A Survey of Issues and Approaches to Remote Laboratory Adoption by Teacher-Academics

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Abstract – Adoption is a key concern for those interested addressing the underutilization of remote engineering instructional laboratories (REIL). Lessons from related areas of technology adoption research are identified, presented, and related to REIL adoption. The REIL adoption perspective taken is that of the individual teacher-academic engaged in some aspect of engineering education which features laboratory work.

Index Terms – Remote laboratory, Educational technology adoption, Teaching and learning

I. INTRODUCTION

With the increased promulgation of remote laboratory initiatives around the world, questions regarding adoption of remote laboratories are naturally coming of interest. In particular, remote labs intended to support teaching and learning of engineering subjects are being constructed and deployed with presumption of use; yet, many of these remote engineering teaching laboratories remain underutilized. Increased remote laboratory utilization is synonymous with increased remote laboratory adoption. Adoption is a key concern for those interested addressing the underutilization of remote engineering instructional laboratories (REIL).

REIL are a class of innovative technology. Moreover, REIL represent a novel educational technology. The literature which specifically considers adoption of REIL is quite sparse. However, there is a great deal of literature which considers the general matter of technology adoption. Likewise there is a large body of work which considers educational technology adoption.

Two broad adoption perspectives are found within each of three rubrics. The organizational perspective and the individual perspective are addressed, alone or together, in the literatures of general technology adoption, educational technology adoption, and remote laboratory adoption. This paper is predominantly concerned with the adoption decisions that are made by individuals.

There are those who construct REIL. There are those who use REIL. In both cases, constructor and user, it would be beneficial to understand those mechanisms, imperatives, barriers, and incentives that drive the adoption of these technological creations. For the institutions that construct REIL, an understanding of adoption drivers should make it possible to improve the desirability of the REIL that they deploy. For the teachers that use REIL, an understanding of adoption drivers should make it possible to make appropriate choices as to whether a given REIL is suitable for use in delivery of some laboratory based learning curricula.

Whereas specific questions surrounding the matter of remote laboratory adoption for teaching and learning are still new and largely un-researched, questions regarding the general matter of technology adoption and the more particular matter of technology adoption for educational purposes are long studied.

For those interested in REIL adoption, it is a worthwhile exercise to see what can be learned, borrowed, and applied from the research which comes from general technology adoption and from the more specific research of technology adoption to support teaching and learning. With lessons obtained from related work that has gone before, a clearer conceptualization of the problems to be associated with REIL adoption can be had and a fruitful research program for REIL adoption articulated.

The contribution of this paper: i) identification, selection, and analysis of related work found in the literature of technology adoption and the literature of technology adoption for educational use; ii) use of the analysis to show that a number of conclusions from these related research tracks are applicable to REIL adoption.

The paper is organized as follows: section II discusses general technology adoption; section III discusses educational technology adoption; section IV discusses remote laboratory adoption; section V is the discussion; section VI is the conclusion.

1. Why Investigate REIL Adoption?

REIL have been around since at least 1996 [1]. There are more REIL at present than ever before and still more REIL are being built with an ever increasing diversity of subject matter [2]. There are conferences where REIL come under discussion. There are journals where research papers regarding REIL are published. There are government-funded initiatives to create infrastructure for nationwide sharing of REIL [3]. There are international consortia being created in which REIL figure prominently [4]. There are REIL actively employed for teaching and learning [5,6]. By these indicators, it is clear that REIL are of widespread and growing interest. A widespread and growing interest,
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Contemporary engineering instructional laboratories typically exist in one of three modes: proximate; virtual; and remote. Proximate labs are ‘traditional’ labs in which the apparatus and engineering student are co-located in a physical facility. Virtual labs have mathematical simulations represented within a computer; there is no apparatus. Remote labs have physical apparatus that are made available to the engineering student across a network; the apparatus and the student are independently located. For some, proximate labs remain the ‘gold standard’ against which the other modes are judged; e.g. [7], yet there are conditions in which research has shown other modes to be superior with respect to certain learning outcomes [8].

There are two good reasons that make REIL adoption a topic of interest:
- underutilized capacity
- unrealized opportunity

Underutilized capacity means that there are REIL that have been deployed but which do not receive full utilization: that is to say, there are REIL that sit idle. Increased adoption of REIL is a mechanism by which underutilized REIL become more fully utilized.

To date, there is no comprehensive survey of REIL utilization exists of which this research is aware. Nonetheless, there is ample anecdotal evidence that suggests underutilization is the case. Note in particular a number of papers that make reference for the need to encourage uptake or foster sustainability of REIL e.g. [2,9].

Unrealized opportunity is less obvious than underutilized capacity but unrealized opportunity is perhaps a more important motivation for the need to study REIL adoption. REIL represent a new medium for teaching and learning. This new medium has already been proven to be more effective than proximate or virtual labs at attaining certain learning objectives [8]. Where REIL are known to be more effective, yet are not being employed, is an unrealized opportunity. Furthermore, as REIL are relatively new, there may be more opportunities that are as yet unknown but that will only become apparent with usage and time [10]. Thus unrealized opportunity represents another important reason to study REIL adoption.

2. Research Perspective

The research perspective chosen for this investigation is that of the individual teacher engaged in delivery of laboratory-based curriculum to university engineering students. There are a number of reasons for choosing this analytic position as a lens through which to consider the matter of REIL adoption. A clarification of this position is followed by the motivating rationale.

Clarification

The individual teacher-academic is the focus of this research. Teaching occurs at the university level. The subjects taught are engineering subjects. The engineering subjects taught ordinarily feature laboratory work. Furthermore, this research regards:
- the decision making of individuals; not organizational decision-making.
- teachers; not students; not administrators; not support personnel.
- teaching and learning; not research; not commerce.
- stated choice, not revealed choice.
- engineering education.

Motivation

The motivation for selecting this analytic perspective is manifold. Most significantly, it is the teacher who employs the laboratory in a pedagogical context. Irrespective of where in a decision hierarchy the decision to adopt is made, it falls upon the teacher to put the laboratory to use for teaching and learning. At the university level, teacher-academics do have some manner of say about which tools and strategies they will employ as individuals in the preparation and delivery of subject material.

REIL, of course, are developed and deployed to support teaching and learning in the engineering disciplines. It follows that research on REIL looks most closely within the bounds of engineering education.

Education itself is a specific mission that differs in kind from either commerce or research. This, too, motivates and sets bounds on the present research.

II. TECHNOLOGY ADOPTION

The general matter of technology adoption is a long studied matter within a range of disciplines which consider important the uptake and subsequent use of a newly introduced technology. A number of theories have emerged through the years that attempt to understand, explain, and/or predict patterns of adoption.

Technology adoption is often considered from a societal perspective, organizational perspective, and/or an individual perspective [11-14]. The present research is concerned with individuals – teacher-academics – so this part of the discussion will focus predominantly on theories of technology adoption with an emphasis on patterns of individual adoption.

There are quite a litany of theories that address technology adoption; too many to consider in the context of this present work. Three exemplars which tie nicely into the purposes of the present research are: i) diffusion of innovation; ii) technology adoption model (TAM); and, iii) unified theory of acceptance and use of technology (UTAUT).

1. Diffusion of Innovation

Diffusion of innovation (DOI) is a theory of technology adoption that attempts to explain the penetration and spread of a innovative technology throughout a society or culture [14,15]. This theory has been undergoing development since around the turn of the 20th century. Among the
features of this broad-reaching theory include a characterization of individual adopters. Individual adopters are characterized as 'innovators', 'early adopters', 'early majority', 'late majority', or 'laggards'. Each class of adopter, as characterized, has a particular attitude towards adoption, along with a set of corresponding needs with respect to the adoption of innovations.

2. Technology Adoption Model

Technology adoption model (TAM) is a theory of individual technology adoption that attempts to explain decisions of individuals to use – or not to use – a given technology according to a simple dichotomy. TAM asserts that two key individual-is-likely-to-adopt-some-technology indicators are 'perceived usefulness' and 'perceived ease-of-use' [13,16]. TAM is appropriately criticized for lack of rigor but the theory has a lengthy history and continues to receive attention and application [16]. Among the criticisms of TAM is that, to some degree, it states the obvious. If an individual perceives a technology both easy to use and useful then, of course, there is a greater likelihood of adoption than if the technology were perceived difficult to use and useless. An accompanying complaint is that TAM says nothing about how to go about creating the desirable perceptions: i.e. what makes a technology easy-to-use and useful? Still, even without guidance on intervention and lacking in rigor, TAM still provides a well-known platform for discussing technology adoption decisions of individuals.

3. Unified Theory of Acceptance and Use of Technology

Unified theory of acceptance and use of technology (UTAUT) is another theory of individual adoption (and use) of technology [17]. UTAUT emerged in 2003 and is the result of scholars reducing a collection of complementary (and sometimes competing) theories of individual adoption to a single unified theory. UTAUT asserts that there are three contributing factors to an individual’s decision to adopt a technology. These three factors, together, are shown to account for approximately 70% of the variance in adoption decisions. The three UTAUT factors shown to influence behavioral intention towards a technology are: i) performance expectancy (i.e. will the technology help get a job done); ii) effort expectancy (i.e. will the technology take much work to employ); and iii) social influence (i.e. peer environment pressures). Where a technology is perceived to improve job performance, perceived to have acceptable level of effort to employ, and has the good word of colleagues, that technology will more likely be adopted by individuals. The converse is also true.

TAM is counted among the eight theories of individual adoption combined into UTAUT. UTAUT has the benefit of additional rigor and better predictive success than TAM [17]. Despite this, UTAUT has not displaced TAM. TAM remains very much a part of the technology adoption theoretical landscape [16] even though UTAUT has analogs to the TAM measures; i.e. performance expectancy in UTAUT maps closely to TAM’s perceived usefulness; and effort expectancy in UTAUT maps closely to TAM’s perceived ease of use. UTAUT is ‘better’ but TAM is ‘more popular’; hence the inclusion of both in this discussion.

DOI, TAM, and UTAUT are three theories that have something to say about the general matter of individual technology adoption decisions. DOI provides a taxonomy of adopter types (innovator, early adopter, early majority, late majority, and laggard) along with the guidance that adoption drivers will differ among the types. TAM provides a well know dichotomous vocabulary for discussing individual adoption (perceived usefulness, perceived ease of use). UTAUT provides rigor missing from TAM and further adds social influence as a contributing factor of individual adoption decisions.

DOI, TAM, and UTAUT are all general theories of technology adoption. From these theories is learned, first, that there are different types of individual adopters, each type with its own balance of adoption imperatives, and, second, that the general drivers for adoption of a given technology include a mix of three elements. These three elements are perceived usefulness (performance expectancy) of the technology; perceived ease of use (effort expectancy) of the technology; and social influences surrounding use of the technology.

There are lessons, then, to be learned from general theories of technology adoption. General theories, however, are general and there are additional lessons to be learned from domain-specific research into technology adoption by individuals to support teaching and learning. It is to this matter this discussion turns next.

III. EDUCATIONAL TECHNOLOGY ADOPTION

Technology has long been part of the education enterprise infrastructure. Technology for active delivery of teaching and learning (educational technology) is far less prevalent. Technology for infrastructure exists in such forms as systems for admissions and records; financial systems; and asset management systems. Educational technology, technology used for teaching and learning, includes such things as classroom-situated computer-based learning programs; distance learning technologies; learning management systems; and remote laboratories. Whereas use of infrastructure technology is ubiquitous, the use of educational technology (for purposes other than distribution of materials and email) is comparatively sparse [18].

The minimal penetration of educational technology into ordinary use by teachers for delivery of teaching and attainment by students of learning objectives to students is a puzzle to many given the financial outlay expended to facilitate and encourage such use. There is an ostensible (financial) commitment to educational technology yet the tangible result (actual use relative to outlay of capital) is an ongoing disappointment [18].

There has been a great deal of research regarding the adoption of educational technology by teacher-academics in
higher education (e.g. [18-26]. A number of themes are recurrent in the literature; among the more notable themes are faculty resistance and the unique character of necessary support needed for successful incorporation of educational technology into the classroom. One piece of research in particular [22] sheds light on the faculty adoption cycle and is worth mentioning in this present context.

1. Faculty Resistance
   There is a general resistance on the part of individual faculty to incorporate technology into ordinary teaching practice [23,26]. An exception is the use of learning management systems (e.g. Blackboard, Moodle, Sakai) for distribution of course materials and, of course, email. The general resistance is attributable to the need of teachers to rethink and revise their pedagogical approach [23]. New technologies require new ways of teaching and developing a novel pedagogy (when the extant approach seems to be working) is often an over-onerous task for teacher-academics that already face an overcommitted schedule. [18] goes so far as to say that until teaching practice changes, technology will not make significant inroads into ordinary teaching (other than for distribution of material and email). To overcome teacher resistance, a more robust support strategy is needed.

2. Support Issues
   Incorporation of technology into teaching practice requires a different sort of support than ordinarily provided by a normal IT helpdesk [19-21]. The sort of support that teachers need to incorporate novel technology into ordinary practice goes beyond having a tech available to troubleshoot a faulty installation or an operator available to reset a password. Teacher-academics need institutional support, peer support, and pedagogical support (all of a certain kind) to increase the likelihood of educational technology adoption. Institutional support in the form of time allotted for the purpose of assimilating the educational technology into teaching practice. Peer support in the form of collaboration around the use of the technology as well as peer mentoring. Pedagogical support in the form of domain experts and education professionals to assist in the preparation of assignments, assessments, and learning objectives tailored to the teaching use of the technology in question.

3. Faculty Adoption Cycle
   Emergent from a Grounded Theory investigation, [22] proposes a five technology-adoption model for teacher-academics. The five phases are: i) time commitment; ii) competence development; iii) course design; iv) teaching and learning experience; and v) reflection. Time is needed by teachers to understand and incorporate an educational technology into ordinary practice. The teacher must develop competence with the technology before the technology can be put to use. Novel educational technology often requires novel course design. The course design must be put to the test in situations of actual teaching and learning and the experience gained applied to refinement of future iterations. Reflection is the introspective assessment of practice that engenders improvement to practice (see [27] for a thoughtful consideration of reflection-in-practice).

Research regarding educational-technology-adoptions-by-individual-teacher-academics suggests that faculty resistance is an issue that interferes with uptake and utilization of novel technologies in the normal course of teaching practice. Among the strategies for overcoming faculty resistance include providing the ‘right’ kind of support. The ‘right’ kind of support includes such things as organizational leadership, training and skills development, peer-encouragement, pedagogical help, and adequate time. These are seen as important factors influencing educational technology adoption patterns of individual teacher-academics. A five-phase faculty technology adoption cycle, just discussed, provides a descriptive conceptual framework.

IV. Remote Laboratory Adoption
   Among other things, a remote laboratory is an educational technology. Whereas there has been a great deal of research on technology adoption (in general) and on educational technology adoption (more particularly), there has yet been rather little research conducted on the quite specific matter of REIL adoption. The papers on REIL adoption that do exist tend to offer adoption advice based on experience [28,29].

   For example, PEARL was a European Union funded initiative to develop and evaluate effectiveness of remote teaching labs in practice. Four remote labs were deployed for study; two sciences (physics, biochemistry) and two engineering (manufacturing, electronic). Based on experience and observation, the author identifies a number of issues to be addressed if remote labs are to be widely adopted. The experiential (rather than empirical) suggestions include: the importance of learning objectives; choosing appropriate laboratory modality (i.e. proximate, remote, virtual); fitting remote laboratories into the larger educational context; performing sound cost-benefit analyses; and ensuring that remote laboratories score well for both usability and accessibility [28].

   A recently completed national survey of practical laboratory education in Australian undergraduate engineering programs included some general questions regarding the ‘familiarity and potential’ of remote labs for adoption [3]. Simple awareness is among the issues identified that may be a potential barrier to remote lab adoption. Some 30% of respondents had not yet heard of remote laboratories. Among those that had heard of remote laboratories, understanding of the concept was of varying quality with some unable to distinguish between virtual labs (computer simulations) and remote labs (real apparatus remotely controlled). When asked to remark on the possibility of remote laboratory adoption, many (teacher-academic) respondents pointed to pedagogical effectiveness as being a key consideration.

Session GOLC1
V. DISCUSSION

REIL are a technology. As such, research regarding the adoption of remotely accessible instructional laboratories can benefit from research that has considered the general matter of technology adoption. Technology adoption theories such as the diffusion of innovation, the technology assessment model, and the unified theory of acceptance and use of technology have produced results that are relevant to those interested in remote laboratory adoption. Among these results are the observation that individual technology adopters can be classified as innovators, early adopters, early majority, late majority, and laggards, and that the different types have different priorities and motivational needs. Furthermore, to increase the likelihood of technology (REIL) adoption, the remote lab in question needs to be perceived as useful and perceived easy to use. Positive social influences with respect to REIL (e.g. good REIL reviews from colleagues) will additionally improve adoption chances.

REIL are an educational technology. As such, REIL adoption investigations can benefit from research that has considered the matter of educational technology adoption. The educational technology adoption literature is extensive. Among the results from this literature that speak to REIL adoption are the importance of overcoming faculty resistance. That an important means of overcoming faculty resistance is by providing the ‘right’ kind of support. For REIL, this support would include such things as: pedagogical expertise to assist with REIL exercise design and alignment of REIL work with learning objectives; competence training for each REIL to be employed in teaching; peer-interaction with colleagues that have experience utilizing REIL; and provision of sufficient time to learn the REIL and incorporate its use into ordinary teaching practice.

The five phase faculty adoption cycle, emergent from a Grounded Theory investigation of educational technology, should pertain also to REIL adoption. REIL adopters will cycle through the phases of i) time commitment; ii) competence development; iii) course design; iv) teaching and learning experience; and v) reflection with respect to REIL.

REIL are a particular sort of educational technology, unfamiliar to many and misunderstood by others. REIL adoption will be served by raising awareness that REIL exist and clarifying, just what exactly, a REIL is. Beyond awareness and clarity, the importance of pedagogical effectiveness is a key concern for teacher-academics considering the possible adoption of a REIL for teaching purposes.

VI. CONCLUSION

The contribution of this paper is to identify and draw forth a number of specific issues learned from other research into technology adoption that are relevant and applicable to the matter of REIL adoption. These issues point us towards numerous areas that would benefit from further consideration. The first of these is the development of a clear taxonomy of characteristics that capture the key differentiating aspects of remote engineering instructional laboratories and hence can form the basis of decisions regarding their relevance or suitability, as well as potentially forming the basis for decisions in other areas such as apparatus design. A subsequent research focus will include empirical investigations into the identification of which of these characteristics are perceived as relevant to teacher-academics when making REIL adoption decisions. This can potentially be taken further into supporting the design of remote laboratories that are most likely to exhibit characteristics that lead to appropriate adoption.

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