Remote Versus Hands-On Labs: A Comparative Study

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Abstract - **Advocates of hands-on laboratories and advocates of simulation have debated for years. Proponents of hands-on laboratories argue that student engineers need to be exposed to the physical experiences - and the uncertainties - of real environments. Advocates of simulation argue that physical labs are wasteful – they tie up badly needed space, and consume student's time in menial set-up and tear-down procedures. Now remote laboratories have appeared as a third option. These laboratories are similar to simulation techniques in that they require minimal space and time, because the experiments can be rapidly configured and run over the Internet. But unlike simulations, they provide real data. It is unknown what the relative effectiveness of hands-on, simulated, and remote laboratories is. This paper presents a model for testing this relative effectiveness, and discusses the results of a preliminary assessment study comparing versions of remote labs versus hands-on labs in a junior-level mechanical engineering course on machine dynamics and mechanisms.**

Index Terms – remote laboratories, cognitive style, educational effectiveness, user interfaces, presence

INTRODUCTION

A debate has been raging for decades between advocates of hands-on labs and those of simulated laboratories. Hands-on adherents think that engineers need to have contact with the apparatus and materials they will design for and that labs should include the possibility of unexpected data occurring as a result of apparatus problems, noise, or other uncontrolled real-world variables. Adherents of simulation often begin by invoking the specter of costs – laboratories take up space, and student time. Setup and teardown time is usually greater than the actual experiment performance time. They then claim that simulation is not only cheaper, but it is also better, in that more situations can be tried than with real laboratories. The arguments on both sides are well-developed [1-7]. In addition, researchers have looked at student preferences and educational outcomes related to simulation [8-10].

A third alternative, remotely operated laboratories, are somewhere in between – they require some space, but less than a real lab. These laboratories have been described before [11-14]. They use real data, but the data is acquired through the mediation of a web interface. They are inexpensive to operate. Other researchers have noted this three way distinction [15].

Related issues have been debated in the literatures on design of instruction and educational media. Adherents of hands-on learning suggest that there is much more information, many more cues, in working with real equipment. Their argument is supported by theories of presence and media richness [16-21]. The parallel position in the collaboration literature is the advocacy of face-to-face contact over mediated communication. But there is another position – that the richness of media does not matter, that we adapt to whatever media are available [22]. We may have a preference for hands-on, or face-to-face, but this might be socially rather than technologically determined. Nowak, Watt and Walther [23] articulate this later position and present evidence that, for their collaboration task, mediated asynchronous video is less preferred than face-to-face – but just as effective.

The debate as to which type of educational lab is best can be settled only by conducting careful evaluation studies, designed to compare these formats with common instructional content and identical populations of students.

THE ASSESSMENT MODEL

We present here a model which we intend to use to aid us in designing a series of experiments as part of our overall research program.

We build on previous research in this area [24], which has culminated in the construction and use of remote laboratories with engineering students. Thus, the model is grounded both in the literature and in the accumulated experience of several years of instruction (by the authors and other educators) using hands-on and remote laboratories.

What can we measure in terms of the end result? We can of course look at student test scores. Of most interest are the responses to questions constructed to directly test the knowledge and skills taught in the laboratory assignment. Student grades on the actual lab assignments are also relevant. Furthermore, we can ask about student preferences for specific labs and their associated formats and interfaces.

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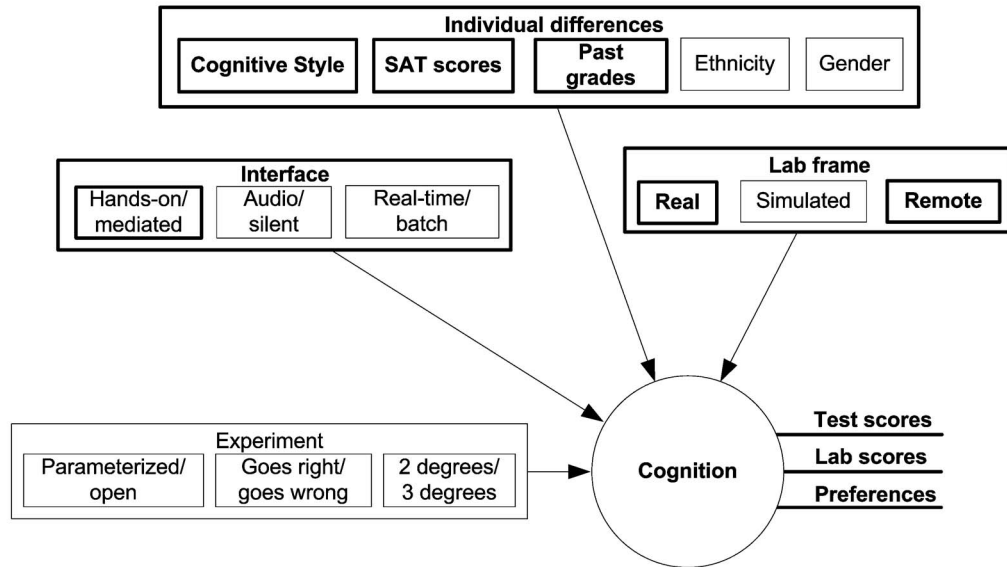
FIGURE 1
A MODEL FOR INVESTIGATING THE RELATIVE EFFECTIVENESS OF HANDS-ON LABS, REMOTE LABS, AND SIMULATED LABS. CONSTRUCTS MARKED WITH BOLD ARE
CONSIDERED IN THE EXPERIMENT DESCRIBED HERE.

Independent variables cluster into several areas. First are student characteristics, including individual differences in abilities and cognitive style. The intelligence and motivation of students is often correlated with test scores – we want to control for these variables. For example, there is some evidence that media-rich environments help good students less than poor students [25, 26].

Second, the actual topic or experiment performed may have an effect on the results. For some experiments, the results can be easily imagined – for others, the results may be unexpected. We are currently using vibration experiments with either one, two or three degrees of freedom. The latter are more complex and harder to predict. Also associated with the experiments is their openness – some experiments may only allow certain parameter values to be fed in – others may force the student to discover valid ranges. And some experiments may provide good data – and others bad data. Hands-on adherents claim that coping with bad data is a skill learned from real experiments. Simulation adherents argue that well-designed simulations can simulate these experiences as well.

Third are characteristics of the remote labs interface. Even in hands-on experiments, there are issues of mediated interfaces, as hands-on engineering experiments might entail the use of an oscilloscope, or a LabVIEW-controlled data acquisition tool. Theories related to presence imply that the richer the interface the better. Theories of adaptation predict that this does not matter very much.

The issue of real-time versus batch mode of execution is of particular interest. With remote labs, the ability to use batch is convenient from a scheduling perspective – students can

initiate a run, and later view a video of the experiment. But there is obviously little presence in viewing an old video. The work of Nowak et al. [23] suggests that the preference will be for hands on, but asynchronous video will be just as good.

Fourth is the format of the educational laboratory – whether the lab is real, simulated, or remote. To be more precise, it may be the *perceived* format of the lab that is critical – whether the student *believes* the lab to be remote or simulated, for example. We will refer to manipulations of these beliefs as *framing* of the lab format. If we find that remote or simulated labs are more effective than the other, we may want to manipulate the perception of the lab in order to see if the effectiveness is socially or technologically determined. For example, we can describe a remote lab as being a simulation, or a simulation as being a remote lab, and see if the students' preferences and scores change. If either do, it suggests that the framing, which is a social construction, overrides the technical differences of the interface.

METHOD

Procedure

The evaluation study was designed and conducted as part of a course on machine dynamics and mechanisms at an urban college of engineering during the Fall 2003 semester. Students in the course were junior mechanical engineering majors (N=29). The course content focused on the kinematics and dynamics of mechanisms such as linkages, cams and gears. In this course, labs are used to deepen conceptual understanding

of the topics, and to give students practice in collecting and analyzing data, and drawing conclusions based on the data and their understanding of the issues.

Six labs were conducted during the course. For this study, three of the labs (free, step, and frequency response of a mechanical vibration system) were given as remote labs, and three (gear box, flexible machine, rotor balancing) were given in the traditional hands-on format. The two lab formats were compared by gathering data on student satisfaction with the remote labs, and by measuring student educational outcomes. In addition, we investigated if student preferences for and success with remote labs are related to student characteristics, in particular cognitive style and ability (as measured by SAT scores and high school GPA).

Measures

Educational outcomes were measured by exam scores and lab grades in the course. Two midterm exams were constructed to include exactly two questions on the content of each of the labs. Student satisfaction with the remote labs was assessed by a questionnaire (the Student Feedback Form, SFF) constructed for that purpose. It also included questions evaluating specific aspects of the remote lab interface and lab procedures, and included comparable questions regarding the hands-on labs. Individual student characteristics were assessed through student records, including demographic information, SAT scores, and GPA.

Finally, a measure of individual students' cognitive style, the VARK [27, 28] was administered. This instrument measures student preferences for specific modes of communication, including visual, auditory, textual, and kinesthetic modes. A cognitive style measure was included because it is a widely accepted view in educational psychology that students vary along a verbalizer-visualizer dimension, such that they prefer to work with and learn from one type of materials more than the other [29]. It has recently been argued that some students show predilections for other modes of information acquisition, such as motor or kinesthetic modes [27, 30] . The VARK was chosen for this study because it has been used before in the context of remote labs [31], and because the possibility of students being kinesthetically-oriented seems relevant to predicting student success with remote labs.

Results – Student Perceptions of Remote Labs

Our main question was if remote labs are as effective as hands-on labs. We first checked student reactions to the labs. One item on the SFF asked students to rate how effective were the remotely-operated labs (labs 1-3) compared to the traditional labs (labs 4-6) in providing applications of course concepts to real-world systems. Of the 26 students responding to this item, 3 (or 10%) responded "more effective", 21 (72%) said "about the same", and 2 (8%) said "less effective". Another item asked students to rate (on a 9-point scale) five specific aspects of the labs (both remote and traditional) as to their value in promoting understanding of course concepts, as shown in Table I.

TABLE I
IMPORTANCE OF LAB ACTIVITIES (FOR BOTH HANDS-ON AND REMOTE LABS): MEANS AND STANDARD DEVIATIONS OF STUDENT RATINGS.

Lab Activity	Mean	Std. Dev.
Preparatory instructions	6.59	1.78
Data acquisition	5.93	1.98
Lab report	6.52	2.05
Team work	6.07	2.18
Physical presence in lab	5.37	2.12

Results show that the aspects rated most important were the preparatory instructions (with a mean rating of 6.6), followed by writing the lab report (6.5). "Team work" was third (6.1), followed by data acquisition (5.9). Rated least important was "physical presence in the lab" (5.4). This low rating is another indication that students viewed the remote and hands-on labs as essentially equivalent in effectiveness. Ratings of individual lab's impact (without specifically addressing lab format) on the students' understanding revealed few differences between the remote and hands-on labs. The remote labs actually were rated as having slightly higher impact on average (6.1 vs. 5.7 on a 9-point scale), but this seemed mainly due to one hands-one lab that was rated lower than the other five.

The Student Feedback Form also contained questions that dealt with other aspects of student experience and satisfaction with the remote labs specifically, as shown in Table II.

The most highly rated aspects of remote labs were: convenience in access (mean rating 8.6 on a 9-point scale), convenience in scheduling (8.4), ease of use (8.4), and reliability of setups (8.2). Overall satisfaction was rated at 7.2. The lowest-rated aspect of the remote labs was "feeling of immersion", with a mean of 6.2 on the 9-point scale.

TABLE II
SATISFACTION OF STUDENTS WITH SPECIFIC ASPECTS OF THE REMOTE LABS: MEANS AND STANDARD DEVIATIONS OF RATINGS.

Lab Aspect	Mean	Std. Dev.
Overall satisfaction	7.15	1.17
Feeling of immersion	6.23	1.31
Ease of use	8.37	0.88
Obviousness of use	7.81	1.15
Total time required	7.89	1.67
Convenience of scheduling	8.44	1.28
Convenience in access	8.56	0.85
Clearness of instructions	7.59	1.47
Reliability of setups	8.15	0.91

Results – Learning Outcomes

Actual learning outcomes for the content of the remote labs versus the traditional labs were assessed by questions on the midterm and final exams directed specifically at that content. A composite score variable for remote-labs content was constructed by summing five items aimed at the instructional

content of labs 1-3 (the remote labs) and dividing by the total number of points, and a composite score variable for the hands-on lab was constructed analogously for four relevant test items. Results revealed very similar achievement levels: the mean proportion correct for the remote-lab contents was .60, while for the hands-on labs it was .61.

Results – Individual Differences in Perceptions of the Labs

The results reported above suggest that remote labs can be effective educationally. But are they equally effective for all learners? In particular, does their effectiveness vary with student ability, or with differences in students' "cognitive style"?

First, we correlated student ability (measured by SAT scores) with student perceptions of lab effectiveness, as shown in Table III.

It is widely accepted that a student's cognitive style can affect their preferences for educational media, presumably including preferences for hands-on versus remote labs. Accordingly, we correlated VARK subscale scores (visual, aural, read/write and kinesthetic) with various student preference and satisfaction measures (Table 3). VARK subscale scores were not correlated with student SAT scores nor with GPA. A preference for aural materials (and a higher total VARK score) was correlated with a feeling of immersion in the remote labs. In terms of specific lab activities, students with a kinesthetic style gave lower importance ratings for the value of preparing lab reports and for team work. feeling of immersion, ease of use, total time required, and convenience in scheduling. However, in the question that asked students to *directly* compare the effectiveness of the remote labs versus the traditional hands-on format, students with lower SAT score gave slightly (but not significantly) higher ratings to the remote labs.

Those with a visual style (and with higher total VARK score) gave lower ratings to the importance of the preparatory instructions and, importantly, to the importance of physical presence in the lab. Those with read/write cognitive style as measured by the VARK. SAT scores were marginally correlated (p<.1) with overall satisfaction ratings for the remote labs, meaning that more able students were more satisfied with the remote labs, and students with higher SAT scores also rated the remote labs more positively on preferences gave lower ratings to preparatory instructions. We

first checked that SAT scores (SAT-M, SAT-V, and SAT-total) did not correlate with any of the measures of and data acquisition. No other correlations of the VARK subscale scores with preference variables were found.

It should be noted that only a few of the correlations in Table 3 are significant, therefore it is prudent to worry about the possibility of Type I error. Thus, any inferences about relationships among variables resulting from this correlational analysis should be viewed with caution and replicated if possible.

DISCUSSION

The results of this pilot assessment study were encouraging. More than 90% of the student respondents rated the effectiveness and impact of the remote labs to be comparable (or better) than the hands-on labs. This equivalence was also demonstrated by analyses of scores on exam questions involving specific lab content.

Results involving the relation of specific student characteristics to rated satisfaction with the remote lab format were inconclusive. There was some tendency for students of higher ability to give higher ratings to specific aspects of the remote labs, but lower-ability students gave slightly higher ratings to the remote labs when they were directly compared to the hands-on format. 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).

FUTURE RESEARCH

More research is planned to replicate these results with a broader range of topics and tested skills. We wish to further investigate how student characteristics affect their satisfaction with remote labs (and simulations) using larger samples, and to test the impact of distinct features of the interface. In the area of cognitive styles, we plan to more thoroughly investigate the role of visual preferences and visual abilities; for example, it may be that spatial ability influences a student's learning with or preferences for remote labs versus hands-on labs [29, 32].

TABLE III
CORRELATIONS OF STUDENT ABILITY AND COGNITIVE STYLE (VARK) SUBSCALES WITH STUDENT RATINGS AND LAB-RELATED TEST SCORES. SIGNIFICANT CORRELATIONS ARE INDICATED WITH AN ASTERISK.

Rating variable/score	GPA	SATV	SATM	SATT	Vark-visual	Vark-aural	Vark-read	Vark-kines	Vark-total
Effectiveness: remote vs.	.10	-.23	-.27	-.26	.21	.46*	.17	.13	.44*
Overall satisfaction	.12	.10	.23	.16	-.03	.13	-.21	-.22	-.13
Feeling of immersion	.18	.33	.24	.35	-.12	-.01	-.20	-.21	-.22
Physical presence in lab	-.33	.06	.08	.07	-.47*	-.15	-.20	-.23	-.44
Remote labs test score	.57*	.01	-.10	.00	-.15	-.16	.13	.17	-.01
Hands-on labs test score	.32	.29	.39	.39	-.06	.05	.32	-.23	.06

SUMMARY

We have outlined a model for testing the relative effectiveness of hands-on, remote, and simulated laboratories, and we have discussed results from a pilot assessment study that directly compared remote and hands-on labs in the context of a single course. This focused comparison, though limited in scope, allows for carefully controlled comparisons of the two lab formats, because exactly the same students take part in both types of labs. Results suggest that remote labs are comparable in effectiveness to hands-on labs, at least in teaching basic applications of course content.

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