Factors that impact learning outcomes in Remote Laboratories

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Abstract: Remote laboratories offer new opportunities for students to engage in laboratory-based learning, providing both increased flexibility and opportunities for resource sharing. The move from face to face to remote laboratory classes can appear on the surface to be a simple change of access mode; however there are a wider range of factors at play in the changed learning environment. These have the potential to significantly affect students' learning outcomes – particularly if they are not taken into account in the design of the laboratory experience. In this paper we discuss a number of these factors, showing that the change of access mode is a much more complex change to the students' learning environment.

Introduction

It is readily acknowledged that the environment in which learning takes place, whether online or face to face, involves a complex array of factors that influence learner satisfaction and achievement (Stein and Wanstreet 2003). These factors, as they relate to the online learning experience, may include an understanding of the relationships between the user and the technology, the instructor and students, and the relationships among the students (Gibbs 1998). If it is acknowledged that the determinants of the traditional classroom experience are irrevocably changed, a significant resultant task is – how do we best assist students to be successful in such a learning context? The development of remote laboratories during recent times, particularly in the engineering educational field, has seen many course designers face similar hurdles to those of other researchers in the online and distance education learning environments.

As a part of the adoption process of remote laboratories into engineering curricula, various authors have made attempts to determine an appropriate list of "quality indicators" for the online engineering educational experience. These have often been linked with matters of implementation and design in order that the laboratory experience can be suitably evaluated. The challenge of identifying appropriate indicators in turn has been approached primarily from two perspectives, the first being relative to the expectations of students (e.g. Amigud, Archer et al. 2002; Cohen and Ellis 2002; Patil and Pudlowski 2003); and the latter being driven by course content (e.g. Mbarika, Chenton et al. 2003). A consideration of these indicators highlights some factors of commonality and importance that can be considered in the design of online laboratories and assessed during evaluation. These include the level and speed of interaction, clear articulation of expectations, timeliness of feedback, and access. Similarly, educational bodies have also recognised the need to address educational quality in online learning environments. The Sloan Consortium for instance has identified and adopted five key pillars of quality online learning to be utilised as a means for creating explicit metrics for online education and gauging progress in the field. These include *learning effectiveness, cost effectiveness, access, student and faculty satisfaction.*

In highlighting such factors and relating them to the remote access mode, it is important to note that implicit to this discussion is how these factors impact learning outcomes and whether or not the remote access modality actually enhances certain learning outcomes in (engineering) education, in comparison with its traditional face-to-face counterpart. From a broader perspective, simply referring to the literature to determine an appropriate answer is inconclusive. On the one hand, there is the proposition that there is no significant difference between the educational outcomes from students who performed an experiment remotely, versus those who carried out the experiment proximate to the equipment and apparatus (Imbrie and Raghaven 2005). Such findings are similar in orientation to the majority of research in web based learning (WBL) which has focused on WBL effectiveness compared with traditional classroom learning (Barraket, Payne et al. 2001; Bourne, Harris et al. 2005). According to a number of these studies, there is "no difference effect" in performance between students enrolled in the two environments (Ogot, Elliot et al. 2002; Ogot, Elliot et al. 2003; Tuttas, Rutters et al. 2003; Corter, Nickerson et al. 2004). The alternate view however proposes that students' performances on different criteria can vary depending upon the form of access used and that indeed some outcomes appear to be enhanced by non-proximate access modes, whilst others seem to be degraded (Lindsay and Good 2002; Taradi, Taradi et al. 2005).

Factors affecting educational outcomes

Discussion of modality then as an explanatory note regarding educational outcomes must relate to their intrinsically multi-dimensional nature in order to provide a more complete understanding of how learning is impacted, particularly as it relates to the provision of remote laboratories. Such factors provide possible explanations as to why remote and simulated laboratories may appear to do as well or better than traditional hands-on (i.e. proximate) laboratories in promoting certain educational outcomes.

Understanding Procedures and Time on Task

According to students' responses, a significant proportion of time and attention in traditional laboratories must be devoted to understanding the procedures to be followed and to setting up and taking down equipment. In turn, less of the students' focus can be given to developing conceptual understanding of how the data and relevant theories/concepts relate. However for students performing the remote and simulated based laboratories, the notion of increased exposure, in which there is more "time on task" during the data acquisition phase represents a significant advantage. In the technology enabled laboratory setting, there is a greater opportunity to collect data individually and in turn, students (presumably) have more opportunities to repeat experiments, vary parameters, observe their effects, and otherwise structure their own individual learning experiences. As a direct consequence, this should lead to an improvement in the development and assimilation of relevant knowledge in those students that are exposed to such laboratory formats (Corter, Nickerson et al. 2007).

Social and Instructional Resources

Students' use of social and instructional resources differs in the non-traditional laboratory formats (Corter, Nickerson et al. 2007). Many students in the simulated laboratories were relatively unhappy with the provided instructions on operating that technology and in turn more readily sought out the assistance of TAs, fellow students and instructors. The possibility of misunderstood instructions or a lack of (students') experience with the equipment aside, the relative success of the simulation labs in terms of learning outcomes may then be a result of students being forced to interact to a greater degree. As a consequence, there is a need to consider further the impact of the quality of instruction or the availability of instructor assistance, as well as the provision of access to asynchronous communication media (see Tutor Assistance and Group Work and Collaboration).

Student Preferences for Laboratory Formats

Of interest, student preferences for certain laboratory formats in some way reflect the advantages that are inherent to these access modes. For instance, remote laboratories are especially appreciated by students for their convenience, ease of setup and the relatively modest time required running the laboratory. Similarly, the unique advantages of simulation laboratories are reflected in their higher ratings for presence and realism measures, an outcome which is believed to be due to the perceived realism of the exercise as facilitated by the students' capability to interact with the display in the simulation, by changing views, sensor points, etc. With regard to traditional hands-on laboratories, there is some argument for a preference in the teaching of practical skills. Traditional hands-on laboratories may indeed represent the only feasible manner by which students can learn such skills and this may well explain students' ratings of proximate laboratories as having higher learning effectiveness versus remote or simulation laboratories (Corter, Nickerson et al. 2007).

Learning Style of Students

The style of learning employed by students plays a significant role in the educational pathway and teaching (Corter, Nickerson et al. 2007). Although it has not always been clear as to the causal relationship between learning style and academic performance, students are likely to be prone to certain learning preferences which ultimately impact their relative motivation and satisfaction in a learning environment. This includes the notion that a students' cognitive style can affect their preferences for educational media, including their interactions with hands-on versus remote laboratories. As such, effective pedagogy must employ a multitude of modalities that addresses various learning styles and preferences. In particular, instructional materials presented in a variety of formats that are aligned to student preferences are more likely to engage and maintain student attention and be conducive to learning.

One such model that has seen some attention in the literature regarding remote laboratories is the VARK Learning Preferences Theory. The VARK model supports the notion that there are four sensory preferences utilised by students including Visual, Aural; Read/Write, and Kinaesthetic. The use of the VARK in the literature regarding engineering laboratories has thus been predicated on its relative strengths. For instance, in an assessment of one hundred laboratories to establish a small set of properties that any successful web-enabled laboratory needs, Amigud, Archer et al. (2002) observed that VARK support was one of the top ten vital components of such laboratories. These authors contend that the VARK model is an appropriate model to utilise as students use different learning styles in their educational path. Latter work has considered how students' sensory preferences impact their interaction with laboratory access mode. Corter, Nickerson et al. (2004) correlated VARK subscale scores with various student preference and satisfaction measures to determine the possibility of students being kinaesthetically-oriented as relevant to predicting student success with remote laboratories. They found that a Total VARK score (claimed to measure comfort with multiple modalities of information) did predict higher ratings of effectiveness for the remote laboratories versus hands-on, and also predicted a lower rating of the importance of physical presence in the laboratory (as did the visual style subscale score). These findings replicated those of earlier work which concluded that remote laboratories may be especially appropriate for students possessing a highly visual or highly flexible learning style.

Prior Learning and Experience

The importance of prior exposure to information relevant to the laboratory experience of students has been highlighted in the work of Ogot. (2004). In this study, results indicated that there were significant differences between the remote subgroups that did and did not have an hour's access to do the pre-laboratory, with those that were provided with access performing better. The work of Bohne, Faltin and colleagues has also highlighted the importance of prior experience. Describing this quantity as "initial knowledge", these authors considered prior experience in terms of it being linked to the issue of self-directed learning such that a lack of relevant knowledge (in this case knowledge of Java programming) would equate to problems with self-directed learning and the need for special support from a tutor. Conversely students with experience in programming will be able to work mostly independently as their level of prior experience facilitates a degree of autonomous learning.

Tutor Assistance

A significant limitation in many remote laboratories is the lack of tutor assistance experienced by students (Bohne, Faltin et al. 2002). The importance of such a factor is accentuated in the learning environment of the remote laboratory particularly as social cues are not as prominent and there is not necessarily a high social relatedness between tutor and students (Faltin, Bohne et al. 2004). Although a distinct advantage of remote laboratories is that they provide students with the opportunity for self-directed learning in which independent, asynchronous, unsupervised access to hardware is the norm, it has been pointed out that the presence of an expert mentor is critical in the area of learning by doing. The laboratory setting provides an example of a learning environment in which instructional support can be critical to the learning process of students. In the remote laboratory then, the quality of instructional support (and initial knowledge) may serve as more important predictors for the motivation and task success of students versus any gradual difference in instructional method (Lindsay and Good 2005). However, this said, observations of how students work in a laboratory setting without tutorial assistance has shown that a combination of desktop sharing and video chat can be as effective as a support from a local tutor. Such a combination makes for a communication and collaboration framework that provides a high quality of instructional support in a remote laboratory with tele-tutorial assistance (Faltin, Bohne et al. 2004). Of course, it should be noted that the change from supervised to unsupervised learning in the laboratory setting facilitates a substantial effect upon the learning experience, an effect which Lindsay and Good (2005) have argued is above and beyond any difference that can be accrued to that of simply changing access mode.

Group Work and Collaboration

Of parallel interest is the issue of distributed group work. One of the characteristics of both distance learning and similarly the remote laboratory experience is that students often do not share the same space and therefore do not have the opportunity to share information to the same extent as their counterparts who work side by side in hands-on laboratories. Without support for communication, students undertaking a remote laboratory are faced with a very strong sense of isolation. In order to address this sense of separateness, there is a need to establish a social protocol through which students may linger, talk about their findings, help each other, and form collegial relationships. Such opportunities for collaborative learning in combination with active presence and users having complete control over the environment and the freedom to determine which action to take immerse students in a process of active learning. Aktan, Bohus et al. (1996) point out that the three criteria for a successful distance learning application designed for laboratory teaching include i) active learning, ii) data collection facilities and iii)safety.

In an attempt to determine how a collaboration process is related with meaningful learning in the laboratory context, Ma (2006) considered students interactions with their group members in both hands-on and remote laboratories. By focussing on time (synchronous and asynchronous), place (co-located and distributed) and collectivity of the group (how groups structure their work: individually or collectively) in order to capture the nature of group interactions in laboratories, Ma (2006) observed that different collaboration designs were adopted by different student teams. These designs included integrated collaboration, responsive collaboration and isolated collaboration as defined by interaction intensity and closeness between group members. The results of Ma's (2006) work suggest that many factors, such as geographic distance and relationship histories between group members, (which are less important in hands-on laboratories), may become critical factors in determining the way students communicate and collaborate in remote laboratories.

Research by Nickerson, Corter et al. (2006) also found that there was a great variability in the strategies employed by student laboratory groups toward remote laboratories. While some student groups would meet in a dormitory room and run the remote laboratories together, other groups would break up, run the experiments separately and then reconvene the next day to discuss the results. However, in this instance, the authors do not provide an explanation similar to that of Ma (2006), instead simply proposing that students much prefer communication between themselves regarding any problems they may encounter versus with faculty staff. Whether there was some impact due to the depth of relationships between students was not explored.

Corter, Nickerson et al. (2007) noted that differences in laboratory formats led to changes in group functions particularly in terms of coordination and communication between students. For example, students did less face-to-face work when engaged in remote or simulated laboratories as they usually ran laboratories individually in the data acquisition phase. In hands-on laboratories however, often only one student interacted with the laboratory apparatus, while the remainder of the group observed. Depending on what is considered to be the most important outcome of the laboratory (i.e. witnessing the actual physical experiment as in the hands-on situation, versus individual interaction and potential for multiple runs of the procedure as in the simulation and remote laboratory scenario), it is postulated that the latter reasoning may be an observed advantage in learning outcomes for remote and simulated laboratories. This said, the authors also propose that possibly most of the learning for a laboratory experience takes place after the actual laboratory session, when results are compiled, analysed and discussed. Given the separateness of students undertaking the remote laboratory, the provision of opportunities for co-operative learning in which there is group discussion and deliberations can be highly beneficial. However, the authors note that while most students perceive that group work aided their understanding, the combination of individual and group work may provide better educational outcomes. As an improvement on all-group work for instance, it may be best for the interactive hands-on experience of individual experimentation to be followed by group discussion of the results. In this regard the mix of individual and group work may be more important than the specific technology platform used.

Interaction

Implicit to any discussion of tutor assistance and group work and collaboration in the remote laboratory setting, is an understanding of interaction. Interaction has been noted as a defining and critical component of the educational process and context (Ng 2007) and has received much attention in the literature regarding learning theories with a particular focus on active learning that promotes an increase in learning effectiveness. In describing active learning, two contexts for interaction have been identified: individual and social. The individual context refers to interaction between the individual learner and learning material. The social context refers to interaction between two or more people and learning content, and supports collaborative theories of learning.

Interaction has commonly been addressed as a key issue facing program designers, particularly in the distance education field. In an attempt to improve the quality of the learning experience in distance learning environments and enhance learning outcomes and student satisfaction, many distance educators have incorporated collaborative learning methods among students. This is particularly in light of research findings that show that students benefit significantly from their involvement in small learning groups and that students are more motivated when they are in frequent contact with the instructor.

While the lack of face to face contact between instructors and students is perceived by many administrators and faculty as a significant drawback in the delivery of distance education, it has been observed that two way distance education systems which promote high levels of interactivity and user control are best suited to instructional needs (So and Brush 2006). Deep and meaningful formal learning then is supported as long as one of the three forms of interaction (student-teacher, student-student, student-content) is at a high level. The other two ways may be offered at only a minimal level or even eliminated, without degrading the educational experience. The term “equivalency of interaction” has been used to describe this perspective on interaction as it relates to online learning.

The effectiveness of the interactive learning experience however is not simply influenced by the level or form of interaction and is subject to a range of diverse and complex factors (Ng 2007). It has been argued that the essential determinants of the success of interactive, computer-enhanced learning environments include an increased level of participation on the part of learners and the creation of learning opportunities more aligned to the characteristics and preferences of individual users. This has been supported in other work which has found that ***student-teacher*** and ***student-student interaction*** is critical to successful online learning, whereby frequent, positive and personal interactions assist in bridging the communication gap created when face-to-face courses are moved online. Opportunities for high levels of participation were also seen as a key course design feature for promoting learning. In particular, courses which encouraged equitable exchanges of ideas, in which the contributions of all students were valued, were seen as the preferred option.

Mental Perception of Hardware

Students’ engagement with hardware which is present in front of them in a hands-on laboratory can be quite different to hardware which is located elsewhere such as in another room. This difference in engagement can significantly alter the nature of their learning experience (Yarkin-Levin 1983). Similarly, the feedback received by students can differ substantially between a hands-on laboratory versus its remote counterpart. While in the former instance, students’ interactions with the hardware is technology mediated, there still exists the opportunity for them to inspect the hardware itself minus this mediation. In remote laboratories however, all of the students' interactions including the processes by which they establish their understanding of the hardware, are moderated by the technology (DeVries and Wheeler 1996), leading to a situation in which the student may question the reality of the experimental experience (Lindsay and Good 2005). In the remote setting then, establishing trust that student-initiated actions are being relayed to the distant site is a prime concern in order to convey a genuine sense of actually being in the laboratory (Lindsay and Good 2005) and preserving student engagement. As students like to perceive and influence reality (Bohne, Faltin et al. 2002), the need to consider the issue of presence and more particularly how to address the critical challenge of establishing presence through the mediation of technology is of paramount importance (Aktan, Bohus et al. 1996).

Presence

The concept of presence has seen a great deal of attention in the literature regarding online learning environments and distance education, and is of particular relevance to the remote laboratory given the issue of separation of the learner and the equipment, and the impact this has on the learning experience of students (Tuttas and Wagner 2001). Such separation occurs in terms of both physical and psychological distance, with the literature on distance learning illustrating that both are equally important in determining the effects of separation, with the possibility that psychological distance may be more meaningful (Lindsay, Naidu et al. 2007).

Various attempts to explain the concept of presence have been made. The simplest definition of presence is that it is the sense of being in a place. However it is true to say that various other interpretations of presence have arisen over time in the literature. Most recently, Lee (1998) has defined presence as "a psychological state in which the virtuality of experience is unnoticed". Given these varied approaches to presence, it is important to note that in qualifying an individual's perceptions of others in a different place and time, two commonly discussed constructs in the literature on presence have included telepresence and social presence. **Telepresence** has been defined as involving a user's sense that remotely located people or machines are working as expected so that they can control them without being physically present at the place. Telepresence is particularly useful when working in potentially hostile environments (e.g. mines or underwater) or when performing difficult surgical operations (Mandernach, Gonzales et al. 2006). **Social presence** on the other hand has been defined as the degree to which a person is perceived as "real" in mediated communication. As communications media vary in their degree of social presence, these variations are important in determining the way individuals interact. The degree of social presence of a communications medium is determined by the capacity of the medium to convey information about various factors including non-verbal cues - facial expression, direction of gaze, posture, dress etc. In a remote or distance learning environment, establishing social presence is a more challenging task, although not impossible. A third construct, **Instructor presence**, has also seen some discussion, particularly given that it is central to a consideration of the effectiveness of online learning and is related to discussions of social presence. The importance of the instructor in learner efficacy can not be understated and instructor presence forms a key distinction between online versus traditional education (Garrison, Anderson et al. 2000). Whereas traditional instructors may readily utilise their physical presence to signal their active involvement with a class, online instructors can't afford such subtlety and must actively participate in the course to avoid the perception of being invisible or absent. Of course a sense of presence or feeling of community does not just occur in an online environment, nor can it be mandated by an instructor/facilitator. However, the instructor can play an important role in facilitating a sense of presence through the implementation of various strategies and techniques which serve to increase feelings of connection and belonging as students adjust and adapt to such an environment.

Conclusions

Remote laboratories offer new opportunities for students to engage in laboratory-based learning. The increased flexibility of access provides a solution to the logistical challenges of both students and institutions, enabling greater utilisation of limited resources. Whilst these benefits are usually ascribed to a simple variable – a change of mode – the reality of the situation is far more complex. The move from face to face interaction to a remote interaction involves changes to a wide range of elements in the learning environment. Many of these changes have already been shown to impact upon the learning outcomes of the students; many more are yet to be explored.

The reality of the situation is that a change to remote laboratory access is a sophisticated and complex shift – the single-dimensional variable, "Mode", is in fact an aggregation of a myriad of other important variables. Similarly there are a wide range of intended learning outcomes from laboratory-based instruction, each of which depends upon some or all of the (sometimes competing) facets of the learning environment.

Students' interactions with the laboratory-based learning environment constitute a complex system, and the design of these environments – whether remote or face to face – needs to account for the way in which the many important aspects interact. The simplistic model – shifting from "Face to Face" to "Remote" masks the true complexity of the situation, and compromises the potential educational value of remote laboratories. An awareness of all of the factors involved is necessary to get the full value from these learning experiences.

Acknowledgements:

Support for this publication has been provided by The Carrick Institute for Learning and Teaching in Higher Education Ltd, an initiative of the Australian Government Department of Education, Employment and Workplace Relations. The views expressed in this publication do not necessarily reflect the views of The Carrick Institute for Learning and Teaching in Higher Education.

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