote laboratories constitute an alternative delivery mode; provided they are adequately monitored they are not an impediment to accreditation.

Discussion

Of the 22 criteria comprising the three categories, three have marginal links and six have strong links to remote laboratories. It is also worth noting that of the remaining criteria, none are inherently negatively impacted by the inclusion of a remote access mode laboratory.

The operating environment criteria include three which are fostered by the inclusion of remote laboratories in a program. There is evidence to suggest that a program is drawn closer to EA's stated performance indicators of accreditation through the inclusion of remote laboratories in the operational environment. This is most notably apparent in the funding criteria, which as stated earlier is one of the key advantages of remote laboratories compared to traditional hands on laboratories.

Academic programs benefit from the inclusion of remote laboratories and are therefore just as likely, and potentially more likely, to gain accredited status. The key criteria affected by remote laboratories in engineering programs are related to educational outcomes and exposure to engineering practice. While further research is required to identify an exhaustive listing of learning outcomes which are affected by different access modes, it is currently accepted that there is an impact on learning outcomes. This implies that academic programs that make use of a range of different access modes, including remote laboratories, will give students access to a range of enhanced learning outcomes, rather than a focus on the outcomes exhibited by the exclusive use of a single access mode. As mentioned earlier the broader scope of access modes will also increase the exposure to engineering practice.

The analysis of EA's accreditation criteria has shown that while the inclusion of remote laboratories into an academic program has the potential to strengthen it overall, a program that relies on the exclusive use of a single access mode will likely be weaker as a result of prioritising one set of learning outcomes over another. In cases where remote laboratories are used the key factor is not the remoteness of a remote laboratory per se; rather, like any other learning experience, the critical factor is whether the remote laboratory is used appropriately. The quality of the laboratory and how it fits with the overall themes of the program are far more relevant than its access mode. When a new technology is initially implemented in an educational context it is appropriate for there to be initial scrutiny as to its appropriateness as a learning tool. A review of the EA accreditation criteria shows that there are no places where well-developed remote laboratories would prevent accreditation of an engineering degree.

Conclusion

The criterion-by-criterion analysis of remote laboratories shows that the majority of criteria are not affected by the inclusion of remote laboratories into the curriculum. Of those that are affected, there are many opportunities for a remote laboratory to be used to enhance a program's accreditation status. Well developed remote laboratory classes, which are carefully integrated into the overall curriculum, serve to enhance the overall degree program. Just as the EA accreditation is performed holistically over the entire degree, so should the development and deployment of remote laboratory experiences.

Remote laboratories have been researched, deployed and reviewed, and shown to be effective for meeting clearly identified learning outcomes. Ultimately it is the balance of these learning outcomes, and the mix of in-person and remote laboratories used to achieve them, that will determine the suitability of engineering degree programs for accreditation.

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