

# A Different Kind of Difference: Theoretical Implications of Using Technology to Overcome Separation in Remote Laboratories\*

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*Laboratory classes are an integral part of undergraduate engineering education, providing a valuable alternative to lectures and tutorials. Recently there has been a trend towards providing these laboratory classes through remote access—where the students are separated from the hardware and interact through a technology-mediated interface. This trend is driven by a demand to provide increased flexibility and opportunities in the delivery of laboratory classes to students, but it has the unintended consequence of affecting the learning outcomes for students in the laboratory class. Remote laboratories are characterised by two key factors—a separation, both physical and psychological, between the students and the laboratory hardware; and a technology-mediated interface that is used to close this distance. Both of these factors have been shown in the literature to affect the way in which students learn, changing the contexts in which they construct their knowledge. The impact of these factors is such that remote laboratory classes are not simply a logistical alternative to in-person laboratories—rather, they are a pedagogically different learning experience, and they must be acknowledged as such.*

**Keywords:** remote laboratories; evaluation; media; transactional distance; presence

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## INTRODUCTION

LABORATORY CLASSES are a traditional part of undergraduate engineering education. They provide a number of valuable learning opportunities for students in a way that is difficult to reproduce through other teaching approaches. Students get the chance to illustrate and validate material encountered elsewhere; they are introduced to professional practice in the field of engineering, and to dealing with uncertainties; they develop skills with instrumentation; and they also develop social and teamwork skills in a technical environment. There is a dominant expectation that students will engage in laboratory activities in the course of their undergraduate studies—an expectation on the part of both students and academics.

The advent of computer technology, in particular the Internet, has seen a change in the nature of engineering laboratory classes in recent years. Computer based simulations have been used to assist the teaching of engineering students for

many years. The ability to conduct laboratory classes remotely first surfaced in 1996 [1], and since then has become increasingly prevalent. Examples of remote laboratory classes available include: determination of the speed of light from the resonant behaviour of an inductive-capacitive circuit [2], use of a transmission electron microscope [3], and control of an inverted pendulum [4]. Indeed, there are now conferences on Internet-based teaching in Engineering, with substantial numbers of papers on telelaboratories [5].

The shift to remote access addresses many of the difficulties involved in undergraduate laboratory work. It allows flexibility in time and place of access—the need to get everyone together in the one place at the one time with the hardware is eliminated. It can eliminate safety risks by separating students from potentially dangerous hardware. It can also allow access to hardware that would otherwise be unavailable, such as for students involved in distance education. It also allows a consortium of universities to share laboratory hardware across multiple campuses, as is the case in Germany at this time [6].

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In addressing these difficulties, however, the nature of the laboratory learning experience is being changed. Remote laboratories introduce two extra elements to the students' learning experience—a technology-mediated interface, and separation from the laboratory equipment. Both technology-mediated interfaces and separation have been shown in the literature to affect the learning outcomes of students involved in distance education, and the combination of the two has been shown to lead to changes in the learning outcomes of students exposed to different laboratory access modes. In a study of an accelerometer calibration laboratory, students were allocated to either a remote, simulation or a proximal access mode [7]. Students in the simulation and remote modes scored an average of 11% and 12% more, respectively, than those in the proximal mode for the learning outcome Exception Handling—differences that were statistically significant ( $p=0.011$  for the simulation mode and  $p=0.005$  for the remote mode). This suggests that the separation from the hardware enabled the students to more deal easily with unexpected results. Students in the simulation mode scored an average of 13% and 14% less than those in the proximal and remote modes, respectively, for the learning outcome Limitations of Accuracy—differences that were statistically significant at the  $p=0.001$  level for both modes. This suggests that the absence of real hardware reduced the students' understanding of the limitations of the calibration process they were performing.

A remote laboratory class is not interchangeable for a 'traditional' one. The introduction of separation—both physical and psychological—and technology-mediated interfaces serves to change the learning experience in significant ways, leading to significantly different learning outcomes. The value of a laboratory class is that it is different from alternative forms of instruction, such as lectures or tutorials. Remote laboratories present a different kind of difference. Rather than being merely a logistical alternative to in-person laboratories, they must be viewed as a pedagogical alternative, and recognised for the significantly different learning experience that they are.

## SEPARATION

The separation of the learners and the equipment introduces the element of distance into the learning experience—both physical distance and psychological distance. The impact of these distances has been reported extensively in the literature on Distance Education. The quintessential element of Distance Education is a physical separation of the learners and their instructors, and virtually all definitions of distance education include it: 'Learners are physically separated from the institution that sponsors the instruction' [8];

'Distance education involves a separation in time and/or space' [9].

Whilst physical separation is a key defining element of distance education, it is widely accepted that the psychological distance between the student and the teacher is as important—'research has provided compelling evidence that decreased physical and/or psychological distance between teachers and students is associated with enhanced learning outcomes' [10]. There is also evidence to suggest that the psychological distance is in fact more meaningful in determining the effects of the separation than physical distance [11].

### *The sense of reality*

When students and teachers are in close proximity, there is little doubt as to the authenticity of the interaction—both parties can directly observe each other. When dealing with parties that are not co-located, the concept of social presence becomes important. Social presence is 'the degree to which a person is perceived as real in a mediated communication' [12]. Social presence is strongly linked to academic outcomes—Social Presence is a strong predictor for student satisfaction [12–14]. Social presence is also a predictor for perceived achievement [15, 16].

Social presence can be established through a number of immediacy behaviours—actions that promote a sense of presence and interaction. The choice of expressions and vocabulary of the teacher is one such behaviour. Learning the students' names is another. Punctuality demonstrates a sense of perceived value in the teaching on the part of the teacher, and serves to enhance social presence. These immediacy behaviours have an impact upon student outcomes—greater teacher immediacy results in higher cognitive and affective achievement [17]. It is not just in distance education contexts that social presence is important, however. Spaulding found that a strong psychological presence from the teacher had a positive impact upon engagement and achievement for students in a writing task in a face-to-face classroom setting [18]. The psychological distance is as important as the physical distance.

Establishing social presence is a more challenging task in a remote or distance learning environment, but it is not impossible. Some immediacy behaviours do not depend upon proximity—learning students' names is possible regardless of any physical or psychological distance. Many of the behaviours, however, are not as robust to the separation of the teacher and the learner. Rather, they are dependent upon the nature of the communication medium used to close the distance—the medium moderates the interactions, and in so doing can potentially impact upon the social presence of the parties involved. Whilst there is a consensus that the medium itself does not influence the learning process per se, nonetheless the combination of the medium and other factors does serve to mediate the learning experience. One of the

critical challenges to overcome is how to establish presence through the mediation of technology.

One of the determinants of presence is 'media form' [19], which depends heavily on the transparency of the medium. The information provided by the medium must be sufficiently abundant to provide the user with a sense of presence, and furthermore this information must correspond to the information that the user would receive in an equivalent unmoderated environment. The second factor deals with how the user interacts with the mediated environment—it should respond to changes in the same way the unmediated environment would (such as views changing when the user changes his or her viewpoint). The first two factors are consistent with Lombard and Ditton's definition of presence as 'the perceptual illusion of non-mediation' [20]—that presence occurs when the users of media are oblivious to the media itself.

Lombard and Ditton give an extensive review of the literature dealing with media factors that affect presence, with the recurring theme being that richer feedback leads to a greater sense of presence [20]. Larger screens promote a greater sense of actually being there. Better image resolution promotes engagement. Colour images are better than black and white. Multi-modal feedback is superior to single mode feedback. The richer the experience, and the more information that is given—provided that this information remains consistent with itself and the environment—the greater the sense of presence reported by the users: the more transparent the interface, the greater the sense of presence.

#### *Transactional Distance*

The transparency of the interface was an important factor in Moore's theory of Transactional Distance [21]. Moore argued that the nature of the communication medium strongly impacted students' perceptions of the separation between themselves and their teachers, with three factors interacting to determine this Transactional Distance: Dialogue, Structure and Learner Autonomy.

Dialogue is the capacity for meaningful interaction between the teacher and the learner. Dialogue need neither be face-to-face, nor instantaneous, but it must be meaningful. Students who interact with their instructors via correspondence through the mail still have the opportunity for dialogue, albeit in a less spontaneous fashion. However, there is even the capacity for a 'virtual dialogue' in which the student has an internalised reaction to their material, thus forming a response. Dialogue is more than simply interaction between the parties.

The medium used alters the level of dialogue—'by manipulating the communications media it is possible to increase dialogue between learners and their teachers, and thus reduce the transactional distance' [21]. Dynamic communication media, such as teleconferencing and indeed most of the

modern electronic media, are more capable of supporting dialogue than their static predecessors. As the time lag between opportunities to interact reduces towards instantaneous interaction, the transactional distance also shrinks.

Structure is a measure of the way in which the interactions between the learner and the teacher are constrained by the course—'the extent to which an education programme can accommodate or be responsive to each learner's individual needs' [21]. Courses that are highly structured allow for only a limited range of dialogue between participants, whilst lightly structured scenarios allow each student to individualise the course for themselves. The extent to which a learner is able to create an individual dialogue impacts upon the transactional distance of the learning experience—highly structured courses have a higher transactional distance than those that are loosely structured.

Teaching strategies, evaluation methods, university imposed constraints, and the personalities of the teacher and the learners all contribute to the extent of the structure of the course. Highly structured communication media—such as a recorded television broadcast—offer the learner little or no opportunity for influencing the nature of the dialogue with the teacher. Less structured communication media—such as interactive video-conferencing—offer more chance for the learners to interact as they see fit. Overly structured environments prevent some interactions—reducing dialogue, and in doing so they increase the transactional distance.

Learner autonomy and transactional distance are linked. Courses with a higher transactional distance require a greater degree of autonomy on the part of the learner in order for him or her to learn. Students with a low capacity for autonomy cannot cope in environments where there is a large transactional distance.

The impact of transactional distance is that courses with a larger transactional distance both require and allow a greater degree of autonomy on the part of the learner—learners are freer within the structures of the programme to learn as they wish, but the corollary is that they are required to take more responsibility for their learning. If students do not have the required level of autonomy they cannot cope with the transactional distance, and they learn poorly, if at all.

Transactional distance is not an absolute concept—rather it is a relative term. Different environments may create different distances for different students. What is important is that the distance can be changed by changing the environment, and thus an improvement—if not a benchmarkable absolute measurement improvement—can be made. The interaction between dialogue, structure, autonomy and transactional distance has been verified by a number of studies [22, 23], but to provide more specific indications as to the impact on overall learning outcomes, the theory

must be extended. This extension was done by one of Moore's doctoral students, Namin Shin, who developed a complementary construct called Transactional Presence [24].

#### *Transactional Presence*

Whilst Transactional Distance is a measure of the barriers between the learner and the instructor, Transactional Presence is a measure of the extent to which the instructor is meaningfully present in the awareness of the student. Shin extended the concept of Transactional Presence to factors other than simply the instructor. Entities such as the learner's fellow students, and the university in which he or she is studying also have a presence that impacts on the learning environment—'Transactional Presence is proposed to be concerned with the degree to which a distance student perceives the availability of, and connectedness with, teachers, peer students and institution' [24].

The extent to which this impact is meaningful was measured by Shin in a study involving distance education students at the Korean National Open University (KNOU) [11]. The perceptions of 506 students from a range of academic programmes were rigorously measured. From these data, the Transactional Presence of their instructors, of their peers and of their university were measured. Three measures of academic outcomes were also evaluated: Learning achievement, both as perceived by students, and as measured by Grade Point Average (GPA), Satisfaction and Intent to Persist.

Analysis of the data showed many significant correlations between measures of Transactional Presence and measures of Academic Outcomes. Shin concluded that the Transactional Presence of each of the three entities had an impact upon the outcomes achieved by the students. Whilst the extent of the impact varied between categories, the sense of presence felt by the student led to a change in their outcomes.

With their perceptions of the Transactional Presence of these three elements of their learning environment seemingly affecting their overall learning outcome, it can be asked whether there are other aspects of their environment whose presence could also have an impact—in particular the presence of the hardware involved in laboratory classes. A differing sense of presence of the hardware may also lead to variations in these same outcomes. This sense of presence will in part be determined by the physical absence of the hardware, and this is a defining aspect of the remote laboratory experience. The other critical factor in determining this presence is the medium that is used to close the separation.

### **CLOSING THE DISTANCE WITH TECHNOLOGY**

Some form of mediation is necessary to enable distance education. This may include anything

from books and other study materials to a range of information and communications technology. The type of technology used has an impact upon the way this form of education occurs. The impact of communications media upon learning outcomes has been the subject of extensive debate in the literature. One of the key aspects of this debate is that media alone cannot influence learning—which is at the heart of the Clark–Kozma debate.

#### *The Clark–Kozma debate*

The Clark–Kozma debate centres on whether media, per se, have any effect upon learning. It was started in 1983 with Richard Clark's paper suggesting that media have no effects on learning outcomes [25]. This paper drew a number of responses (e.g. [26]), but the Clark–Kozma debate, as it is now known, started with Robert Kozma's presentation of a conference paper entitled 'Will media influence learning? Reframing the Debate', given at the International Meeting of the European Association for Research and Learning on Instruction (EARLI) in September 1993 [27]. The debate that arose between the two led to the journal *Educational Technology Research and Development* devoting an edition to the question of the impact of media on learning outcomes. Kozma had submitted his work on the topic for publication in the journal [28], and Clark was invited to write a response to his paper [29].

Clark's initial argument was that researchers in the field of educational technology were disregarding a substantial body of literature that showed that media had no significant independent impact upon learning. Whilst there had been research into comparisons between types of media—television versus traditional methods—there had been no data to show that the media themselves were making a difference. Clark exhorted researchers to take this absence as evidence for the negative, rather than an absence of evidence for the positive—essentially to accept the null hypothesis that there were no differences to be found.

The key principle behind Clark's viewpoint is that it is the teaching method, and not the medium, that is the key element in determining outcomes. The development of new media leads to the development of new teaching methods, and it is these new teaching methods, and not necessarily the new media that they employ, that is responsible for measured differences in outcomes. The attributes of different media—such as a television's ability to zoom in on pictures to highlight areas—are useful tools for an instructional method, but they are not necessary. Other media can achieve the same zoom effect, and there are other ways of highlighting areas within an image that do not involve zooming. Clark argues that it is the instructional method of highlighting, not the media attribute of zooming, that is responsible for the learning outcomes. The same method, with a different medium for highlighting areas of an image, will produce the same outcomes.

Clark's viewpoint reduces the medium to simply a delivery vehicle for the method—exemplified by his now famous quote that 'the best current evidence is that media are *mere vehicles* that deliver instructions but do not influence student achievement any more than the truck that delivers our groceries causes changes in nutrition' [25].

Kozma's viewpoint differs from Clark's in that the medium is not regarded as an inert vehicle for transferring information—that there is interaction between the medium and the message. Different media use different symbols in their conveyance of information [30]. Some symbols are more suited to abstract concepts, whilst others are better for conveying more concrete knowledge. In this way different media are better suited to different content areas. For instance, TV is better for conveying concrete images, rather than abstractions. The learner can only construct their learning from the building blocks that the instructional method provides—and the range of these blocks is further constrained by the selection of the medium involved.

One of the key issues in this debate is whether the medium is in fact an inert vehicle, or whether the medium and the content interact. Clark was initially interpreted as suggesting that the medium was in fact completely inert, with many readers focusing on the analogy of the delivery truck as the key statement in the article. Clark's original analogy, however, was not intended to be sufficiently robust to cope with all elements of the debate on the interaction between content and medium. It was meant as a way of illustrating the difference between the medium and the message that it conveys—a statement diametrically opposed to the theory of Marshall McLuhan.

Marshall McLuhan, in his 1964 book *Understanding Media*, on the other hand put forward the assertion that 'the medium is the message' [31]—that there is in fact no distinction between the message and the medium that carries it. McLuhan argues strongly against the making of distinctions between a medium and what is done with the medium—the two are inextricably linked. McLuhan draws examples from a number of fields, not just communication, to establish his point.

McLuhan presents a different view of the messages carried by media. Rather than the message being some form of content, the message is in fact the impact that the media has upon human association and interaction. Indeed, 'the content of any medium is always another medium'—a separate medium (and thus message) of its own, rather than something that is conveyed on another medium. McLuhan asserts that there is no meaningful distinction between the medium and the content because they are one and the same. There is no interaction between medium and content—content is a medium, and there is no distinction between the two. By McLuhan's definition, the idea of an inert vehicle is ridiculous—the content is its own vehicle. Whilst few

participants in this debate fully share McLuhan's inseparability of the medium and its content, there is agreement that the medium is more than just an inert vehicle.

#### *Biasing expectations*

In addition to considering the medium and the way in which it filters students' interactions, it is important to consider the medium as part of the overall learning context. 'Media are part of the context and are much richer than the attributes ascribed to mere vehicles' [32]. The attributes of the media change the environment in which the students engage in the learning process—different media lead to different contexts. 'Media bias perceptions' argues Jonassen [32], and this can have considerable effect upon the overall outcomes.

In addition to the direct effects of the interaction between the medium and the content, it is important to consider also the indirect impact that the medium may have upon the learning process. Reiser asks 'Might learners' beliefs about a delivery system affect how much they learn?' [33]—raising the possibility that there is an interaction between the learner and the medium from which they are learning, and that this interaction impacts upon the learning process.

This interaction has been shown to have an impact in a study of students learning from video. Preconceptions about the amount of effort involved to learn from a particular medium can influence the efforts students do make, and in some cases, affects their learning outcomes [34].

The consensus is that the medium is not simply an inert vehicle. The choice of medium has an impact upon the way in which students can and do engage with the content it conveys. What must be considered is if this impact is significant—whether it is an impact that could be produced by another, equivalent medium, or if there is some attribute to the medium that makes it irreplaceable. It is this issue of replaceability that is the core difference between the views of Clark and Kozma.

#### *Replaceability of media*

The original intention behind Clark's delivery truck analogy was misconstrued by many of those who responded to his work. Clark's argument was not necessarily to argue that the medium had no effect upon the content—rather, his argument was that media were replaceable. One delivery truck was as good as another in delivering our groceries. It is this topic of replaceability that lies at the core of Clark's arguments concerning media, and of the disagreements between Clark and Kozma's viewpoints.

Clark's argument is that for a medium to have an effect upon learning outcomes, there must be some attribute of that medium that make it irreplaceable in the learning experience—that its presence was necessary for learning to occur. If the medium could be replaced by another medium,

and the same outcomes achieved, then it was the attribute shared by the media, and not the medium itself, that was responsible for the learning. It is the way in which the instructional methods employ these attributes that is important—‘When a study demonstrates that media attributes are sufficient to cause learning, the study has failed to control for instructional method and is therefore confounded’ [29]. Clark instead contends that it is the attributes that are necessary for learning that are important in the comparison of learning methods—and that it is the necessary attributes of the method, and not the sufficient attributes of the medium, that are crucial.

The counterargument of Kozma and others is that it is not a matter of necessary attributes that are important, but rather of sufficient conditions—what conditions, if met, will cause learning to occur, rather than what conditions, if not met, will prevent it. A medium is replaceable if there is another medium that can achieve the same outcomes, regardless of which attributes are employed. It may be that two different media can achieve the same outcomes without similar approaches—neither would be essential to the learning, but either is sufficient [35].

It is the development of new media, with new capabilities, that leads to the misconception that new media can be responsible for different learning outcomes. But it is the attributes of the new media, employed by the new teaching methods, that make the differences—when additional media that share those attributes are created, then the initial media will again become replaceable.

The validity of the whole replaceability argument is questioned from an instructional design viewpoint by Reiser [33], who argues that the necessary versus sufficient argument is unnecessary—when it comes to designing learning experiences, it is simply a matter of what works. Some teaching methods require certain media attributes—without those attributes, those methods are impossible. Whether any improvements because of these new methods are due to media, or method, or attributes, is unimportant—what is important is that it works.

There are two take-home messages from this debate: first, that it is effectively impossible to distinguish between the effect of an instructional method and the medium that it employs; and second, that it is ultimately not necessary to make this distinction. Attention should be focused instead upon the overall learning context—of which the selection of appropriate media is an important part, but ultimately just a part.

## CONCLUSION

Laboratory classes are a valuable learning tool for undergraduate engineering students. They provide opportunities for the students to validate concepts encountered elsewhere, to develop their skills as professional engineers, and to gain experience in a technical environment. The underlying reason for the value of laboratory classes is that they are a fundamentally different context for the students’ learning. Students in a laboratory class engage with the material and their environment differently from when in other learning modes, such as lectures or tutorials. They embed their learning into a different context, and construct different knowledge as a result.

There are strong parallels between the Clark–Kozma debate on the replaceability of media, and the issues surrounding the replacement of in-person laboratory classes with remote laboratory classes. Just as substituting one communication medium for another has wider ramifications for the overall learning experience, the shift to remote access for laboratories has a broader impact upon the students. Whilst it may appear that all that is being changed is that the students and the hardware are no longer together, what has in fact happened is that the learning context has fundamentally changed. A physical and mental separation has been introduced, a separation that changes the way in which the students perceive their laboratory class as real. To close this separation, a technology-mediated interface is introduced, and in doing so the students’ interactions with the hardware are filtered, and their attitudes potentially biased.

The initial motivation of remote laboratories was to provide a logistical alternative to having students in the laboratory. What has been achieved is in fact a pedagogical alternative—a learning context that provides a significantly different experience. This shift of context has gone largely unremarked. The objectives of the laboratory classes remain unchanged, and the intended outcomes are the same—it is viewed merely as a logistically convenient rearrangement, rather than pedagogical paradigm shift.

But a paradigm shift it is. The very features that distinguish remote laboratories—distance and technology-mediated interfaces—have significant impacts upon students’ learning. Students have a fundamentally different learning opportunity in a remote laboratory, and this must be acknowledged as investigations into their effectiveness are conducted.

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