Literature Review

Remotely Accessible Laboratories – Enhancing Learning Outcomes

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Abstract

It is readily acknowledged that within any learning environment there are a complex array of factors that influence learning outcomes and learner satisfaction and achievement. The recent move to remote laboratory experiences sees the introduction of an environment with additional factors for consideration by course designers. Given that the field is relatively young and experimental in nature, much of the focus in this area has been on the development and implementation of laboratory infrastructure, with the corresponding evaluation framework being focussed predominantly on student and faculty satisfaction with this process, rather than learning ourcomes. Concurrent with this approach, attempts to develop a set of standardised criterion for the evalution of these laboratory experiences (particularly in terms of the extent to which they support student learning) have only been made by a few notable authors although for the most part this still represents a key challenge to be further addressed.

One of the critical factors impacting upon the difficulty in evaluating the success or otherwise of remote laboratories is the lack of clear objectives for engineering laboratory experiences. Many educators, when developing both proximal and remote laboratory experiences, have either not explicitly defined learning objectives or have only done so in terms that make it difficult to assess whether those objectives have been achieved. Another factor worth noting is the lack of agreement as to which of the three laboratory formats (i.e. traditional hands-on or proximal; simulation; and remote hands-off) is more efficient and best facilitates effectiveness in student learning.

The literature which does exist on remote laboratory evaluation is somewhat contradictory. While some research has shown that there is no discernible difference between students performing an experiment in person versus students performing an experiment remotely, there is other evidence that students' performances on different criteria vary according to the form of access used. Further to this point, recent literature suggests that for certain educational objectives certain technologies, when coupled with associated coordination processes, may achieve educational goals more effectively.

IF we move beyond simple achievement of learning outcomes, we can investigate the relationship between these outcomes and the the particular characteristics of the different access modes, and in particular whether the remote mode enhances certain learning outcomes rather than others. Various factors have been observed in the literature as being of significance in this regard. Some of these issues such as the separation of the learners and the equipment, and the impact of presence and the type of interaction on the nature of the learning experience of students, have been previously considered in the literature on Distance Education. However in acknowledging this previous work, the literature on remote labs is generating a discussion of related issues that may serve as possible explanations as to why remote (and simulated labs) appear to do as well or better than traditional hands-on labs in promoting understanding of course concepts. Such factors include the importance of the level of tutor assistance, the learning styles employed by students and the benefits of prior learning and experience to students' educational experiences.

The development then of a prescribed evaluation framework for remote lab education has seen many researchers adopt descriptive research designs commonly in use prior to the advent of remote labs. These have typically included pre and post knowledge tests to measure learning effect as well as student surveys and faculty feedback on "identified" quality indicators of the online experience. Although some instances exist where researchers have utilised a pedagogical framework to underpin their investigations, there is opportunity to further link such research with work already conducted in other fields such as distance education and e-learning. This is particularly so given that a number of learning theories and approaches (e.g. social presence theory, social constructivism, transactional

distance theory and learning space theory) have arisen to underpin this literature and may prove of some assistance in terms of a framework that the engineering education community may adapt to guide its own assessment and evaluation efforts.

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). How best to assist students to be successful in such a learning context is a significant task, as the determinants of the traditional classroom experience are irrevocably changed. Learning activities as applied to the online learning environment must take into consideration group dynamics, social interaction and instructional technology (So and Brush 2006) with course designers having to address major challenges such as the increasing time for delivery of the course, creating a sense of online community, and encouraging students to become independent learners (Wiesenberg and Hutton 1996).

The development of remote engineering educational laboratories during recent times has seen many course designers face similar hurdles to those of other researchers in the online and distance education learning environments. One of the distinct challenges implicit to this process is that the literature is either spread across many fields (Amigud, Archer et al. 2002) or is focused in Engineering (Ma and Nickerson 2006). The reasons for the later phenomenon are varied, with Ma and Nickerson (2006) observing the following reasons as to why much of the literature appears to be focussed in the Engineering domain:

i) Engineering is an applied science and laboratories are a place to practice the application of scientific concepts;

ii) Engineering educators are more likely to create technology enriched laboratories; and

iii) No off the shelf remote laboratory systems are currently available and therefore educators who desire them are more likely to develop these themselves if they have the skills.

Certainly it may be argued that this is indicative of the significance of laboratories to the teaching-research nexus in this discipline.

Other factors worthy of a more detailed consideration will be discussed in the following sections.

1.0 Assessment of Online Laboratories

The establishment of criteria for the structured assessment of remote laboratories is still rare in the literature (Amigud, Archer et al. 2002; Sicker, Lookaburgh et al. 2005; Ma and Nickerson 2006); and provides an indication that the field is relatively young and experimental in nature (Sicker, Lookaburgh et al. 2005). The work by Amigud, Archer et al.(2002) is a point in hand. Having assessed one hundred laboratories from fifteen disciplines, (Amigud, Archer et al. 2002) observed that while 71% of laboratories have a clearly defined educational goal, only 22% assess their students' performance. Furthermore, whilst many laboratories (72%) acknowledged the importance of student assessment and readily possessed an assessment feature, more often than not such a feature was only a recent addition, having for the most part been developed within the last four years.

1.1 Quality Indicators:

While it has been observed that the majority of work regarding the application of remote labs does not in general go beyond a cursory assessment of educational outcomes (Sicker, Lookaburgh et al. 2005), it is acknowledged that a framework for the evaluation of the lab experience is critical, particularly in ensuring that the effectiveness of the implementation is measured suitably and to assist in the design of the remote laboratory (Imbrie and Raghaven 2005).

To this end, attempts to address matters of implementation and design have been concurrent with the desire for the achievement of quality in online education and have proven motivation for various authors to endeavour to identify quality indicators for online engineering education and their importance, as perceived by students and faculty in measuring the success of the online experience. The challenge of identifying appropriate quality indicators has been addressed from two perspectives then, the first being relative to the expectations of students (e.g. Amigud, Archer et al. (2002), Patil and Pudlowski (2003); Cohen and Ellis (2002) and the latter being driven by course content (e.g. Mbarika, Chenton et al. (2003). A consideration of these prescribed lists of essential characteristics (see Table 1) highlights some factors of commonality and importance that can be considered in the design of online labs and assessed during evaluation. These include the level and speed of interaction, clear articulation of expectations, timeliness of feedback, and access (Imbrie and Raghaven 2005).

TABLE 1: Essential Characteristics for Online Engineering Education

Amigud et al. (2005)	***Mbarika et al (2003)***	***Patil and Pudlowski (2003)***
• Clear goal statement • VARK support • Interactivity • User guide • Quick to download • Website easy to navigate • Aesthetic appeal • Chat function • Links to helpful ancillary information • Accomplishment of goal verified by student test results	• Timeliness • Learning • Quality • Teamwork • Oral and written communications • Incorporation of leading edge technologies	• User friendliness • Appropriate engagement for self motivation • Simple web delivery methods • Learner centred focus • Opportunities for learners to test theories • Facilitation of active learning • Facilities for self-assessment throughout the learning process.
Cohen and Ellis (2002)		
Factor 1: Instructor-Student Interaction • Connection with professor • Effective instructor-to-students communication • Effective student-to-instructor communication • Feedback clear, timely and meaningful • Expectations clearly articulated	***Factor 2: Student-Student Interaction*** • Connection with other students • Effective student-to-student communication • Peers adequately prepared for online course • Class size	***Factor 3: Class Organisation*** • Immediately engages the student • Learner (student) centred • Anytime, anyplace learning • Self paced schedule • Simulates an in-class feel • Incorporation of leading edge technologies

Previous work in the literature regarding e-learning has made similar attempts at determining appropriate (design) metrics for evaluating student interaction with an electronic learning system. Most notably, the work of CMEC (2001) and Sivakumar (2003) have addressed this matter from student, university/instructor/facilitator and technology viewpoints. These design metrics are listed below in Table 2.

TABLE 2: Design metrics for evaluating student interaction with an e-learning system

Student-centric design factors	University-centric design factors
CMEC (2001) • Ease of use • Learning at anytime • Learning at any place • System availability and ease in locating facilitator • Quality of inter-student interaction and multi-media exchanges **Sivakumar (2003)** • Privacy and secure communication **IMS Global Learning Consortium (2003)** • Real-time perception	**Sivakumar (2003)** • Accessibility • Reliability of system • Help available • Responsiveness of the system and appropriateness of system response to student input • Support for multiple simultaneous student interactions

Sivakumar and Robertson (2004) note that good e-learning encourages the student to spend time electronically to bring about learning and in particular it requires effective real-time, reliable and secure student interaction. For this to occur there is a need to customise and personalise the interaction, learning process and communication channel, thereby ensuring that student interaction is successful through a two-way, integrated, recorded and managed process. Student interaction is a key aspect to the efficacy of the e-learning process as other steps in the process are reliant on this phase. These include addressing the pedagogy employed in instructional design, infrastructure management for delivering learning materials and tracking student performance for grading purposes. Schocken (2001) concurs that online learning design objectives include tailoring course content and technological capabilities to address how students engage in learning, fostering effective learning strategies, providing a rich repertoire of resources and aids, and articulating an instructional design that incorporates the latest techniques in pedagogical research in order to support learning at a pace that is comfortable to the student.

Given these considerations, the university-centric metrics by which e-learning resources may be evaluated can be drawn from *curriculum quality; ease of use; continuous student assessment methodology; real-time feedback to track student performance; multimedia simulations; laboratories and user interaction; and enhanced problem-solving techniques on an individual or group basis* (Dorneich 2002; Sivakumar 2003).

Educational bodies too have recognised the need to address educational quality in online learning environments. The Sloan Consortium 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* (Barraket, Payne et al. 2001; Bourne, Harris et al. 2005). Similarly, a 2001 report by Department of Education Training and Youth Affairs (DETYA) regarding an evidence based approach to the usage of computer and information technology (CIT) in higher education recommends not only a focus on determining how CIT can cost effectively add value to students' learning, but also comments that decisions regarding usage should be informed by evidence which supports that any improvements to learning contribute to the achievement of the objectives of the respective learning program (Moulton, Lasky et al. 2004).

1.2 Laboratory Aims and Objectives:

Ma and Nickerson (2006) observe that a number of approaches have been adopted to associate laboratory aims and outcomes in the literature regarding remote engineering laboratories. These have included Fisher (1977) proposing that the variance between ideal aims and actual results should be used as the assessment criterion to evaluate laboratory learning outcomes, to the development of a checklist of different learning aims with relative weightings (Boud 1973; Rice 1975; Cawley 1989). Others, most notably Hegarty (1978), has also argued for a change in the primary focus of laboratory work to that of purely scientific inquiry.

More recent reviews have discussed different approaches to investigating lab work (Scanlon, Morris et al. 2002), a consideration of LabView-based laboratories with respect to both simulated and remote laboratories (Ertugrul 2000) and attempts at the development of criterion for assessing virtual laboratories (Amigud, Archer et al. 2002; Patil and Pudlowski 2003). Ma and Nickerson (2006) note that whilst these later reviews provide invaluable insights in studying laboratories, they are limited to within their focus topic.

In keeping with the observations of Ma and Nickerson (2006), efforts to come to a general agreement on the objectives of engineering instructional laboratories or to develop a comprehensive set of objectives has been lacking in the literature, with there being many instances in which educators have not explicitly defined objectives at all or when doing so, doing so in terms that make it difficult to assess whether those objectives have been achieved (Feisel and Rosa 2005). This state of affairs was particularly highlighted to the Accreditation Board for Engineering and Technology (ABET) when distance education programs began inquiring about accreditation and it became apparent that whilst criteria existed for evaluating the cognitive component of engineering education, no such understanding existed for laboratories. Working in conjunction with the Sloan Consortium during a colloquy session, the ABET defined objectives for evaluating the efficacy of distance delivered engineering laboratory programs in line with the key educational question – “What are the fundamental objectives of engineering instructional laboratories?” independent of the method of delivery. The hope of these objectives is to not only prompt discussion as to why laboratories are important and what characteristics are entailed in a good laboratory exercise, but to also direct and facilitate curricular discussions and assist in the judgement of effectiveness of practises in institutions (Feisel and Rosa 2005).

The fundamental objectives of engineering instructional laboratories (Feisel and Peterson 2002) were defined as follows:

Objective 1 – Instrumentation. Apply appropriate sensors, instrumentation, and/or software tools to make measurements of physical quantities.

Objective 2 – Models. Identify the strengths and limitations of theoretical models as predictors of real-world behaviours. This may include evaluating whether a theory adequately describes a physical event and establishing or validating a relationship between measured data and underlying physical principles.

Objective 3 – Experiment. Devise an experimental approach, specify appropriate equipment and procedures, implement these procedures, and interpret the resulting data to characterise an engineering material, component, or system.

Objective 4 – Data Analysis. Demonstrate the ability to collect, analyse, and interpret data, and to form and support conclusions. Make order of magnitude judgements and use measurement unit systems and conversions.

Objective 5 – Design. Design, build, or assemble a part, product, or system, including using specific methodologies, equipment, or materials; meeting client requirements; developing system specifications from requirements; and testing and debugging a prototype, system, or process using appropriate tools to satisfy requirements.

Objective 6 – Learn from failure. Identify unsuccessful outcomes due to faulty equipment, parts, code, construction, process, or design, and then reengineer effective solutions.
Objective 7 – Creativity. Demonstrate appropriate levels of independent thought, creativity, and capability in real world problem solving.
Objective 8 – Psychomotor. Demonstrate competence in selection, modification, and operation of appropriate engineering tools and resources.
Objective 9 – Safety. Identify health, safety, and environmental issues related to technological processes and activities, and deal with them responsibly.
Objective 10 – Communication. Communicate effectively about laboratory work with a specific audience, both orally and in writing, at levels ranging from executive summaries to comprehensive technical reports.
Objective 11 – Teamwork. Work effectively in teams, including structure individual and joint accountability; assign roles, responsibilities, and tasks; monitor progress; meet deadlines; and integrate individual contributions into a final deliverable.
Objective 12 – Ethics in the Lab. Behave with highest ethical standards, including reporting information objectively and interacting with integrity.
Objective 13 – Sensory Awareness. Use the human senses to gather information and to make sound engineering judgements in formulating conclusions about real world problems.

1.3 Assessment Practices:

Apart from a few examples indicating preliminary intentions of how evaluation will be undertaken (e.g. Tuttas and Wagner 2002), the majority of literature has focussed on determining the feasibility of remote laboratories or on the mechanics of providing remote access versus evaluation of actual outcomes (Lindsay and Good 2005). Given this state of affairs, the popularity of descriptive designs (e.g. surveys, interview, focus groups, observation and experimental designs) in the remote laboratory literature is both unsurprising and well documented. That such practises are commonplace is an outcome of both the observable advantages that such designs possess and a reflection that the use of these research methodologies were commonly in place prior to the advent of the remote lab experience and continue to be so as a matter of convenient habit. Olds, Moskal et al. (2005) point out that the advantages of descriptive research include the efficiency in capturing data that cannot be readily observed, the facilitation of probing opportunities regarding subjects' responses, and its usefulness in capturing behaviours that participants are unlikely to report. Of course, drawbacks also exist and may range from difficulties in ensuring the accuracy of data due to its dependence on the honesty of subjects, to low response rates and the need for significant time and labour investment in order to collect reliable and valid data (Olds, Moskal et al. 2005).

The use of such designs then has seen particular relevance in the validation of evaluation frameworks (as cited in the work of numerous authors mentioned in TABLE 1.), and has typically included pre and post knowledge tests to measure learning effect as well as student surveys and faculty feedback on "identified" quality indicators of the online experience (Lang, Mengelkamp et al. 2003; Ogot, Elliot et al. 2003; Tuttas, Rutters et al. 2003; Dearholt, Alt et al. 2004). The focus for such work has predominantly been to determine student and faculty satisfaction with the implementation and development of relative laboratory platforms e.g. Rice, Owies et al. (1999); Tzafestas, Palaiologou et al.(2005). However, whilst much of the literature agrees that increased motivation and enthusiasm among students is often observed, and that students may potentially benefit from exposure to more sophisticated hardware, it has been argued that the reliance on anecdotal evidence and student surveys in particular is problematic. Lindsay and Good (2005) point out that a fundamental problem with student feedback is the potential for dissonance between the students' perceptions of their learning and the reality of this learning. While students may be able to determine a broad progress in their learning, this does not necessarily extend to a capacity to adequately evaluate alternative access modes. Similarly, positive student feedback (a commonly cited validation for research of this nature), does not necessarily equate to an improvement in learning outcomes. In other words, irrespective of whether a student believes he/she has learned better, the actual outcomes may differ somewhat and should not be predicated on assumption alone.

Research in the distance education field has highlighted similar concerns in regard to student satisfaction, specifically as a means for evaluating course and faculty excellence (Gisburne and Fairchild 2004). In particular, it has been suggested that there are varied student agendas, motivations and expectations that occur readily in the distance education environment, but fall outside the scope of academic excellence. Judgements of value and quality are subjective at best and difficult to produce. By inference, consideration of satisfaction relative to the implementation and development of laboratories is fraught with similar concerns.

The same can be said for faculty and academic quality and excellence which can also be viewed from different perspectives (Trindade, Carmo et al. 2000). For those institutions that use student satisfaction evaluations, rather than other measurable professional outcomes (Strother 2002), there is an increased risk of finding themselves striving to meet the lowest students' lowest expectations, and in turn bringing about a drop in academic credibility. What may be more advantageous, is for institutions to invest in the utilisation of student professional performance measures and outcome assessments, which would benefit not only program participants and external stakeholders (Kretovics and McCambridge 2002), but could also provide a means for systematic measurement for continuous faculty, course and program improvement (Gisburne and Fairchild 2004).

In this respect, Olds, Moskal et al (2005) propose that the research already undertaken in education provides a framework that the engineering education community may adapt to guide its own assessment and evaluation efforts. Indeed, partnering with educational researchers to support and compliment efforts in engineering education assessment should provide fruitful outcomes and opportunities for rapid advancements within this field.

1.4 Definition of Laboratories:

Whilst Ma and Nickerson (2006) have provided definitions of the three types of laboratories (see TABLE 4), they are quick to point out that such definitions have been inconsistent and ambiguous in previous literature with various authors utilising different nomenclature. For example, remote labs have also been called web labs (Ross, Boroni et al. 1997), virtual labs (Ko, Chen et al. 2000), distributed learning labs (Winer, Chomienne et al. 2000) or (more recently), hands off labs (Feisel and Rosa 2005).

TABLE 3: Types of Engineering Laboratory *Source: Ma and Nickerson (2006).*

Type of Laboratory	*Definition of Laboratory*
Hands-On	Hands-On labs involve a physically real investigation process and possess two characteristics which distinguish them from the other two labs: i) All the equipment required to perform the laboratory is physically set up, and ii) the students who perform the laboratory are physically present in the lab.
Simulated	Simulated labs are the imitations of real experiments. The entire infrastructure required for laboratories is not real, but simulated on computers.
Remote	Remote labs are characterised by mediated reality. Similar to hands-on labs, they require space and devices. In remote labs, experimenters obtain data by controlling geographically detached equipment i.e. reality is mediated by distance.

1.4.1 Advantages and Disadvantages of Different Laboratory Types:

1.4.1a Hands-on/ Traditional Labs

The traditional methodology of utilising local laboratories for engineering education has been predicated on the belief that such activities provide invaluable opportunities for measurement, data collection, analysis and design activities, as well as for hands on experience of equipment, physical devices and for empirical evaluation (Deniz, Bulancak et al. 2003).

In opposition, reasons for seeking out alternatives to the traditional format for engineering laboratories have arisen due to disadvantages such as fixed time and place, limitation on the number of equipment sets and hence the number of students who can use them, and the need for some rare and expensive equipment (Deniz, Bulancak et al. 2003), all of which are subject to rising costs (Ma and Nickerson 2006). These limitations on space and resources also impact specific groups of students, particularly the special needs of disabled students (Colwell, Scanlon et al. 2002) and distant users (Shen, Xu et al. 1999). Other reasons to find alternative lab set-ups include that the set-up and calibration of hands-on labs are often disproportionately time consuming, they may not necessarily represent the best example of teaching efficiency i.e. a closed laboratory setup is not necessarily the most conducive to learning, and there maybe questions relating to feasibility and safety (Esche 2002a).

1.4.1b Simulated Labs

In response to the issue of increasing costs of hands on labs, labs that utilise simulation are seen as an appropriate alternative, particularly as they may reduce the amount of time it takes to learn (Ma and Nickerson 2006) and can readily provide opportunities for students to stop the simulation, review the simulated process and better understand what has happened (Parush, Hamm et al. 2002). In this regard, they also promote an active mode of learning that improves students' performance (Whiteley and Faria 1989; Faria and Whiteley 1990).

Other uses of simulation in the laboratory include as a pre-lab experience to give students some idea of what they will encounter in an actual experiment (Hodge, Hinton et al. 2001), as stand-alone substitutes for physical laboratory exercises which are then assessed by comparing the performance of students who used simulation with those who used traditional laboratories (Campbell, Bourne et al. 2002), and for experimental studies of systems that are too large, too expensive or too dangerous for physical measurements by undergraduate students (Baher 1999; Lee, Gu et al. 2002; Svajger and Valencic 2003).

Of course one of the main criticisms of simulation labs relates to their inherent artificial nature which can translate into an inability to instil the sense of reality into the learner (Tuttas and Wagner 2001; Feisel and Rosa 2005), resulting in a disconnection between the real and virtual worlds (Magin and Kanapathipillai 2000), and also inhibit opportunities for students to learn from trial and error through a lack of realistic data Grant, 1995). The cost of running simulations is another issue worth noting. It can be both expensive and time consuming to mathematically model many systems which is the first step in developing a simulation environment, and in the complex process of making the simulation as close to real as possible, close attention will need to be paid to a number of inner and outer parameters (Deniz, Bulancak et al. 2003).

1.4.1c Hands-off/ Remote Labs

Proponents for the utilisation of Remote labs cite a number of advantages to this lab format. (Esche 2002b) provides a useful segmentation of the various advantages according to the perspectives of students, instructors and institutions respectively. For students, the benefits of remote labs include exposure to a comprehensive experimental experience without requiring physical access to a building with specific experimental equipment ((Baranuik, Burrus et al. 2004; Peek, Depraz et al.

2005), the encouragement of asynchronous learning as suited for non-traditional, commuting and part-time students (Esche 2002b; B. Oakley II 2005), and students who are not conveniently located to their institutions (Lindsay and Good 2004b), the promotion of self and collaborative learning (Esche 2002b; Esche 2002a; Almgren and Cahow 2005) and the integration of self-assessment and feedback (Esche 2002b). For instructors, the ability to monitor the remote use of experimental setups and track student performances (B. Oakley II 2005) is matched by an increased flexibility in tailoring experiments and the opportunity to include laboratory experiment demonstrations in lectures (Esche 2002b; Almgren and Cahow 2005). For institutions, remote labs become the vehicle to realise distance learning with an experimental component whilst providing an inherently safe experimental environment (Esche 2002b; Lindsay and Good 2004b; Muller and Ferreira 2005). Furthermore, strains on class schedules, equipment budgets and key personnel are reduced (Salzmann, Gillet et al. 2000; Esche 2002b; Lindsay and Good 2004b), particularly where universities are able to share laboratory hardware with other institutions or industry to provide affordable real experimental data for a learning opportunity (Ogot, Elliot et al. 2002; Sonnenwald, Whitton et al. 2003; Zimmerli, Steinemann et al. 2003; Lindsay and Good 2004b; Muller and Ferreira 2005) and where the number of times and places students can perform experiments is increased (Salzmann, Gillet et al. 2000; Canfora, Daponte et al. 2004; Almgren and Cahow 2005; Muller and Ferreira 2005).

Other advantages to the use of remote labs include opportunities for student teams to collaborate across multiple institutions and the use of synchronous tools for bringing experts live to a class (B. Oakley II 2005), plus the provision of a multi-cultural environment via a network of online labs that is appreciated by students and which effectively contributes to an improvement in their communication and language skills (Muller and Ferreira 2005).

The main limitations identified regarding remote labs begin with the significant up-front investment needed in development time and effort. This includes the need to address such issues as request queuing, task scheduling, handling of equipment and network failures, and the design of feasible experiments (Esche 2002b). Other disadvantages may be the loss of haptic experience (Muller and Ferreira 2005), and the limited and conditional equivalence between the original experiment and its remote implementation as experienced by students (Keilson, King et al. 1999). In particular, students' engagement with the experiments may suffer from distraction and impatience with the computers, as they may not consider the remote lab experience as realistic (Nedic, Machotka et al. 2003). Another disadvantage focuses on the difficulty in enforcing independence of student work (Esche 2002b).

1.5 Goal Model for Lab Education

Having reviewed the literature regarding engineering laboratories, and generally observing a lack of agreement on what constitutes effectiveness in student learning plus a contradiction of results as to which format is more efficient, Ma and Nickerson (2006) propose a four-dimensional goal model for laboratory education. This model was designed to specifically test the hypothesis that "since advocates of the competing technologies measure against different objectives, they all can claim superiority, but each in reference to a different criterion."(p.7)

TABLE 4: Educational Goals for Laboratory Learning *Source: Ma and Nickerson (2006).*

Lab Goals	Description	Goals from ABET
Conceptual Understanding	Extent to which laboratory activities help students understand and solve problems related to key concepts taught in the classroom	• Illustrate concepts and principles
Design Skills	Extent to which laboratory activities increases student's ability to solve open-ended problems through the design and construction of new artefacts or processes.	• Ability to design and investigate • Understand the nature of science (scientific mind)
Social Skills	Extent to which students learn how to productively perform engineering-related activities in groups	• Social skills and other productive team behaviours (communication, team interaction and problem solving, leadership)
Professional Skills	Extent to which students become familiar with the technical skills they will be expected to have when practicing in the profession.	• Technical/ procedural skills • Introduce students to the world of scientists and engineers in practice • Application of knowledge to practice

When applied to a sample of 60 articles from the literature, the focus on educational goals differs slightly from one lab type to another. For Hands-On Labs, a strong emphasis was placed on Conceptual Understanding, Professional Skills and Design Skills respectively (see FIGURE 1). In terms of Simulated Labs, the results skewed even more so towards Conceptual Understanding and Professional Skills, with less than half of the articles discussing Design Skills (See FIGURE 2). Remote Labs differed greatly from the previous two formats, with their focus being largely on conceptual understanding and professional skills and very few addressing Design Skills or Social Skills (See FIGURE 3) (Ma and Nickerson 2006).

While all lab types typically focussed on conceptual understanding and professional skills, the teaching of design and social skills varied across the different formats, suggesting that the value associated with each of these goals differs according to the approach taken by the relative educators. In the way of explanation, Ma and Nickerson (2006) propose that the proponents of Hands-On Labs may find other lab types to be lacking. This is particularly the case with regard to design skills which many authors have argued for as the essential element of traditional laboratories (see Hegarty 1978; McComas 1997; Magin and Kanapathipillai 2000). While the addressing of design skills and social skills is present amongst the literature on Hands-On Labs, there is less focus on such goals with regard to Simulated Labs and then relatively few examples with regard to Remote Labs. The majorative absence of design skills in this literature may suggest that educators utilising this lab format are more predisposed to assess their efforts with regard to conceptual understanding and professional learning. They may not perceive that Remote Labs provide the best possible opportunity to teach design skills, although they may provide some advantage in the teaching of both concepts and professional skills.

FIGURE 1: Educational Goals of Hands-On Labs.

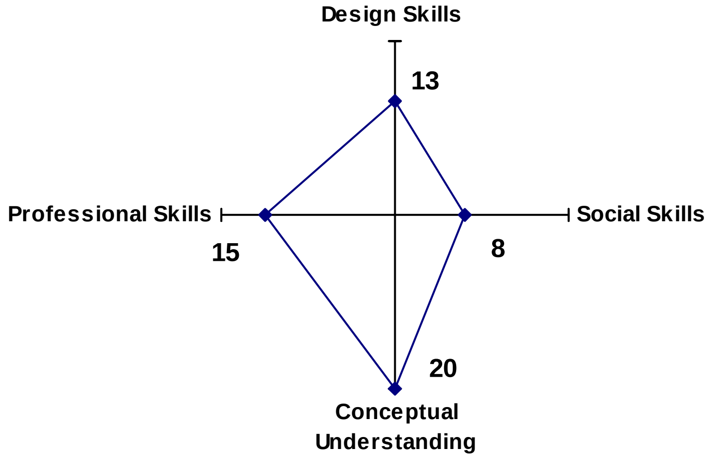


FIGURE 2: Educational Goals of Simulated Labs.

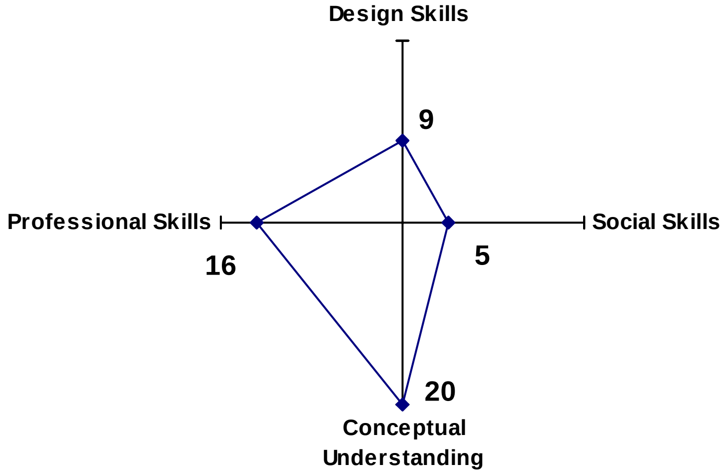
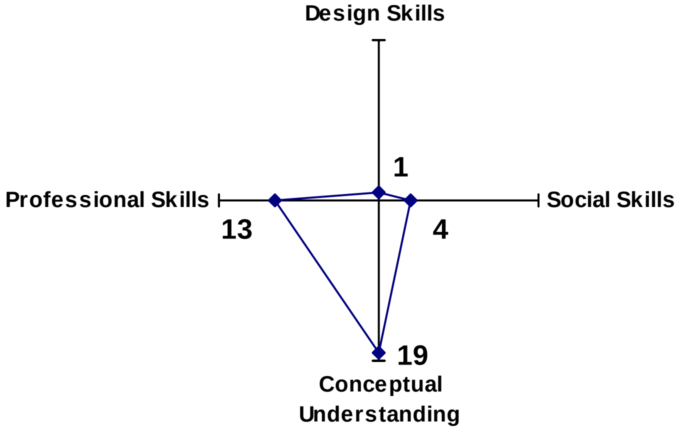


FIGURE 3: Educational Goals of Remote Labs.



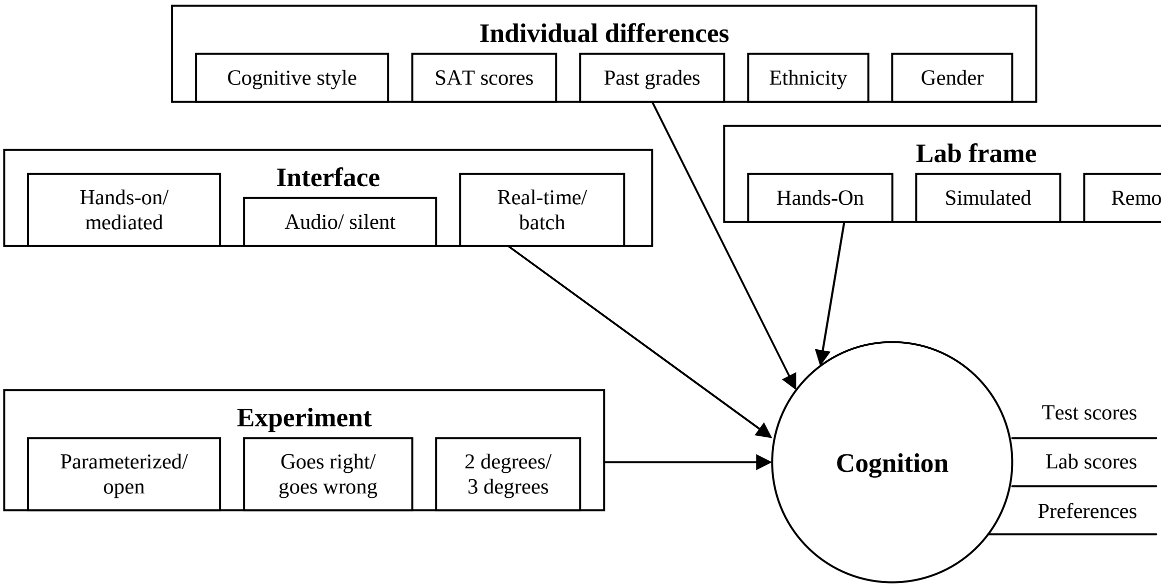
1.6 Assessment model for investigating effectiveness of the three types of labs

In an effort to work towards resolution of the debate as to which type of educational lab is best, Corter, Nickerson et al. (2004) present a model for investigating the relative effectiveness of hands-on, simulated and remote labs (see FIGURE 4). This model builds on previous work conducted by Esche, Chassapis et al (2003).

The independent variables considered in this model are clustered into several areas as follows:

i. Student characteristics including individual differences in abilities and cognitive style.
ii. The topic or experiment performed including degrees of freedom, openness and whether the data is good or bad.
iii. The characteristics of the lab interface including hands-on versus mediated, real-time versus batch mode of execution and audio versus silent.
iv. The format of the educational laboratory i.e. whether the lab is hands-on, simulated or remote. To be more specific, the perceived format of the lab such as whether the student believes the lab is remote or simulated. Manipulations of these beliefs are referred to as framing of the lab format.

FIGURE 4: Assessment Model for Lab Types *Source: Corter, Nickerson et al. (2004)*



More recent work by Nickerson, Corter et al (2007) provides a more comprehensive explanation of the initial efforts of Corter, Nickerson et al (2004), providing additional aspects to this model. FIGURE 5 illustrates the revised model with the following explanation:

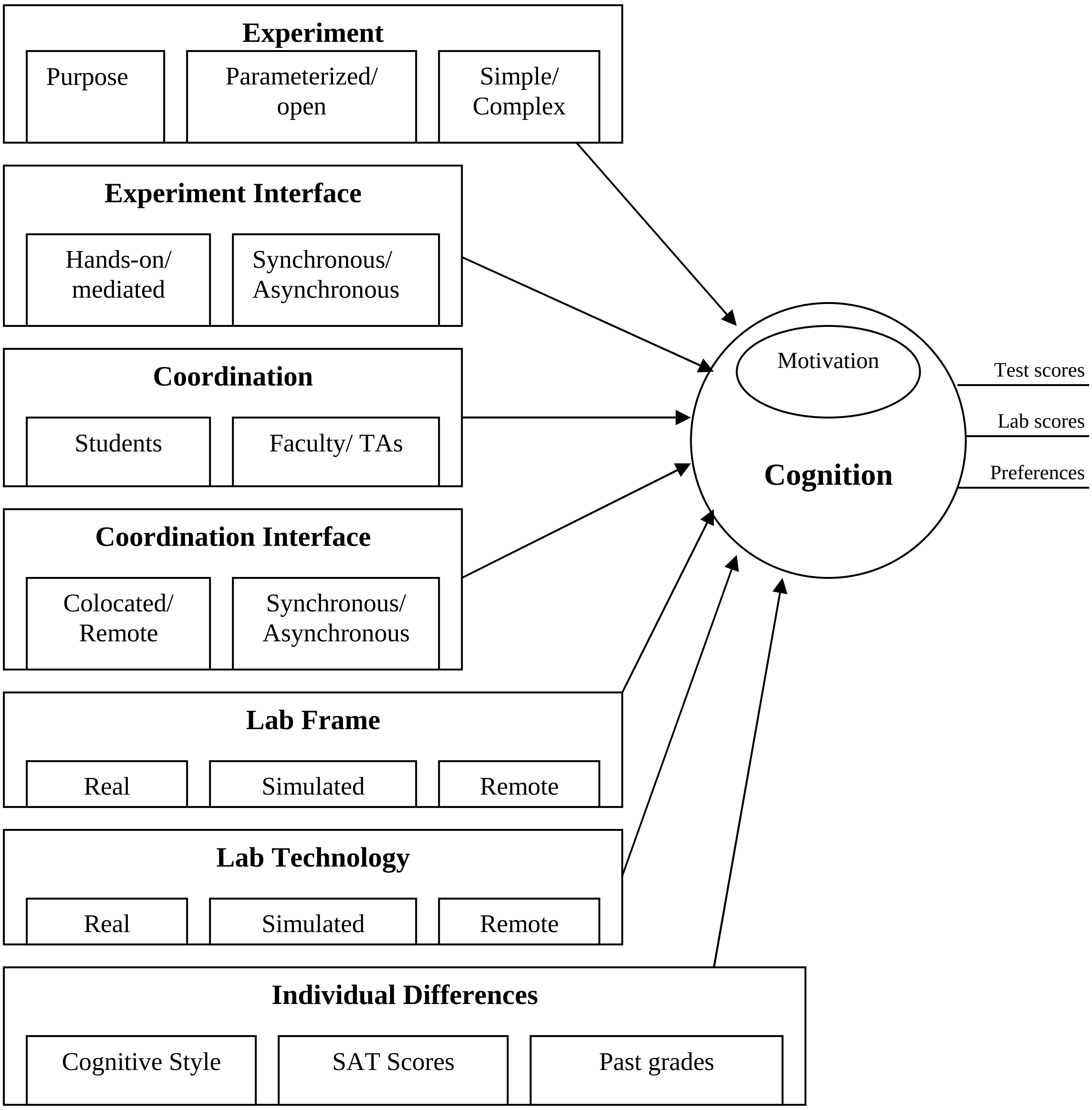
i. Three types of outcomes are measurable – student test scores, student grades and student preferences for specific labs and their associated formats and interfaces;
ii. Motivation is perceived of as an important factor in education and as such educators often measure motivation (as an individual trait) by considering grade point averages, which is shown as a variable in the individual differences box;
iii. Experiment and experiment interface including purpose, openness (depending on whether the problem, the method and the answer is given), complexity (more complex experiments may be more appropriate to a particular type of laboratory); and design of the interfaces to the equipment (hands-on versus mediated), and synchronous versus asynchronous communication.

iv. Social coordination and the coordination interface including communication between students and between students and faculty; and collocated versus remote, and synchronous versus asynchronous communication.

v. Lab frame and lab technology which includes whether the lab format is real, simulated or remote. This is reliant on two factors - the technology underlying the lab may affect outcomes or the *perceived* format may be critical (i.e. whether the student believes the lab to be remote or simulated)

vi. Individual differences including the cognitive style of students, SAT scores and past grades.

FIGURE 5: Assessment Model for Lab Types (Revised) *Source: Nickerson, Corter et al (2007)*



The findings of both the Corter, Nickerson et al. (2004) and Nickerson, Corter et al. (2007) studies were identical. Both studies indicated that more than 90% of the student respondents rated the effectiveness and impact of remote labs to be comparable (or better) than the hands-on labs. This level of equivalence was also demonstrated by analyses of exam scores involving specific lab content. Such findings are consistent with the observations of other researchers who found that there is no discernible difference in performance between students performing experiments on campus or from a distance (Gurocak 2001; Ogot, Elliot et al. 2002).

1.7 Learning Outcomes:

Linked to the question of efficacy of lab format, is whether or not the remote access modality enhances certain learning outcomes in engineering education. While there are many examples of studies conducted to evaluate the educational outcomes for online courses that evolved from lecture styles courses (Baher 1999; Jimoyiannis and Komis 2001; Mackenzie and et.al. 2001) or laboratory courses that are now purely simulation (Starr 1998; Mason 2000; Thiagarajan and Jacobs 2001), very few studies exist that have considered the educational outcomes of remote labs (Ogot, Elliot et al. 2003). The little work that has been undertaken in this regard however, suggests that there is no significant difference between the educational outcomes from students who performed an experiment remotely, versus those who carried out the experiment in-person (Ogot, Elliot et al. 2002; Ogot, Elliot et al. 2003; Tuttas, Rutters et al. 2003; Corter, Nickerson et al. 2004). Such findings are similar in orientation to the majority of research in web based learning (WBL) which has focussed on WBL effectiveness compared with traditional classroom learning (Taradi, Taradi et al. 2005). According to a number of studies, there is "no difference effect" in performance between students enrolled in the two environments (Phipps and Merisotis 1999).

However, work by Lindsay and Good (2002) has shown that students' performances on different criteria can vary depending upon the form of access used. In their work, while similar outcomes for most criteria were produced for both the proximal and simulated approaches, results for the remote approach appear to differ substantially on some criteria. Outcomes were notably poorer for the Generation and Evaluation of Multiple Solutions, and Demonstration of Multiple Design Techniques, whereas the Handling of Exceptions was stronger. Given that Lindsay and Goods' (2002) work is only a pilot study and entails some inherent limitations (i.e. small class size and possible lack of uniformity of criterion skill requirements between the assignments) these results should be considered as indicative only.

This said, later work by the same authors has supported these preliminary results. Substantial differences in student perceptions of learning objectives and outcomes appear to depend on the access mode to experimental equipment. It appears (that depending on the access mode) students infer different objectives for the laboratory class and also emphasize different outcomes. Lindsay and Good (2004a) found that some outcomes appear to be enhanced by non-proximal access modes, whilst others seem to be degraded. The remote access experience seems to promote Processing of Data and Handling of Exceptions when these outcomes are considered as the primary objectives of a laboratory experiment. Outcomes such as Identifying Assumptions and Limitations of Accuracy on the other hand have been shown to be degraded by the simulation mode. The authors concluded that non-proximal access modes served to change the deep learning outcomes of the laboratory class i.e. the ability to understand and identify the behaviour of the system, both expected and unexpected. Remote implementations then, are feasible and possibly desirable in promoting specific types of learning outcomes.

Other authors have also identified similar findings and have noted the impact of access mode on related student behaviours. For instance, Ma and Nickerson (2006) observe that with respect to the effect of technology on cognition, students intend to treat remote labs the same as hands-on labs. However, with respect to the effect of technology on action, this does not appear to be the case as students treat remote labs differently. While students perceive that they will treat remote labs in the same fashion as hands-on labs, students demonstrate an obvious preference for remote labs. Although all students agree that hands-on labs are good for learning, remote labs are preferred for their flexibility and convenience.

Likewise Corter, Nickerson et al. (2007) found that both remote labs and simulations appear to work at least as well as hands-on labs in promoting understanding of course concepts specifically related to the lab topic. This suggests that in courses where the lab is intended to aid in conceptual understanding of the course content, remote and simulation labs can be valuable tools and perhaps even preferable to the traditional hands-on lab.

In keeping with this train of thought, Nickerson, Corter et al. (2007) theorise that for certain educational objectives certain technologies, with associated coordination processes, achieve educational goals more effectively. In other words, the application of the remote or simulation lab format may prescribe certain educational advantages and disadvantages versus those of the proximal lab format and vice versa. This is supported by Lindsay and Good (2005) who also observe that alternative access modes may improve some learning outcomes of laboratory classes, at the expense of degradation in others. Learning outcomes of either the remote or simulated mode differ from their proximal counterpart in both positive and negative ways. For instance Lindsay and Good (2005) found that the remote implementation was shown to emphasize hardware objectives in the students' minds, while the simulation implementation emphasized theoretical objectives. Nickerson, Corter et al. (2007) have tentatively entitled this as a theory of appropriateness, but have warned that further research is necessary before such a theory can be formalised.

1.8 Factors impacting Learning Outcomes:

In considering then how the characteristics of the different access modes may impact educational outcomes, there is a need to discuss various factors that have been observed in the literature as being of significance. Such factors provide possible explanations as to why remote and simulated labs may appear to do as well or better than traditional hands-on labs in promoting understanding of course concepts.

1.8.1 Understanding Procedures and Time on Task

According to students' responses, a significant proportion of time and attention in traditional labs 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 labs, 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 lab 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 lab formats (Corter, Nickerson et al. 2007).

1.8.2 Social and Instructional Resources

Students' use of social and instructional resources differs in the non-traditional lab formats (Corter, Nickerson et al. 2007). Many students in the simulated labs 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).

1.8.3 Student Preferences for Lab Formats

Of interest, student preferences for certain lab formats in some way reflect the advantages that are inherent to these access modes. For instance, remote labs are especially appreciated by students for their convenience, ease of setup and the relatively modest time required running the lab. Similarly, the unique advantages of simulation labs 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 labs, there is some argument for a preference in the teaching of practical skills. Traditional hands-on labs may indeed represent the only feasible manner by which students can learn such skills and this may well explain students' ratings of proximal labs as having higher learning effectiveness versus remote or simulation labs (Corter, Nickerson et al. 2007).

1.8.4 Learning Style of Students

The style of learning employed by students plays a significant role in the educational pathway and teaching (Amigud, Archer et al. 2002). Although it has not always been clear as to the causal relationship between learning style and academic performance (Hashemi, Austin et al. 2005), students are likely to be prone to certain learning preferences which ultimately impact their relative motivation and satisfaction in a learning environs (Sternberg and Grigorenko, 2001 as cited in Hashemi, Austin et al. 2005). This includes the notion that a students' cognitive style can affect their preferences for educational media, including their interactions with hands-on versus remote labs (Corter, Nickerson et al. 2004). 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 (Mayer, 2002 as cited in Hashemi, Austin et al. 2005) and be conducive to learning (Dillon and Gabbard 1998).

One such model that has seen some attention in the literature regarding remote labs is the VARK Learning Preferences Theory. The VARK model supports the notion that there are four sensory preferences utilised by students (Fleming and Mills 1992). These preferences can be described as follows, and give rise to the acronym used to describe this theory i.e. VARK:

Visual – Members of this group like information to arrive in the form of graphs, charts, flow charts, various diagrams, etc. They have a preference for all the symbolic arrows, circles, hierarchies and other devices instructors utilise to represent what could have been presented in words (Fleming and Bonwell 1997) and are particularly sensitive to matters like colour coding or spatial layout (Fleming and Mills 1992).

Aural – Students with this preference learn best from lectures, tutorials and discussions (including with other students), etc. and reflect that speech is the most common mode of information exchange in human society (Kalnishkan 2005).

Read/ Write – People with this preference prefer to receive information from written or printed words and learn best from textbooks, lecture notes, handouts, etc. It has been shown that many academics have a preference for this modality (Fleming and Bonwell 1997).

Kinaesthetic – The last group relies on concrete multi-sensory experience and learn by doing. Students in this group learn best from practical sessions, field trips, experiments, role-playing or simulation, etc. In order for these people to acquire conceptual and abstract material they need it to be accompanied by analogies, metaphors, and real life examples (Kalnishkan 2005). By definition this modality refers to the "perceptual preference related to the use of experience and practice (simulated or real)", with a significant key being that the student is connected to reality, "either through experience, example, practice or simulation" p. 140-141 (Fleming and Mills 1992).

Of interest, Fleming (1995) points out that an immediate addition to these four groups are the groups of various multi-mode preferences. While there are only four different preferences on the VARK scale, there are 23 different permutations of preferences. This is because within each single preference, a person can have a mild, strong or very strong preference for that mode, plus a person can also be multi-modal, with any combination of the preferences (e.g. AR, WRK or even all four VARK)(Allen 2005). Individuals with multi-mode preferences are able to acquire information and gain effective understanding by using more than one mode equally effectively. In this circumstance, students should be encouraged to try study strategies listed under their preferences that they may not have tried previously, as experience has shown that students are inclined to be much more successful if they develop a range of study strategies based upon their preferences. Conversely, it is not helpful to utilise strategies that are outside students' preference, such as mind-maps for students who do not have a visual preference or mnemonics for students who have low read/write scores (Fleming and Bonwell 1997).

A key strength of the VARK inventory then is in the promotion of "active reflection by students on their learning activities" (Fleming and Mills 1992). It provides support to students who are having difficulties with their studies and teachers who would like to develop additional learning strategies for their classrooms that can be utilised on both an individual or group basis (Fleming and Bonwell 1997). However, it should be noted that the VARK has yet to be statistically validated and as such the analysis of any data collected using the questionnaire is necessarily limited (Allen 2005).

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 labs. 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 lab 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 labs. They found that Total VARK score (claimed to measure comfort with multiple modalities of information) did predict higher ratings of effectiveness for the remote labs versus hands-on, and also predicted a lower rating of the importance of physical presence in the lab (as did the visual style subscale score). These findings were replicated by Nickerson, Corter et al. (2007) who also concluded that remote labs may be especially appropriate for students possessing a highly visual or highly flexible learning style.

1.8.5 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. (2003). In this study, students were randomly allocated to one of two access modes, either remote or proximal. The students in the remote group were further separated into two subgroups with one subgroup given an hour in the laboratory to go through the pre-laboratory exercise, whilst the other subgroup was only permitted to attend the laboratory to conduct the experiment. 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 et al. (2002), Faltin, Bohne et al. (2004) and Bohne, Rutters et al. (2004) has also highlighted the importance of prior experience. Entitled 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.

1.8.6 Tutor Assistance

A significant limitation in many remote labs 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 labs is that they provide students with the opportunity for self-directed learning in which independent, asynchronous, unsupervised access to hardware is the norm (Lindsay and Good 2005), it has been pointed out that the presence of an expert mentor is critical in the area of learning by doing (Shank and Cleary, 1995, as cited in Lindsay and Good, (2005). 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 lab 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 (Faltin, Bohne et al. 2004). 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.

1.8.7 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 lab experience is that students often do not share the same space and thereby do not have the opportunity to share information to the same extent as their counterparts who work side by side in proximal/ hands-on labs. Without support for communication, students undertaking a remote lab 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 (Schnepf, Du et al., 1995 as cited in Aktan, Bohus et al. 1996) and users having complete control over the environment and the freedom to determine which action to take (Schank, 1993 as cited in Aktan, Bohus et al. 1996) 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 lab context, Ma (2006) considered students interactions with their group members in both hands-on and remote labs. 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 labs), may become critical factors in determining the way students communicate and collaborate in remote labs. For instance, Team 1 favoured physical interaction and group work. This reflected the large overlap in both personal and study relationships of the group members and was also readily exhibited in the time they spent together and in the real-time, face-to-face meetings to organise their interactions and finish the assignment., Team 3 also utilised a similar communication style in hands-on labs (i.e. students ran the lab in the classroom and used a real-time, co-located interaction pattern in the following stages of the laboratory activity), however in remote labs, team members changed the way they contacted each other, using more remote communication and relying on email and online chat. This reflected that team members in Team 3 were not as closely coupled as those in Team 1. The final team, Team 2, consistently worked remotely, asynchronously and individually. In the hands-on setting, team members had no physical interaction except for running the lab in the classroom and a face-to-face meeting to split up the work. In the remote lab, Team 2 used emails to contact each other and to discuss issues only if necessary. The students in this team were only loosely connected and divided up the work on more of an individual basis than the people in the both Team 1 and 3.

Research by Nickerson, Corter et al. (2007) also found that there was a great variability in the strategies employed by student lab groups toward remote labs. While some student groups would meet in a dormitory room and run the remote labs 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. 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 lab 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 labs as they usually ran labs individually in the data acquisition phase. In hands-on labs however, often only one student interacted with the lab apparatus, while the remainder of the group observed. Depending on what is considered to be the most important outcome of the lab (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 lab scenario), Corter, Nickerson et al. (2007) postulate that the latter reasoning may be an observed advantage in learning outcomes for remote and simulated labs.

This said, the authors also propose that possibly most of the learning for a lab experience takes place after the actual lab session, when results are compiled, analysed and discussed. Given the separateness of students undertaking the remote lab, the provision of opportunities for co-operative learning in which there is group discussion and deliberations can be highly beneficial. However, Corter, Nickerson et al. (2007) 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.

1.8.8 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 (Bates, 1995 as cited in Webb and Webb 2005).

Two definitions of interaction have often been cited in the literature, beginning with Garrison (1993, as quoted in Liaw and Huang 2000) who defines interaction as a "sustained two-way communication among two or more person for purposes of explaining and challenging perspectives". Moore's (1989) definition suggests three types of interaction including learner-content interaction, the process of "intellectually interacting with content" (p.2); learner-instructor interaction, which attempts to motivate and clarify misunderstandings about content; and learner-learner interaction, which occurs "between one learner and another…with or without the real-time presence of an instructor"(p.4).

Interaction has commonly been addressed as a key issue facing program designers, particularly in the distance education field (Egan, Jones, Ferraris and Sebastian, 1993 as cited in DeVries and Wheeler 1996). 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 (Graham, Scarborough et al. 1999; McAlpine 2000; Curtis and Lawson 2001). This is particularly in light of research findings that show that students benefit significantly from their involvement in small learning groups (Webb, Troper et al. 1995; Barak and Maymon 1998) and that students are more motivated when they are in frequent contact with the instructor (Coldeway, Macrury and Spencer, 1980 as cited in Hua and Ganz 2003). However, while improvements in technology and access have provided increased opportunities to employ such methodologies (Mangan, 1999; Grencher, 1998; Schrum, 1998 as cited in Schrum and Hong 2002), student dissatisfaction and frustration with cooperative learning experiences highlights the simple fact that students do not always work well in a co-operative manner. Similarly, employing cooperative learning in distance learning environments is difficult to implement due to the lack of immediate feedback, verbal and non-verbal cues, and face-to-face interaction (So and Brush 2006).

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 (DeVries and Wheeler 1996)[1], 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 (Ellis and Mathis, 1985; Hackman and Walker, 1990, as cited in DeVries and Wheeler 1996). This perspective is supported by Anderson (2003) who proposes that deep and meaningful formal learning 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. Anderson (2003) uses the term "equivalency of interaction" to describe this perspective on interaction as it relates to online learning. In this respect, interactivity can facilitate opportunities for distant learners to engage in a form of personal involvement that can have a positive impact on learning and learner's satisfaction and is essential to effective mediated learning (DeVries and Wheeler 1996). In other words, interactivity can lead to active learning, whereby students engage in some activity that forces them to think about and comment on the information presented.

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). Using a survey instrument to examine perceptions of the relationship between interactivity and learning in the context of online and flexible learning environments, Sims (2003) identified six themes related to participants' expectations of effective interactive online learning experience -

[1] Similar concerns have been raised in the literature regarding the development of remote laboratories in engineering education as per the lack of teacher's presence and online access (Machotka and Nedic, 2006).

engagement, control, communication, design, the individual and learning. Sims (2003) argues that 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.

Fredericksen, Pickett et al. (2000) also identify and discuss a number of factors that impact on the efficacy of online education – *interaction with teacher, high levels of participation, interaction with classmates, help desk, motivation, age, gender and computer skill level*. They 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. Similarly, gender and age played a role in the levels of perceived learning in the student cohort they investigated. The online classroom for instance appears to be a female friendly environment with women reporting that they feel they participate at higher levels than men in the classroom, that they learn more, that technical difficulties are less likely to impede their learning, that they are more likely to want to continue taking online courses, and that they are more satisfied with their specific courses and more satisfied with online learning in general than their male classmates. In terms of age, perceived levels of learning differed significantly between younger students (i.e. 16-25 years old) versus older students (i.e. 36-45 years old) with the latter reporting that they learned the most and were the most satisfied with online learning. In this respect, (older) students who are attracted to and succeed in online learning may share certain traits which age may serve as indicator for. Such traits may include that they are voluntarily seeking further education, are motivated, have higher expectations, tend to be older and tend to possess a more serious attitude about their courses. Fredericksen, Pickett et al. (2000) conclude that in addition to these various factors it is critical that instructors make a concerted effort to value student performance in order to improve the outcomes of the learning process for students. This can occur in a number of ways. One of these includes online discussion whereby students can learn more and are more satisfied when online discussion is valued (graded), authentic (involves real questions), and frequent, and when interactions are positive and enthusiastic. Another means is via portfolio assessment which respects the learner and provides an opportunity for all students to excel.

The significance of *student-instructor interaction* is also worth noting in regard to student learning, particularly as it relates to their pivotal role in maintaining students' alertness in the classroom or distance education setting, irrespective of whether the student is contributing or not (DeVries and Wheeler 1996). *Vicarious interaction*, an internal state in which learners are participating by silently responding to questions (Kruth and Murphy 1990), can result in students having more positive attitudes regarding the instruction. In particular, if learners' perceptions of interactions remain high through vicarious or anticipated interaction (e.g. students being told that they would have subsequent interaction), they are more likely to recall more facts than those who did not anticipate interaction (Yarkin-Levin 1983). Likewise, *structured interaction* can also serve to engage learners, particularly through using methods of advance notice of an expectation and opportunities for interaction (DeVries and Wheeler 1996). For instance, students can be contacted prior to a classroom activity (e.g. video conference) and asked to prepare suggestions and a response to a certain question which they would be asked about at a certain time during the program. As these students know that they will be called upon, they are kept engaged mentally during the conference as they feel the need to relate the responses to the content being presented.

1.8.9 Mental Perception of Hardware

Students' engagement with hardware which is present in front of them in a proximal/ 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 (Lindsay and Good 2005). Similarly, the feedback received by students can differ substantially between a proximal/ hands-on lab 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 labs however, all of the students' interactions including the processes by which they establish their understanding of the hardware, are moderated by the technology (Lindsay and Good 2005), leading to a situation in which the student may question the reality of the experimental experience (Bohne, Faltin et al. 2002). 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 (Aktan, Bohus et al. 1996). As students like to perceive and influence reality (Tuttas and Wagner 2001), 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 (Lindsay, Naidu et al. 2007).

1.8.10 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 (Lindsay, Naidu et al. 2007). 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 (Shin 2003, as cited in 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. This view is supported by both Steuer (1992) and Whitmer and Singer (1998). Steuer (1992) defines presence as "the extent to which one feels present in the mediated environment, rather than in the immediate physical environment" (p.76). Similarly, Whitmer and Singer (1998) refer to presence as "the subjective experience of being in one place or environment, even when one is physically situated in another" (p.255). Whitmer and Singer (1998) comment that presence is a perceptual flow requiring diverted attention and is based on the interaction of sensory stimulation, environmental factors and internal tendencies.

Other authors have focussed on presence in terms of the "perception of reality" versus physical reality. Biocca (1997 as cited in Lee 2004) determines that presence can be generalised to the illusion of "being there" whether or not "there" exists in physical space. Kim and Biocca (1997) propose that (this sense of) presence oscillates around physical (i.e. real environment), virtual (mediated environment), or imaginal (e.g. daydreaming) environments. Such an approach is echoed in later work by Biocca (2001) and also Bentley, Tollmar et al. (2003). Likewise, Loomis (1992) defines presence as a mental projection of the physical object: As a phenomenal attribute it can only be known through inference and is not a physical state. Sheridan (1999) too perceives of presence as a "subjective mental reality" whereby in order to distinguish reality from simulation, one must quantify the amount of noise.

In an attempt to synthesize the previous conceptualisations of presence, Lombard and Ditton (1997) identified six conceptualisations of presence worth nothing. These are presented below.

TABLE 5: Different Conceptualisations of Presence *Source: Lee (2004).*

Conceptualisation	Definitions
Subjective or objective social richness	The warmth or intimacy possible via a medium. "Media having a high degree of social presence are judged as being warm, of a medium personal, sensitive, and sociable" (Short et al., 1976, p.66).
Perceptual or social realism	Social realism: realistic or plausible portrayal of the real world in that it reflects events that do or could occur in the real world. Perceptual realism: life-like creation of the physical world by providing rich sensory stimuli. (Users perceive that the people and objects that they encounter in a virtual world look, sound, smell, and feel like real people and objects.)
Transportation of self, place or other selves	Telepresence in its original meaning – "being there" (Minsky, 1980; Reeves, 1991; Sheridan, 1992). The feeling that you are actually transported to a virtual world "You are there"), or the feeling that the virtual world comes to you while you are remaining where you are initially ("It is here"), or the feeling that you and your interaction partners are sharing a space in a virtual world ("We are together [shared space]").
Perceptual or psychological immersion	Perceptual immersion: "the degree to which a virtual environment submerges the perceptual system of the user" (Biocca & Delaney, 1995, p.57). Psychological immersion: the degree to which users of a virtual environment feel involved with, absorbed in, and engrossed by stimuli from the virtual environment (Palmer, 1995).
Social interaction with an entity within a medium	The degree to which users illogically overlook the mediated or artificial nature of interaction with an entity within a medium (Lemish, 1982; Lombard, 1995).
Social interaction with a medium itself	The degree to which users illogically overlook the mediated or artificial nature of social interaction with a medium itself (Nass & Moon, 2000).

Given their findings, Lombard and Ditton (1997) define presence as the "perceptual illusion of non-mediation" which occurs when a person fails to perceive or acknowledge the existence of a medium in his/her communication environment and responds as he/she would if the medium were not there. The term "perceptual" means that the feeling of presence "involves continuous (real-time) responses of the human sensory, cognitive and affective processing systems to objects and entities in a person's environment" (p.77; (Lombard, Reich et al. 2000)). In other words, as it is a perception, presence can vary from individual to individual; it can be situational and vary across time for the same individual.

The online discussion of Presence-L Listserv during Spring 2000 derived the following explication statement of presence:

> *Presence (a shortened version of the term "telepresence") is a psychological state or subjective perception in which even through part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience. Except in the most extreme cases, the individual can indicate correctly that s/he is using the technology, but at "some level" and to "some degree," her/his perceptions overlook that knowledge and objects, events, entities, and environments are perceived as if the technology was not involved in the experience. Experience is defined as a person's observations of and/or interaction with objects, entities, and/or events in her/his environment; perception, the result of perceiving, is defined as a meaningful interpretation of experience.* (Lee 2004)

Most recently, Lee (2004) has defined presence as “a psychological state in which the virtuality of experience is unnoticed”. Lee (2004) goes further and identifies three types of presence – physical, social and self presence, which are based on the three domains of virtual experience. These are defined as follows:

- *Physical presence*: “a psychological state in which virtual (para-authentic or artificial) physical objects are experienced as actual physical objects in either sensory or non-sensory ways”.
- *Social presence*: “a psychological state in which virtual (para-authentic or artificial) social actors are experienced as actual social actors in either sensory or non-sensory ways”.
- *Self presence*: “a psychological state in which virtual (para-authentic or artificial) self/selves are experienced as the actual self in either sensory or non-sensory ways”.

1.8.11 Constructs of Presence

Given the 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 (Shin 2003). 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 (Mandernach, Gonzales et al. 2006) and is related to discussions of social presence.

1.8.11a Telepresence:

Martin (1981 as cited in Shin 2003) defines telepresence 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 dangerous places (e.g. mines or underwater) or when performing difficult surgical operations (Tammelin 1998). Further definition of the term has included a referral to human-human interaction via communication media. In this regard, telepresence is defined as “the use of technology to establish a sense of shared presence or shared space amongst group members who are geographically separated” (p. 816) (Buxton, 1993 as cited in Shin 2003). Another definition of telepresence has seen this notion linked to the concept of cyberspace and virtual realities. McLellan (1996 as cited in Lee 2004) in particular defines telepresence as a feeling of being in a location other than where you actually are.

1.8.11b Social Presence:

Short et al. (1976 as cited in Lee 2004) define social presence as the “degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationships” (p.65). In other words, social presence is the degree to which a person is perceived as “real” in mediated communication (Richardson and Swan 2003). Short et al. (1976 as cited in Lee 2004) propose that communications media vary in their degree of social presence, and that 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 transmit information about various factors including facial expression, direction of looking, posture, dress and nonverbal cues, etc. Users of communication media are aware of the degree of social presence of each medium and tend to avoid using particular interactions in particular media. Specifically, users avoid interactions requiring a higher sense of social presence in media which lack such capacity. Short et al. (1976 as cited in Lee 2004) also propose that the social presence of the communications medium contributes to the level of intimacy and immediacy, in which intimacy is dependent on nonverbal factors (e.g. physical distance, eye contact, smiling, and personal topics of conversation) and immediacy is a measure of the psychological distance which a communicator puts between himself/ herself and the object of his/her communication. Immediacy or non-immediacy can be conveyed nonverbally (i.e. physical proximity, formality of dress, and facial expression) as well as verbally (Gunawardena and Zittle 1997).

Further research on social presence has examined whether the actual characteristics of the media are the causal determinants of communication differences or whether users' perceptions of media alter their behaviour. (Gunawardena and Zittle 1997) found that social presence can be "cultured" and unlike the findings of Short et al. (1976) is not simply an attribute of the communication medium. They concluded that social presence is both a factor of the medium and of the communicators and their presence in a sequence of interactions. Similarly, Tu and McIsaac (2002) insist that the degree of social presence is based on the characteristics of the medium, as well as the users' perceptions. They define social presence as the degree of awareness of another person in an interaction and the consequent appreciation of an interpersonal relationship. They argue that perception of social presence, initially seen as an attribute of the medium, varies among users and should be viewed as a subjective quality, depending on the objective quality of the medium. While Tu and McIsaac (2002) also recognise intimacy and immediacy as two key concepts of social presence, they highlight three dimensions of social presence worth due consideration. These include Social Context - task orientation, privacy, topics, recipients/ social relationships, and social process; Online Communication - the attributes of the language used in online and the applications of online language (e.g. text-based format); and Interactivity - the activities in which computer users engage and the communication styles they use.

Social presence has also been perceived of as an important factor related to sense of community (Rovai 2002). In this respect social presence can be defined as the ability of learners to project themselves socially and emotionally as real people in a learning community (Garrison, Anderson et al. 2000). It can be regarded as a measure of the feeling of community that a learner experiences (particularly) in an online environment (Tu and McIsaac 2002). As such, social presence has seen further discussion in the literature on instructional communication.

1.8.11c Instructor 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 (Mandernach, Gonzales et al. 2006). Whereas traditional instructors may readily utilise their physical presence to signal their active involvement with a class, online instructors must actively participate in the course to avoid the perception of being invisible or absent (Picciano 2002). Of course a sense of presence or feeling of community does not just occur in an online environment (Ubon and Kimble 2003), nor can it be mandated by an instructor/ facilitator (Cook 1995). 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 (Kerka 1996). Three key issues have been identified in relation to instructor presence: teaching presence, instructor immediacy and social presence.

i) *Teaching Presence* involves frequent and effective interaction with the course instructor (Mandernach, Gonzales et al. 2006) and has been defined as "the design, facilitation and direction of cognitive and social processes for the realisation of personally meaningful and educationally worthwhile learning outcomes" (p.5)(Anderson, Rourke et al. 2001).

ii) *Instructor Immediacy* is conceptualised as those nonverbal behaviours that reduce physical and/or psychological distance between teachers and students (Anderson, 1979 as cited in Rourke, Anderson et al. 2001). Gorham (1988) later classified instructor immediacy into two groups: verbal and nonverbal immediacy whereby the former included actions such as humour, frequent use of student names, encouragement of discussion, encouraging future contact with students, and sharing personal examples, and the latter involved smiling, eye contact, vocal expression, and gesture/ body movements. Gorham's (1988) results suggested that oral behaviours implicit to verbal immediacy contribute significantly to students' affective learning and take precedent in a distance learning environment as a key factor in establishing online instructor presence.

iii) *Social Presence* as defined by Short et al. (1976 as cited in Mandernach, Gonzales et al. 2006) is the "degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationships" (p.65). Various research has supported the notion that social presence is a significant factor in instructional effectiveness such that students who feel they are a part of a group or "present" in a community will wish to participate actively in group and community activities (Picciano 2002). For instance, Dede (1996) found that a strong sense of community not only increases the persistence of students in online programs, but also enhances information flow, learning support, group commitment, collaboration, and learning satisfaction. Similarly, Garrison and Anderson (2003) pointed out that social presence helps to increase social interaction, encourage learning satisfaction, initiate in-depth discussions and promote collaborative learning. The lack of social presence on the other hand can lead to more frustration and less affective learning. Richardson and Swan (2003) identified significant positive correlations between students' social presence scores and perceived learning as well as between students' social presence scores and perceptions of instructor presence. In effect those students who scored highly in terms of social presence felt they gained more from the class and had a more positive impression of their instructor. In addition, students believed that they had learnt more when they were satisfied with the availability of the instructor.

2.0 Pedagogical Frameworks

2.1 Learning Theories

A number of learning theories underpin the literature regarding distance learning and have been used as theoretical frameworks to guide the design of subsequent research in this area. This said, an initial review of the literature on learning theory in general, and on technology-supported learning specifically, contends that there appears to be no one theory which adequately explains how people learn, how instructional systems should be designed, how social interaction affects learning or how people and technologies function best together (Koschmann et al. 1994, as cited in Lucca, Romano Jr et al. 2004). As such, the following sections will provide brief overviews of the more prominent learning theories: Social Presence Theory; Social Constructivism; Learning Space; and the Transactional Distance Theory.

2.1a Social Constructivism -

The perspective on learning held by social constructivism suggests that people construct their knowledge through the process of negotiating meanings with others. As such, a person's cognitive development is highly dependent on their relationship with others (Vygotsky, 1978 as cited in So and Brush 2006) and maybe improved through learning environments which provide opportunities for students to experience multiple perspectives of others who have different backgrounds. Such opportunities as can be provided through cooperative learning environments are believed to also facilitate the development of critical thinking skills through the process of judging, valuing, supporting, or opposing different viewpoints (Fung 2004).

2.1b Social Presence Theory -

Social presence involves the ability of people to be perceived as real, three-dimensional beings that are able to effectively collaborate through technology despite being in different locations and different time frames (Sarbaugh-Thompson and Feldmen, 1998 as cited in Wheeler 2005). Central to social presence theory is the ability for people to work together effectively in groups. As such when social presence is low, group members feel disconnected and group dynamics suffer. Conversely, when social presence is high, members feel more engaged and involved in group processes (Wheeler 2005).

An individual person's perception of social presence is believed to be greatly related to others' intimacy behaviours such as physical proximity, smiling, and eye contact (Short et al., 1976 as cited in So and Brush 2006). As different types of communication media have different capabilities to affect an individual person's perception of social presence (Gunawardena and Zittle 1997), social presence can also be achieved through the hearing of vocal inflections, para-verbal utterances and ambient sounds (in audio communication such as telephone conferencing), and via textual cues and non-verbal devices such as emoticons and images (in text based communication such as email) (Wheeler 2005). In turn, the greater the perception of social presence, the better the ability to substitute telecommunications media for face-to-face encounters and still achieve the desired collaborative outcome. In other words, when the degree of social presence is high, interaction will also be high.

2.1c Transactional Distance Theory -

Transactional Distance Theory as originally proposed by (Moore 1991) defines distance not as a geographical phenomenon but rather as a pedagogical one. Transactional distance, which can be summed up as a learner's perception of psychological and communication gaps as caused by a physical separation from instructor and other learners, is a continuous and relative construct which is determined by structure (course design), amounts of dialogue between the instructor and the learner and learner autonomy (Moore, 1993, as cited in (Moore, 1993 as cited in Stein and Wanstreet 2003). Higher amounts of dialogue and less structure are likely to lead a distance learner to perceive a smaller degree of transactional distance (So and Brush 2006) as they will receive ongoing guidance from instructors and are able to modify instructional materials to meet their needs (Moore and Kearsley, 1996 as cited in Stein and Wanstreet 2003).

2.1d Learning Spaces Theory –

The spatial model proposed by Fulton (1991 as cited in Stein and Wanstreet 2003) considers the relationship of physical environment to satisfaction as critical to adult learners and is based on three premises: i) learner's perceptions of space affect their satisfaction, participation and achievement, ii) certain aspects of a space are subjective, and iii) the authority that is conveyed by the physical environment and its layout can be changed. According to Fulton (1991 as cited in Stein and Wanstreet 2003), an authoritarian learning environment is not necessarily conducive to the learning process, and as such the educational philosophy of the instructor in combination with a course design which encourages students to take control of their environment and gives them the ability to choose whether to work collaboratively in physical space or cyberspace is recommended.

2.2 Learning Styles:

With regard to Learning Styles, different authors have proposed different learning styles. The Occasional Paper by Montgomery and Groat (2002) provides an appropriate description of the four models prevalent in discussions on learning styles. A summary of their comments follows:

2.2a Myers-Briggs Type Indicator

The Myers-Briggs Type Indicator is one of the most well known instruments for identifying personality types. An individual's personality profile is identified along four dimensions: orientation to life (Extroverted/ Introverted); perception (Sensing/ iNtuitive); decision making (Thinking/ Feeling); and attitude to the outside world (Judgement/ Perception). In terms of an individual's preferences along each of these dimensions, they can be said to belong to one of sixteen categories. E.g. An introverted, sensing, feeling, and judging person would be categorised as having an ISFJ personality.

TABLE 6: Preferences of Myers-Briggs Personality Types

ORIENTATION TO LIFE	<u>Extroverted</u> Group interactions Applications	<u>Introverted</u> Working alone Concepts and ideas
PERCEPTION	<u>Sensing</u> Facts and data Routine	<u>Intuitive</u> Impressions Not routine
DECISION MAKING	<u>Thinking</u> Objective Logical	<u>Feeling</u> Subjective Search for harmony
ATTITUDE TO OUTSIDE WORLD	<u>Judgement</u> Planning Control	<u>Perception</u> Spontaneity Adaptive

Although this model has been used widely to classify learning styles in various disciplines (see McCauley et al., 1983; Schroeder, 1993 as cited in Montgomery and Groat 2002), an interesting finding is that the predominant learning styles of college students contrasts sharply with those of faculty, the former being mostly extroverted and sensing and the latter being mostly intuitive and introverted. Similarly, mismatch also seems to occur in the Thinking/ Feeling dimension in terms of a consistent gender difference. About two-thirds of women have profiles in which feeling dominates, while two thirds of men have profiles in which thinking predominates (Kroeger and Thuesen, 1988 as cited in Montgomery and Groat 2002).

2.2b Kolb/ McCarthy Learning Cycle

A key concept in this model is that all learning entails a cycle of four learning modes, but each individual is likely to feel most comfortable in one of these four modes based on his/her preference along two dimensions: Perception and Processing (Kolb, 1984. 1995; Harb et al., 1995 as cited in Montgomery and Groat 2002). Of interest, Perception (Abstract/ Concrete) has been found to correlate with the Decision-Making (Feeling/ Thinking) mode of the Myers-Briggs Type Indicator, and Processing (Active/ Reflective) has been found to match the Orientation (Extrovert./ Introvert) mode of the Myers-Briggs model (Kolb, 1984 as cited in Montgomery and Groat 2002).

Academic fields can be mapped against this set of dichotomous dimensions according to what type of learning mode predominates in that discipline. For instance, the concrete/ reflective quadrant encompasses social science and humanities; the abstract/ reflective quadrant reflects the physical sciences; the abstract/ active incorporates science-based professions such as engineering; and the concrete/ active domain reflects the more social professions such as education.

Research has shown that gender differences exist according to the different learning styles identified in this model. Nearly half of the male respondents preferred the assimilator (abstract/ reflective) mode, whereas the predominant modes for women were diverger (concrete/ reflective) and converger (abstract/ active) (Philbin et al., 1995 as cited in Montgomery and Groat 2002). In teaching terms this would mean that female students are more responsive to faculty who utilise either a motivator or coach stance, whereas male students would be more comfortable with faculty who adopt the role of expert.

2.2c Felder-Silverman Learning Styles Model

The model proposed by Felder and Silverman incorporates five dimensions, two of which replicate aspects of the Myers-Briggs and Kolb/ McCarthy Models. These include, the Perception (sensing/ Intuitive) dimension being equivalent to the Perception mode of both the Myers-Briggs and Kolb, and the Processing (active/ reflective) dimension being found in the Kolb model also. In addition to these two dimensions, Felder-Silverman also propose three other dimensions including Input (visual/ verbal), Organisation (inductive/ deductive), and Understanding (sequential/ global). An inventory questionnaire has been developed by Solomon (1992 as cited in Montgomery and Groat 2002) to be used for the assessment of four of the five learning style preferences in the Felder-Silverman model.

TABLE 7: Felder-Silverman Learning Style Dimensions

Dimension	***Range***	
PERCEPTION	Sensing Data obtained via senses	Intuitive Symbols
	Facts and observations	Interpretations
INPUT	Visual Charts and pictures	Verbal Spoken word
ORGANISATION	Inductive Facts and Observations	Deductive General principles
PROCESSING	Active Doing something	Reflective Introspective processing
	Group work	Independent work
UNDERSTANDING	Sequential Linear connections	Global Holistic connections
	Small connected chunks	“Big picture”

Data compiled by Montgomery and Groat (2002) from engineering and architecture students indicates that engineers are more active, sensing, verbal and sequential than architects. Moreover, when considering architecture students, it was found that advanced students tend to be relatively more reflective, visual and global than beginning students; and the percentage of intuitives at all levels of the architecture program appear to be far higher than in the general population of college students. In addition, the advanced students were more likely than the novice students to have learning style profiles similar to studio faculty. In engineering on the other hand, graduate students and faculty are more intuitive, inductive and reflective that their undergraduate counterparts (Felder and Silverman, 1988 as cited in Montgomery and Groat 2002). In terms of gender differences, Montgomery and Groat (2002) found that both female engineering and architecture students were more geared to an active learning mode than their male classmates.

2.2d Grasha-Reichmann Learning Styles

This learning styles typology is distinct from the other three styles in that it is based on students' responses to actual classroom activities rather than on a more general assessment of personality or cognitive traits. In other words it advocates a situation-specific approach which Grasha argues is more reliable and valid than a personality type approach as the latter requires the researcher to extrapolate the results to classroom settings. The Grasha-Reichmann approach on the other hand can assist faculty to identify teaching techniques that address particular learning styles. The characteristics and classroom preferences for each style are presented in Table 8 below.

Another distinguishing feature of this model is the corresponding typology of teaching styles that was developed, similarly based on actual classroom behaviours. In this respect, learning and teaching styles can be mapped together to more fully describe the social dynamics of the classroom setting. However, Grasha does not advocate attempting to accommodate all learning style preferences at all times, but favours that an awareness of these styles can help faculty augment their methods of presentation. In this way, faculty can assist students in developing learning styles they are weak in by easing them into the corresponding type of activity.

TABLE 8: Characteristics of Grasha-Reichmann Learning Styles

Style	***Characteristics***	***Classroom Preferences***
Competitive	Compete with other students	Teacher-centred, class activities
Collaborative	Share ideas with others	Student-led small groups
Avoidant	Uninterested, non-participant	Anonymous environment
Participant	Eager to participate	Lectures with discussion
Dependent	Seek authority figure	Clear instructions, little ambiguity
Independent	Think for themselves	Independent study and projects

While other researchers have observed some relationship between academic major and learning style, no consistent relationship between academic major and learning style has been noted according to this typology. Grasha (1996 as cited in Montgomery and Groat 2002) has found however that there are some consistent variations due to gender, student age, and grade. For instance, women students typically have higher scores on the collaborative style; students over 25 tend to employ more independent and participatory styles; and students with a participatory style get higher grades than those with avoidant styles. Similarly, women architecture students evidenced substantially higher collaborative and participatory scores, while they also scored substantially lower on the competitive scale. Older architecture students also scored substantially higher on the independent scale.

References

Aktan, B., C. A. Bohus, et al. (1996). "Distance learning applied to control engineering laboratories." IEEE Transactions on Education **39**(No.3).

Allen, S. (2005) "The letter of the law: Is there a link between students with a preference for a read-write learning style (on the VARK scale) and academic success on the Legal Practise Course?" Teaching News **Spring**, from http://www.brookes.ac.uk/services/ocsd/teachingnews/archive/spring06/sarah_allen.html.

Almgren, R. C. and J. A. Cahow (2005). "Evolving technologies and trends for innovative online delivery of engineering curriculum." International Journal of Online Engineering.

Amigud, Y., G. Archer, et al. (2002). Assessing the utility of web-enabled laboratories in undergraduate education. 32nd ASEE/ IEEE Frontiers in Education Conference. Boston, MA.

Anderson, T. (2003). "Getting the mix right again: An updated and theoretical rationale for interaction." International Review of Research in Open and Distance Learning **4**(2).

Anderson, T., L. Rourke, et al. (2001). "Assessing teaching presence in a computer conferencing context." Journal of Asynchronous Learning Networks **5**(2): 1-17.

B. Oakley II (2005). The web and the transformation of ECE education. 2005 ASEE Annual Conference. Portland OR.

Baher, J. (1999). "Articulate virtual labs in thermodynamics: A multiple case study." ASEE Journal of Engineering Education **88**(4): 429-434.

Barak, M. and T. Maymon (1998). "Aspects of teamwork observed in a technological task in junior high schools." Journal of Technology Education. **9**(2): 1-27.

Baranuik, R., C. Burrus, et al. (2004). "Sharing knowledge and building communities in signal processing." IEEE Signal Processing Magazine.

Barraket, J., A. Payne, et al. (2001). "Equity and the use of CIT in higher education." Canberra: DETYA Evaluations and Investigations Program.

Bentley, F., O. Tollmar, et al. (2003). "Perceptive presence." IEEE Computer Graphics and Applications. **23**(5): 26-36.

Biocca, F. (2001). "Inserting the presence of mind into a philosophy of presence: A response to Sheridan and, Mantovani and Riva." Presence: Teleoperators and Virtual Environments **10**(5): 546-556.

Bohne, A., N. Faltin, et al. (2002). Self-directed learning and tutorial assistance in a remote laboratory. Interactive Computer Aided Learning Conference., Villach, Austria.

Bohne, A., K. Rutters, et al. (2004). Evaluation of tele-tutorial support in a remote programming laboratory. 2004 American Society for Engineering Education Annual Conference and Exposition.

Boud, D. J. (1973). "The laboratory aims questionnaire - A new method for course improvement?" Higher Education **2**: 81-94.

Bourne, J., D. Harris, et al. (2005). "Online engineering education: Learning anywhere, anytime." Journal of Engineering Education **94**(No.1): 131-146.

Campbell, J. O., R. J. Bourne, et al. (2002). "The effectiveness of Learning Simulations in electronics laboratories." Journal of Engineering Education **91**(1): 81-87.

Canfora, G., P. Daponte, et al. (2004). "Remotely accessible laboratory for electronic measurement teaching." Comput. Standards and Interfaces **26**(No. 6): 489-499.

Cawley, P. (1989). "Is laboratory teaching effective?" International Journal of Mechanical Engineering Educators. **17**: 15-27.

CMEC. (2001). "The e-learning e-volution in colleges and universities." from mlg-gam.ic.gc.ca/sites/acol-ccael/en/report/e-volution_e.pdf.

Cohen, M. S. and T. J. Ellis (2002). Developing a criteria set for an online learning environment. 32nd ASEE/ IEEE Frontiers in Education Conference. Boston, MA.
Colwell, C., E. Scanlon, et al. (2002). "Using remote laboratories to extend access to science and engineering." Computing and Education **38**(1-3): 65-76.
Cook, D. L. (1995). "Community and computer-generated distance learning environments." New Directions for Adult and Continuing Education **67**: 33-39.
Corter, J. E., J. V. Nickerson, et al. (2004). Remote versus hands-on labs: A comparative study. 34th ASEE/ IEEE Frontiers in Education Conference. Savannah, GA.
Corter, J. E., J. V. Nickerson, et al. (2007). "Constructing reality: A study of remote, hands-on and simulated laboratories." ACM Transactions on Computer-Human Interaction.
Curtis, D. D. and M. J. Lawson (2001). "Exploring collaborative online learning." Journal of Asynchronous Learning Network **5**(1): 21-34.
Dearholt, D. W., K. J. Alt, et al. (2004). "Foundational aspects of student controlled learning: A paradigm for design, development and assessment appropriate for web-based instruction." Journal of Engineering Education **93**: 129-138.
Dede, C. (1996). "The evolution of distance education: Emerging technologies and distributed learning." American Journal of Distance Education **10**(2): 4-36.
Deniz, D. Z., A. Bulancak, et al. (2003). A novel approach to remote laboratories. 33rd ASEE/ IEEE Frontiers in Education Conference. Boulder, Colorado.
DeVries, J. E. and C. Wheeler (1996). "The interactivity component of distance learning implemented in an art studio course." Education Journal **117**(2).
Dillon, A. and R. Gabbard (1998). "Hypermedia as an educational technology: A review of the quantitative research literature on learner comprehension, control and style." Review of Educational Research **68**: 322-349.
Dorneich, M. C. (2002). "A system design framework-driven implementation of a learning collaboratory." IEEE Transactions on Systems, Man and Cybernetics **32**(2): 200-213.
Ertugrul, N. (2000). "Towards virtual laboratories: A survey of LabVIEW based teaching/ learning tools and future trends." International Journal of Engineering Education **16**(No. 3): 171-180.
Esche, S., C. Chassapis, et al. (2003). "An architecture for multi-user remote laboratories." World Transactions on Engineering and Technology Education **2**: 7-11.
Esche, S. K. (2002a). Remote engineering laboratories for asynchronous learning networks. The 8th Sloan Conference - International Conference on Asynchronous Learning Networks. Orlando, Fl.
Esche, S. K. (2002b). Remote experimentation - One building block in online engineering education. 2002 ASEE/ SEFI/ TUB Colloquium.
Faltin, N., A. Bohne, et al. (2004). Evaluation of reduced perception and tele-tutorial support in remote automation technology laboratories. International Conference on Engineering Education and Research "Progress through Partnership". Ostrava, Czech Republic.
Faria, A. J. and T. R. Whiteley (1990). "An empirical evaluation of the pedagogical values of playing a simulation game in a principles of marketing course." Development in Business Simulations Experiential Learning **17**: 53-57.
Feisel, L. D. and G. D. Peterson (2002). Learning objectives for engineering education laboratories. 32nd ASEE/ IEEE Frontiers in Education Conference. Boston MA.
Feisel, L. D. and A. J. Rosa (2005). "The role of the laboratory in undergraduate engineering education." Journal of Engineering Education **94**(1): 121-130.
Fisher, B. C. (1977). "Evaluating mechanical engineering laboratory work." International Journal of Mechanical Engineering Educators. **5**: 147-157.
Fleming, N. D. (1995). I'm different; not dumb. Modes of presentation (VARK) in the tertiary classroom. Proceedings of the 1995 Annual Conference of the Higher Education and Research Development Society of Australasia (HERDSA), HERDSA.

Fleming, N. D. and C. C. Bonwell (1997) "VARK - Advice to users of the questionnaire." from http://www.ntlf.com/html/lib/suppmat/74vark2.htm.

Fleming, N. D. and C. Mills (1992). "Not another inventory, rather a catalyst for reflection." To improve the academy **11**: 137-149.

Fredericksen, E., A. Pickett, et al. (2000). "Courses: Principles and examples from the SUNY Learning Network." Journal of Asynchronous Learning Network **4**(2).

Fung, Y. H. (2004). "Collaborative online learning: interaction patterns and limiting factors." Open Learning **19**(2): 54-72.

Garrison, D. R. and T. Anderson (2003). E-learning in the 21st Century: A framework for research and practice. London, Routledge Falmer.

Garrison, D. R., T. Anderson, et al. (2000). "Critical inquiry in a text-based environment: Computer conferencing in higher education." The Internet and Higher Education **2**(2-3): 1-19.

Gibbs, W. J. (1998). "Implementing online learning environments." Journal of Computers in Higher Education **10**(1): 16-37.

Gisburne, J. M. and P. J. Fairchild (2004). Four families of multi-variant issues in graduate-level asynchronous online courses. DLA 2004 Proceedings, Jekyll Island, Georgia.

Gorham, J. (1988). "The relationship between verbal teacher immediacy behaviours and student learning." Communication Education **37**: 40-53.

Graham, M., H. Scarborough, et al. (1999). "Implementing computer mediated communication in an undergraduate course - A practical experience." Journal of Asynchronous Learning Network **3**(1): 32-45.

Gunawardena, C. N. and F. J. Zittle (1997). "Social presence as a predictor of satisfaction within a computer-mediated conferencing environment." American Journal of Distance Education **11**(3): 8-26.

Gurocak, H. (2001). E-Lab: technology assisted delivery of a laboratory course at a distance. Proc. ASEE Annual Conference and Expo., Albuquerque, USA.

Hashemi, J., K. A. Austin, et al. (2005). "Elements of a realistic virtual laboratory experience in materials science: Development and evaluation." International Journal of Engineering Education **21**(No.3).

Hegarty, E. H. (1978). "Levels of scientific inquiry in university science laboratory classes: Implications for curriculum deliberations." Research in Science Education **8**: 45-57.

Hodge, H., H. S. Hinton, et al. (2001). "Virtual Circuit Laboratory." Journal of Engineering Education **90**(4): 507-511.

Hua, J. and A. Ganz (2003). A new model for remote laboratory education based on next generation interactive technologies - A generic laboratory plug-in using MS ConferenceXP learning infrastructure. Proceeding of ASEE New England Regional Conference, Orono, ME.

Imbrie, P. K. and S. Raghaven (2005). A remote e-laboratory for student investigation, manipulation and learning. 35th ASEE/ IEEE Frontiers in Education Conference. Indianapolis, IN.

Jimoyiannis, A. and V. Komis (2001). "Computer simulations in physics and learning: A case study on students' understanding of trajectory motion." Computers and Education **36**: 183-204.

Kalnishkan, Y. (2005) "Learning style models and teaching of computer science." from http://www.rhul.ac.uk/Educational-Development/Centre/new_lecturers/docs/Learning%20Style%20Models%20and%20Teaching.pdf.

Keilson, S., E. King, et al. (1999). Learning science by doing science on the web. 29th ASEE/ IEEE Frontier in Education Conference., San Juan, Puerto Rico.

Kerka, S. (1996) "Distance learning, the Internet, and the World Wide Web." ERIC Digest **168**, from http://www.modares.ac.ir/elearning/Mchizari/AEA/Page/Class15/distance.htm.

Kim, T. and F. Biocca (1997). "Telepresence via television: Two dimensions of telepresence may have different connection to memory and persuasion." Journal of Computer Mediated Communications **3**(2).

Ko, C. C., B. M. Chen, et al. (2000). "A large-scale web-based virtual oscilloscope laboratory experiment." Engineering Science and Educational Journal **9**(2): 69-76.
Kretovics, M. and J. McCambridge (2002). "Measuring MBA student learning: Does distance make a difference?" International review of research in open and distance learning. **3**(2).
Kruth, J. and K. Murphy (1990). Interaction and teleconferencing - The key to quality instruction. Annual Rural and Small Schools Conference, Manhattan, KS.
Lang, D., C. Mengelkamp, et al. (2003). Pedagogical evaluation of remote laboratories in eMerge project. International Conference on Engineering Education. Valencia, Spain.
Lee, K. M. (2004). "Presence, Explicated." Communication Theory **14**(1): 27-50.
Lee, W., J. Gu, et al. (2002). "A physical laboratory for protective relay education." IEEE Transactions on Education **45**(2): 182-186.
Liaw, S. and H. Huang (2000). "Enhancing interactivity in web-based instruction: A review of the literature." Educational Technology **39**(1): 41-51.
Lindsay, E., S. Naidu, et al. (2007). "A different kind of difference: Theoretical implications of using technology to overcome separation in remote laboratories." International Journal of Engineering Education.
Lindsay, E. D. and M. C. Good (2002). Remote, proximal and simulated access to laboratory hardware - A pilot study. Proceedings of EdMEDIA 2002, Denver, Colorado.
Lindsay, E. D. and M. C. Good (2004a). Effects of access modes upon students' perceptions of learning objectives and outcomes. Proceedings of the 15th Annual Conference for the Australasian Association for Engineering Education, Toowoomba, Australia.
Lindsay, E. D. and M. C. Good (2004b). Effects of laboratory access modes upon learning outcomes. EE2004 Conference. Wolverhampton.
Lindsay, E. D. and M. C. Good (2005). "Effects of laboratory access modes upon learning outcomes." IEEE Transactions on Education **48**(4): 619-631.
Lombard, M. and T. Ditton (1997). "At the heart of it all: The concept of presence." Journal of Computer Mediated Communications **3**(2).
Lombard, M., R. Reich, et al. (2000). "Presence and television: The role of screen size." Human Communication Research. **26**(1): 75-98.
Loomis, J. M. (1992). "Distal attribution and presence." Presence: Teleoperators and Virtual Environments **1**: 113-119.
Lucca, J., N. C. Romano Jr, et al. (2004). An assessment of E-learning technologies to support telecommunications laboratory learning objectives. Proceedings of the 37th Hawaii International Conference on System Science.
Ma, J. (2006). Collaboration processes in hands-on and remote labs.
Ma, J. and J. V. Nickerson (2006). "Hands-on, simulated, and remote laboratories: A comparative literature review." ACM Computing Surveys **38**(No. 3 Article 7).
Mackenzie, J. G. and et.al. (2001). "Amoco computer simulation in chemical engineering education." ASEE Journal of Engineering Education **85**(3): 331-345.
Magin, D. J. and S. Kanapathipillai (2000). "Engineering students' understanding of the role of experimentation." European Journal of Engineering Education. **25**(4): 351-358.
Mandernach, B. J., R. M. Gonzales, et al. (2006). "An examination of online instructor presence via threaded discussion participation." Journal of Online Learning and Teaching **2**(4).
Mason, R. (2000). "From distance education to online education." The Internet and Higher Education **3**: 63-74.
Mbarika, V., S. Chenton, et al. (2003). "Identification of factors that lead to perceived learning improvements for female students." IEEE Transactions on Education **46**: 26-36.
McAlpine, I. (2000). "Collaborative learning online." Distance Education. **21**(1): 66-80.
McComas, W. F. (1997). "The nature of the laboratory experience: A guide for describing, classifying and enhancing hands-on activities." CSTA Journal **Spring**: 6-9.

Montgomery, S. M. and L. N. Groat (2002) "Student learning styles and their implications for teaching." from http://chat.carleton.ca/~tblouin/Learn%20More-%20Research/integrating%20the%20different%20approaches.htm.

Moore, M. G. (1989). "Three types of interaction." American Journal of Distance Education **3**(2): 1-6.

Moore, M. G. (1991). "Editorial: Distance education theory." American Journal of Distance Education **5**(3): 1-6.

Moulton, B. D., V. L. Lasky, et al. (2004). "The development of a remote laboratory: educational issues." World Transactions on Engineering and Technology Education **3**(No. 1).

Muller, D. and J. M. Ferreira (2005). "Online labs and the MARVEL experience." International Journal of Online Engineering.

Nedic, Z., J. Machotka, et al. (2003). Remote laboratories versus virtual and real laboratories. 2003 33rd Annual Frontiers in Education Conference, Boulder, CO.

Ng, K. C. (2007). "Replacing face-to-face tutorials by synchronous online technologies: Challenges and pedagogical implications." International Review of Research in Open and Distance Learning **8**(1): 1-15.

Nickerson, J. V., J. E. Corter, et al. (2007). "A model for evaluating the effectiveness of remote engineering laboratories and simulations in education." Computers and Education **49**: 708-725.

Ogot, M., G. Elliot, et al. (2002). Hands-on laboratory experience via remote control: Jet thrust laboratory. Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition.

Ogot, M., G. Elliot, et al. (2003). "An assessment of In-Person and remotely operated laboratories." Journal of Engineering Education **92**(1): 57-63.

Olds, B. M., B. M. Moskal, et al. (2005). "Assessment in engineering education: Evolution, approaches and future collaborations." Journal of Engineering Education **94**(1): 13-25.

Parush, A., H. Hamm, et al. (2002). "Learning histories in simulation based teaching: The effects on self-learning and transfer." Computing and Education **39**: 319-322.

Patil, A. S. and Z. J. Pudlowski (2003). "Instructional design strategies for interactive Web-based tutorials and laboratory procedures in engineering education." World Transactions on Engineering and Technology Education **2**(No. 1): 107-110.

Peek, C. S., S. Depraz, et al. (2005). "The virtual control laboratory paradigm: Architectural design requirements and realization through a DC-Motor example." International Journal of Engineering Education.

Phipps, R. and J. Merisotis (1999) "What's the difference? A review of contemporary research on the effectiveness of distance learning in higher education."

Picciano, A. G. (2002). "Beyond student perceptions: Issues of interaction, presence, and performance in an online course." Journal of Asynchronous Learning Networks **6**(1): 21-40.

Rice, M., D. Owies, et al. (1999). "V-Lab: A virtual laboratory for teaching introductory concepts and methods of physical fitness and function." Australian Journal of Educational Technology **15**(2): 188-206.

Rice, S. L. (1975). "Objectives for engineering laboratory instruction." Engineering Education. **65**: 285-288.

Richardson, J. C. and K. Swan (2003). "Examining social presence in online courses in relation to students' perceived learning and satisfaction." Journal of Asynchronous Learning Networks **7**(1): 68-88.

Ross, R. J., C. M. Boroni, et al. (1997). Weblab! A universal and interactive teaching, learning, and laboratory environment for the world wide web. Proceedings of the 28th SIGCSE Technical Symposium on Computer Science Education., San Jose, CA.

Rourke, L., T. Anderson, et al. (2001). "Assessing social presence in asynchronous text-based computer conferencing." Journal of Distance Education **14.2**.

Rovai, A. (2002). "Building sense of community at a distance." International Review of Research in Open and Distance Learning **3**(1).
Salzmann, C., D. Gillet, et al. (2000). "Introduction to real-time control using LabVIEWTM with an application to distance learning." International Journal of Engineering Education **16**(No. 3): 255-272.
Scanlon, E., E. Morris, et al. (2002). "Contemporary approaches to learning science: Technology-mediated practical work." Studies in Science Education. **38**: 73-114.
Schocken, S. (2001). "Standardised frameworks for distributed learning." Journal of Asynchronous Learning Networks **5**(2): 97-110.
Schrum, L. and S. Hong (2002). "Dimensions and strategies for online success: Voices from experienced educators." Journal of Asynchronous Learning Networks **6**(1).
Shen, H., Z. Xu, et al. (1999). "Conducting laboratory experiments over the Internet." IEEE Transactions on Education **42**(No. 3): 180-185.
Sheridan, T. (1999). "Descartes, Heidegger, Gibson, and God." Presence: Teleoperators and Virtual Environments **8**(5): 551-559.
Shin, N. (2003). "Transactional presence as a critical predictor of success in distance learning." Distance Education **24**(1).
Sicker, D. C., T. Lookaburgh, et al. (2005). Assessing the effectiveness of remote networking laboratories. 35th ASEE/ IEEE Frontier in Education Conference. Indianapolis, IN.
Sims, R. (2003). "Promises of interactivity: Aligning learner perceptions and expectations with strategies for flexible and online learning." Distance Education **24**(1): 87-104.
Sivakumar, S. C. (2003). A user interaction framework for e-learning. Proceedings of the 6th Annual Conference of Southern Association for Information Systems Conference.
Sivakumar, S. C. and W. R. Robertson (2004). "Developing an integrated web engine for online internetworking education: A case study." Internet Research **14**(2): 175-192.
So, H. J. and T. Brush (2006). Student perceptions of cooperative learning in a distance learning environment: Relationships with social presence and satisfaction., San Francisco, Annual Meeting of the American Educational Research Association (AERA).
Sonnenwald, D. H., M. C. Whitton, et al. (2003). "Evaluating a scientific collaboratory: Results of a controlled experiment." ACM Trans. Comput. Hum. Interact **10**(No. 2): 150-176.
Starr, D. (1998). "Virtual education: Current practices and future directions." The Internet and Higher Education **1**(2): 157-165.
Stein, D. S. and C. E. Wanstreet (2003). Role of social presence, choice of online or face-to-face group format, and satisfaction with perceived knowledge gained in a distance learning environment. 2003 Midwest Research to Practise Conference in Adult, Continuing and Community Education.
Steuer, J. (1992). "Defining virtual reality: Dimensions determining telepresence." Journal of Communication **42**(4): 73-93.
Strother, J. S. (2002). "An assessment of the effectiveness of e-learning in corporate training programs." International review of research in open and distance learning. **3**(1).
Svajger, J. and V. Valencic (2003). "Discovering electricity by computer based experiments." IEEE Transactions on Education **46**(4): 502-507.
Tammelin, M. (1998). "From telepresence to social presence: The role of presence in a network-based learning environment." Media Education Publications 8: 219-231.
Taradi, S. K., T. Taradi, et al. (2005). "Blending problem-based learning with Web technology positively impacts student learning outcomes in acid-base physiology." Advanced Physiology Education **29**: 35-39.
Thiagarajan, G. and C. Jacobs (2001). "Teaching undergraduate mechanics via distance learning: A new experience." Journal of Engineering Education **90**(1): 151-156.
Trindade, A. R., H. Carmo, et al. (2000). "Current developments and best practises in open and distance learning." International review of research in open and distance learning. **1**(1).

Tu, C. and M. McIsaac (2002). "The relationship of social presence and interaction in online classes." The American Journal of Distance Education **16**(3): 131-150.

Tuttas, J., K. Rutters, et al. (2003). Telepresent vs. traditional learning environments - A field study. International Conference on Engineering Education. Valencia, Spain.

Tuttas, J. and B. Wagner (2001). Distributed online laboratories. International Conference on Engineering Education. Oslo, Norway.

Tuttas, J. and B. Wagner (2002). The relevance of haptic experience in remote experiments. EdMEDIA World Conference Educational Multimedia, Hypermdeia, Telecommunications., Denver, Colorado.

Tzafestas, C. S., N. Palaiologou, et al. (2005). Experimental evaluation and pilot assessment study of a virtual and remote laboratory on robotic manipulation. IEEE ISIE 2005. Dubrovnik, Croatia.

Ubon, A. N. and C. Kimble (2003). Supporting the creation of social presence in online learning communities using asynchronous text-based CMC. Proceedings of the 3rd International Conference on Technology in Teaching and Learning in Higher Education, Heidelberg, Germany.

Webb, H. W. and L. A. Webb (2005). Dimensions of learning interaction in the IT-supported classroom. Proceedings of the 2005 Southern Association of Information Systems.

Webb, N. M., J. D. Troper, et al. (1995). "Constructive activity and learning in collaborative small groups." Journal of Educational Psychology **87**(3): 406-423.

Wheeler, S. (2005). Creating social presence in digital learning environments: A presence of mind? TAFE Conference. Queensland, Australia.

Whiteley, T. R. and A. J. Faria (1989). "A study of the relationship between student final exam performance and simulation game participation." Simulation Games **21**(No. 1): 44-64.

Whitmer, B. G. and M. J. Singer (1998). "Measuring presence in virtual environments: A presence questionnaire." Presence: Teleoperators and Virtual Environments **7**: 225-240.

Wiesenberg, F. and S. Hutton (1996). "Teaching a graduate program using computer-mediated conferencing software." Journal of Distance Education **11**(1): 83-100.

Winer, L. R., M. Chomienne, et al. (2000). "A distributed collaborative science learning laboratory on the Internet." American Journal of Distance Education **14**: 1.

Yarkin-Levin, K. (1983). "Anticipated interaction, attribution, and social interaction." Social Psychology Quarterly **46**: 302-311.

Zimmerli, S., M. A. Steinemann, et al. (2003). "Educational environments: Resource management portal for laboratories using real devices on the internet." ACM SIGCOMM Comput. Commun. Review **53**(No. 3): 145-151.