An Assessment of In-Person and Remotely Operated Laboratories

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ABSTRACT

Increasingly mechanical engineering departments are beginning to incorporate remotely operated laboratories into their laboratory curriculums. Yet very few studies exist detailing the extent to which this new medium for laboratory delivery fulfills the educational goals of traditional in-person laboratories. This paper describes a comparison of educational outcomes between in-person and remotely operated laboratories in the mechanical engineering curriculum. The study carried out in the 2001 Fall semester was performed using a remotely operated and an in-person jet thrust laboratory. The laboratories illustrate the fundamentals of compressible fluid mechanics as part of an undergraduate mechanical engineering curriculum. The results from this study indicated no significant difference in the educational outcomes between students who performed the in-person or the remote experiment.

I. INTRODUCTION

Recent years have seen enormous financial pressures on engineering departments struggling to cater to increased enrollments, static budgets, and the need to maintain educational quality. As departments look for ways to cut costs, hands-on instructional laboratories, typically expensive to develop and maintain, are slowly being replaced with simulated experiments [2, 6, 11, 14, 17, 22]. Throughout the paper we take the broad definition of *laboratory* to mean, *the entire experimental experience including, detailed background and contextual information, sources of additional resources, description of the experimental apparatus and laboratory write up information.* An American Society for Engineering Education (ASEE) task force noted with concern that many universities are unable to sustain the cost of maintaining all their laboratory course work and recommended that engineering, "re-think the objectives of laboratory instruction and experiments, and find innovative ways for satisfying objectives" [5].

Computer simulations of laboratory experiments are extremely useful in many cases, and can often be an effective alternative to hardware-based experiments. However, many (if not most) laboratory exercises require visual or auditory interaction with the setup and/or involve concepts that are sufficiently complex that they cannot be accurately simulated. In these cases, the student simply must interact with a hardware-based system, watching and/or listening as the equipment responds under his or her control. Further, a laboratory curriculum based on simulations alone would not adequately present problems that students may see in a physical laboratory nor provide adequate hands-on experience necessary for effective learning [13, 20, 23, 26]. A pedagogically sound mechanical engineering curriculum must therefore provide students with an appropriate balance of simulated and hands-on laboratory experiences.

Recognizing the importance of hands-on experimentation in the undergraduate curriculum [3, 9, 16, 20, 21, 23, 31], several institutions have developed remotely operated laboratories as a *supplement* to their existing laboratory curriculum [1, 4, 10, 12, 19]. Developing remotely operated laboratories—through (1) the automation of experimental controls, (2) the addition of cameras and microphones to capture and transmit the visual and auditory information, and (3) relaying sensor outputs (temperature, pressure, velocity, etc.) via appropriate software—allows a remote-student to perform the same functions and receive much of the same sensory and digital feedback as a student conducting the experiment in the room. Provided the experiment is set up to run without the need for human intervention, hands-on laboratories can be made available via the Internet on a 24 hours/day, 7 days/week basis, facilitating access at times that accommodate individual student needs.

Remotely operated laboratories, however, also have their disadvantages. The lack of physical contact with the experimental apparatus by the student results in a lack of experience with even simple tasks, for example attaching patch cables, trouble shooting problems, and familiarity with how components are wired together. As noted by Burks Oakley II, Associate Director of the University of Illinois Online, "...I'm still one that says you have to go [into the laboratory] and do something...It's that hands-on component where you are connecting wires together" [7].

To date, very few studies have been performed to determine the effectiveness of remotely operated laboratories in meeting stated educational objectives. In an ABET-sponsored meeting held in San Diego in January 2002, engineering officials acknowledged a lack of evaluation data on online labs as one of the impediments to setting guidelines or standards [7].

This paper provides a comparison between the educational outcomes from in-person vs. remotely operated laboratories.

II. REMOTELY OPERATED LABORATORIES

The development of a complete remotely operated laboratory experience goes well beyond the design and construction of the experimental apparatus and support software. The experience must be pedagogically sound to ensure that students achieve the same level of performance with respect to the learning outcomes as would be expected from in-person labs. We therefore developed the *Instructional Remote Laboratory Environment (IRLE)* whose constituent experiments have the following characteristics:

1. *High visual and audio (if applicable) components.* This not only makes the experiment more interesting to run, but allows students to use all their senses and better understand that they are running an actual experiment, and not a simulation. Several developers of remotely operated labs have made similar observations. For example, Michau et al., [25] noted that, "…real-time video transmission of the experiment…combined with sound transmission is essential to the credibility of a remote experiment."
2. *Students are able to remotely run the labs using a regular Web-browser without the need to install specialized software.* This requirement facilitates the running of the experiments from dormitories, apartments or any university computer laboratory where it may be difficult or costly to have specialized software installed. This requirement is also in line with one of the recommendations of an NSF-sponsored workshop of the Engineering Coalition of School for Excellence in Education and Leadership (ECSEL) that stated, "Recognize that not everyone in the world have the same computer systems or web-browsers…Design to include the widest range of anticipated users possible" [5].
3. *The experiments are sufficiently complex making simulation difficult or impossible.* Although many experiments can be simulated, many cannot or differences between the simulation and real-world experiment are important for students to observe and understand. For example, Gonzalez-Castano et al. [12] noted that, "Although it is important to use simulation to teach many practical skills to students, there exist several situations where the use of real equipment is compulsory: either the development of a simulator from scratch is infeasible or real industry equipment is too complex to simulate." Also Web-based remote laboratories give the students opportunity to use equipment that may not be available in in-person laboratories due to safety issues (e.g., high noise levels, high-energy lasers).
4. *The labs provide an integrated learning environment.* This environment is embodied in a pre-lab (which provides background on the experiment and the general subject area and includes links to other information resources), remote access to the experiment, and a post-lab (which contains information necessary to complete the laboratory write-up). Students are able to perform the entire experiment, analyze the data and complete the necessary reports with minimal instructor intervention.

III. THE JET THRUST LABORATORY

In July 2001, through an Instructional Technology Initiative Grant from Rutgers University, we developed the remotely operated jet thrust laboratory. The aim of the jet thrust laboratory is to give students a laboratory experience in the general area of fluid mechanics, highlighting the integral control volume formulation of the governing equations, and general aspects of compressible flow. The laboratory is one of several that form the required senior level laboratory course, *Mechanical Engineering Senior Laboratory I*. The course is offered each Fall semester with enrollments of 70–90 students. A full description of the laboratory can be found in [28].

Figure 1 shows a schematic of the primary components of the jet thrust laboratory. The experiment consists of a 10.2 mm axisymmetric jet mounted on a balance allowing the direct measurement of the thrust using a load cell. The stagnation pressure of the jet is regulated with a computer-controlled valve. A pitot probe can be scanned across the exit of the jet using a stepper motor operating a linear traversing stage. A *Schlieren* system has also been set-up so that the students can observe the shock pattern from the jet when it is operated at supersonic Mach numbers. All the equipment is computer controlled through a LabView® program. Through this laboratory, the students learn how to calculate the thrust from a jet using three different methodologies and verify assumptions made in the calculations. In addition, the students operate the jet in the

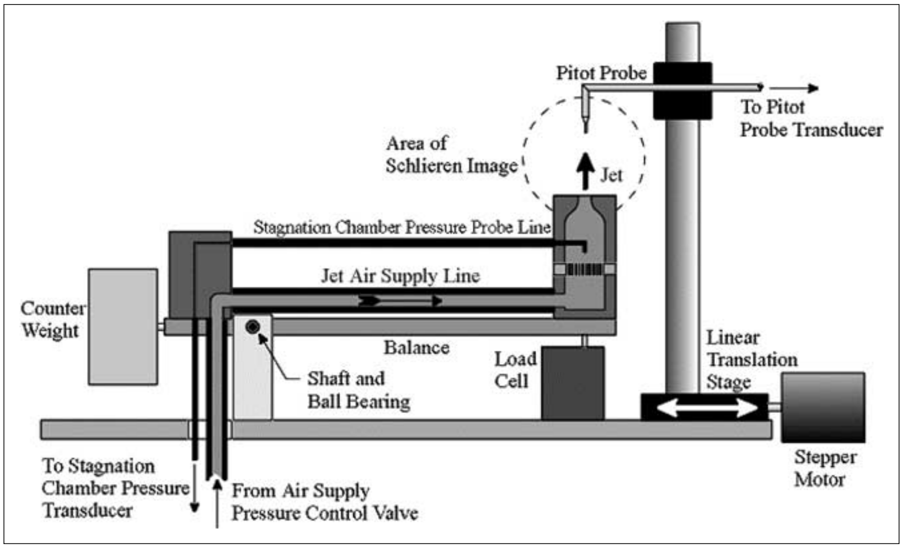


Figure 1. Schematic of experimental apparatus.

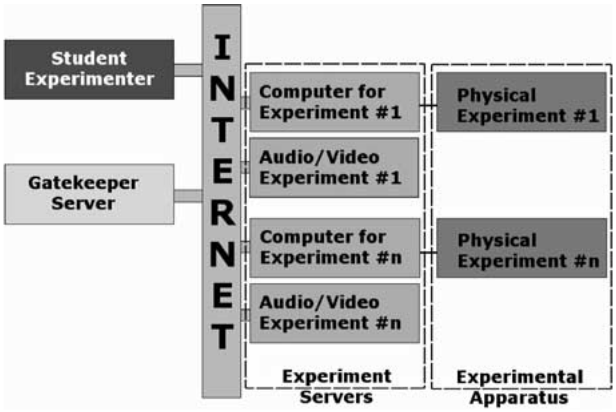


Figure 2. Basic structure of the Instructional Remote Laboratory Environment (IRLE).

supersonic (underexpanded) flow regime and learn basic characteristics of compressible flow such as choked flow, shock waves, and expansion waves.

The Instructional Remote Laboratory Environment (IRLE) through which the laboratory is run, is modular in nature, i.e., experiments controlled by different types of computers and software in separate locations could easily be added or removed from the system with minimal effort. To achieve this, IRLE was divided into three basic components connected via the Internet. They are the gatekeeper server, the experimental apparatus and the experiment servers, as illustrated in Figure 2.

The *gatekeeper server* is the students' entry point into IRLE. Students have their own accounts that they can login to at any time. Once logged in they can:

1. *Sign up to run a laboratory.*
2. *Select and view the prelab materials for a particular experiment.* The prelab contains a motivation section which gives the history and examples (with MPEG movie clips) of thrust, thrust measurement, and supersonic flow. This is followed by detailed step-by-step examples of how to calculate thrust from a control volume analysis. Then the experiment and components are described in detail with schematics, pictures of the apparatus, and short video clips of each major component. The video clips provide uniformity of presentation to all students and allows the students to review the material over and over again. This approach has been shown to be effective in ensuring students have a successful experience when they run the lab—for example [16]. As students view each page in the pre-lab materials, the date and the amount of time they spend on each page is noted in a Filemaker® database. This information allows the determination of how much time each student spent on the pre-lab and correlation to how well they do in the laboratory. In addition, it provides quantitative information on which pages are appealing to the students, based on the time spent on that page, and which ones are not. Information on the latter item allows corrections to the laboratory documentation to be made. Quantitative data collected in this way is also compared to qualitative evaluations performed at the end of the laboratory in the form of student questionnaires to try and determine student attitudes towards various features of IRLE.
3. *Run the experiment.* When students select this option, they are transferred to the computer that controls the experiment.
4. *Generate an E-Lab Notebook.* As the students run the experiment, all their experimental data is automatically stored for them. In addition, students can enter comments on any observations, problems or about the data itself at various points in the experiment. On completion of the experiment, the students have access to all their data and comments from the e-lab notebook resident in their individual accounts.
5. *Read the Post-Lab Instructions.* This contains instructions for completing the laboratory write-up.

On the experimental apparatus side, three servers simultaneously send information to the student during the course of the experiment (refer to Figure 3). The servers individually provide control of the experiment, step-by-step instructions and streaming video of the Schlieren images. The experiment is controlled through a LabView® Virtual Instrument. To allow the laboratory to be controlled remotely, a *Virtual Network Computing (VNC) server* is installed on the experiment computer. The VNC server allows the computing "desktop" environment to be viewed from anywhere on the Internet through any Java-capable browser. It allows the remote real-time transmission of keyboard commands and mouse movements as if one were sitting at the host computer.

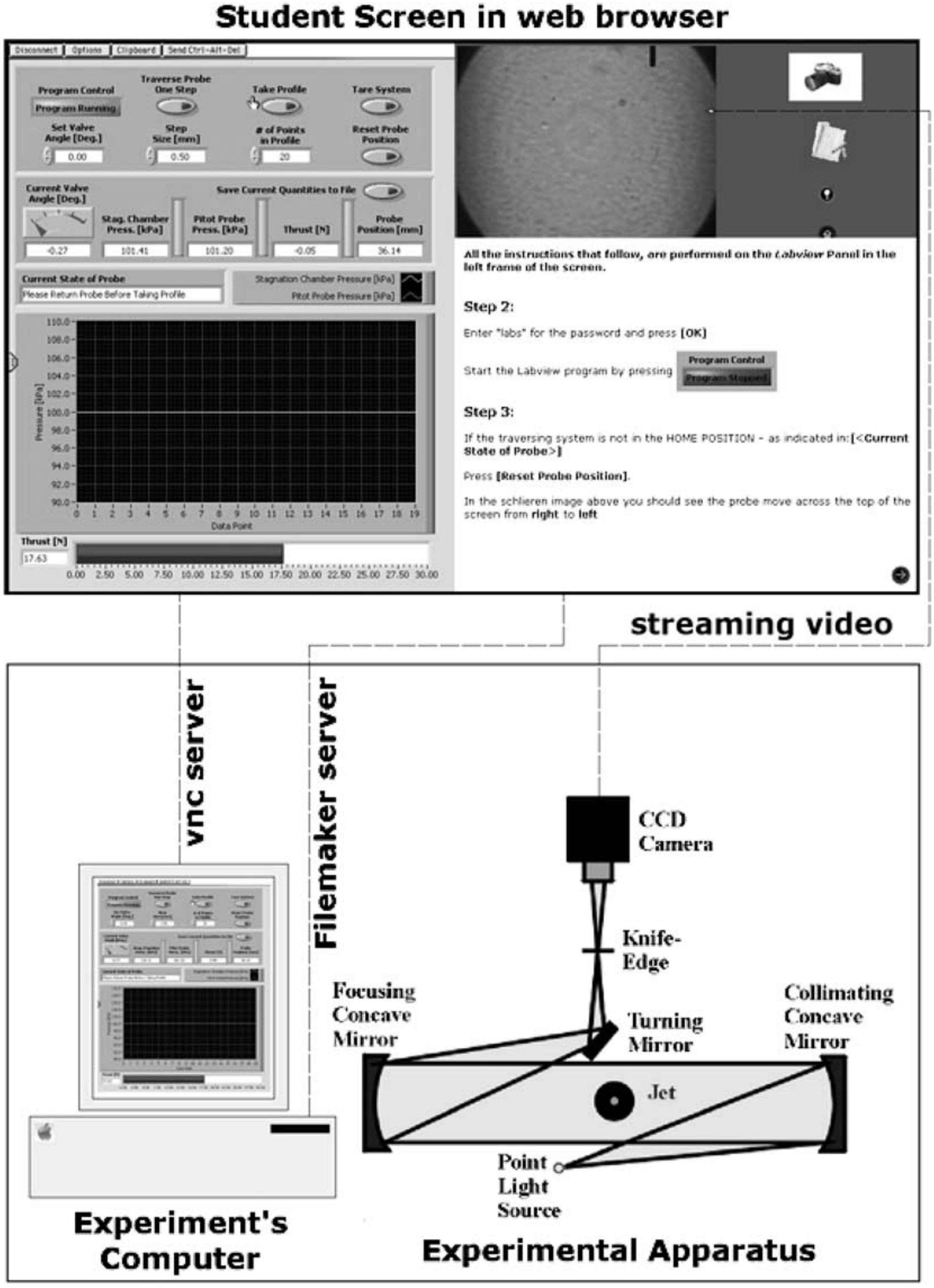
The Filemaker® database controls access to the experiment. The system (a) allows students to run the laboratory only once, and only during their scheduled time slot, and (b) allows re-entry to run the lab if the remote-students' computer becomes disconnected before the lab is complete. The Schlieren images are *streamed using an Axis 2100 CCD camera with built in Linux-based web server.* As a result no PC or specialized software was required.

IV. EVALUATION

How effective are remotely operated laboratories? Do they provide the same hands-on learning outcomes similar to performing the experiment in person? The literature is rich on studies conducted to evaluate the educational outcomes for on-line courses that evolved either from lecture style courses [8, 15, 18, 24, 27, 29, 30] or laboratory courses that are now purely simulation [2, 17, 22, 26]. Due to the infancy of remotely operated experimentation in the undergraduate curriculum, very few studies have been done to assess their educational outcomes.

Two sets of student groups were run through the lab. Each set had six groups with group sizes ranging from two to three students. The first set (Set 1) performed an in-person version of the laboratory and the second set (Set 2) conducted the remotely operated version of the same experiment. The course instructor arbitrarily created the sets and groups. Students had no prior knowledge or input as to which set they would be placed. Further, no attempt was made to balance the sets by gender or academic aptitude. It should be noted that a teaching assistant was present in the room during in-person laboratories, while the remote laboratory groups conducted the experiments alone in the department computer lab.

The evaluation compared the learning outcomes of the two sets of students and compiled statistics on their opinions about the experiment. The students conducting the remotely operated experiment were further divided into two subsets of three groups each. Students in subset 2a were given approximately an hour in the



Set Valve Angle [Deg.]: 0.00

Step Size [mm]: 0.50

# of Points in Profile: 20

Current Valve Angle [Deg.]: -0.27

Stag. Chamber Press. [kPa]: 101.41

Pitot Probe Press. [kPa]: 101.20

Thrust [N]: -0.05

Probe Position [mm]: 36.14

Current State of Probe: Please Return Probe Before Taking Profile

Thrust [N]: 17.63

All the instructions that follow, are performed on the *Labview* Panel in the left frame of the screen.

Step 2:

Enter "labs" for the password and press **[OK]**

Start the Labview program by pressing Program Control Program Stopped

Step 3:

If the traversing system is not in the HOME POSITION - as indicated in: **[<Current State of Probe>]**

Press **[Reset Probe Position]**.

In the schlieren image above you should see the probe move across the top of the screen from **right** to **left**

Figure 3. Screen shot of experiment page as seen by the students through a Web-browser.

computer lab to individually go through the prelab (which describes the experiment, relevant analysis and general information about jet thrust) before performing the experiment in their groups. The second subset (Subset 2b) individually went through the prelab at their convenience and only came to the computer lab to conduct the experiment in their groups. These groupings are summarized in Table 1.

A. Learning Outcomes

Laboratory report grades between the two sets of students were compared. The reports were graded on criteria associated with the inclusion of various report components (abstract, introduction, experimental arrangement, results, discussion, sample calculations and derivations, etc.), presentation of the information (spelling, appropriate graphs and their presentation, tables, etc.), and correctness of the

Set 1: 'In Person' Labs	Set 2: 'Remote-operated' Lab	
	Subset 2a: In-class prelab	Subset 2b: Prelab at own convenience
Student groups 1-6	Student groups 7-9	Student groups 10-12

Table 1. Division of student groups.

	Mean	Standard deviation	Number of students	Calculated value of *t*	Degrees of freedom	Critical value of *t*
Set 1	85.6	11.6	35	1.165	66.50	1.295
Set 2	82.1	13.5	35			
Subset 2a	86.2	11.1	17	2.042	31.43	1.309
Subset 2b	77.2	14.8	18			

Table 2. Scores of students conducting in-person and remote laboratory and values needed for unpaired t-test.

analysis. The grading sheet criteria are given in the appendix. A teaching assistant graded the laboratory reports. He had no knowledge of this study and did not know which students conducted the experiment remotely or in-person. With reference to Figure 4, the average report grade of students who conducted the remote-control laboratory was essentially the same as that of students who conducted the laboratory in-person. Table 2 gives the values for an unpaired *t*-test, which indicates that the difference between the scores of the two sets of students was not significant (the calculated value of *t* is less than the critical value required for a level of significance ($\alpha = 0.05$).

A comparison of report scores was also made between students in subsets 2a and 2b; their lab report scores are summarized in Figure 5. As can be observed, the mean value score was 11.6% higher for students in subset 2a, i.e., those who performed the prelab in class. Using the unpaired *t*-test (with the values given in Table 2) the difference was found to be significant. Why the large difference between the two groups? Using the tracking data from the gatekeeper server, we found that students in subset 2b spent significantly less time on average reading prelab material than students in subset 2a who spent an hour going through the material in class. The success of students in subset 2a indicates that a multimedia prelab is an effective method to disseminate information needed to conduct the laboratory and write the report. The challenge, however, is to develop methodologies that ensure students completely go through the prelab exercises if left on their own. Possible solutions include detailed online quizzing or not allowing the experiment to be run unless the students have spent sufficient time going through the prelab material.

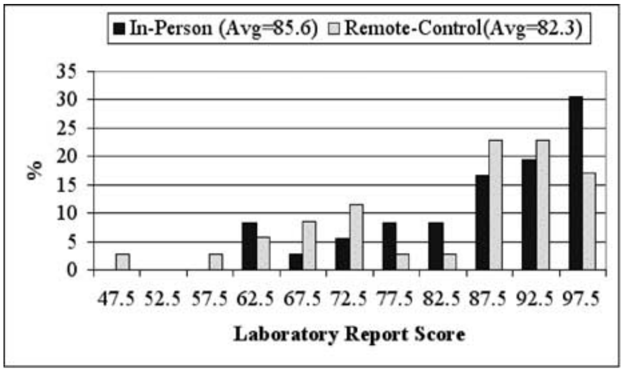


Figure 4. Comparison of laboratory report scores between the in-person and remote student groups.

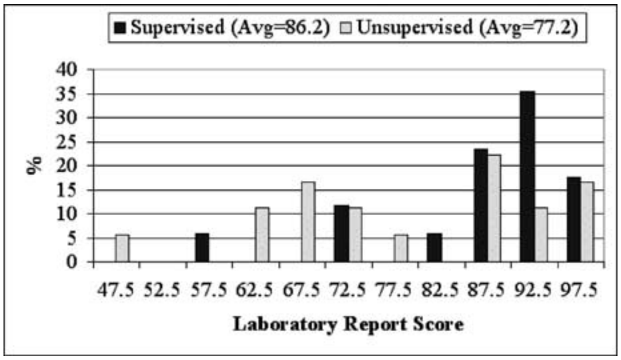


Figure 5. Comparison of scores between Web-groups who had supervised prelab session and groups who were unsupervised.

B. Student Attitudes

A survey was also taken to document student attitudes for comparison between the in-person and remotely operated laboratories. Two areas we were particularly interested in learning more about were, (a) the students' perception of the accuracy of their experimental data, and (b) the students' confidence in their ability to perform the experiments. Survey results are shown in Figures 6 and 7. Student ratings were based on a scale ranging from 1–5 depending on their level of agreement with each of the statements.

The first question asked students if they felt they had taken good data (refer to Figure 6). The vertical axis in the figures corresponds to the percent of students in each set who gave each particular rating. Both sets of students groups show general agreement that accurate data was taken (mean value remote operated = 3.93, mean value in-person = 4.22). The striking difference appears if one looks at what percentage of students "agree somewhat" or "strongly agree" that the data was accurate: 66 percent for remote operated and 87 percent for in-person. These results illustrate that students who perform the experiment in-person have significantly more confidence in their data than students who perform the experiments remotely. It should be noted that quick checks of data from both groups indicated that all the data taken was within acceptable levels of uncertainty.

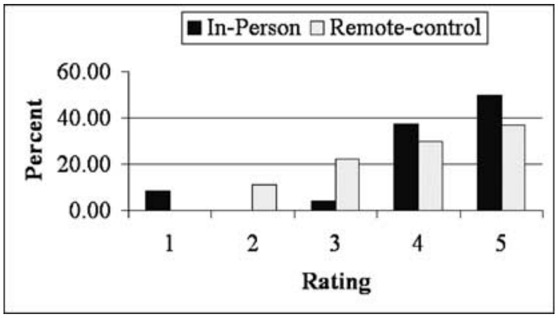


Figure 6. Please select a number between 1-5 that best matches your level of agreement with the statement, "Upon completion of the experiment, I had accurate data available to me." where 1–strongly disagree, 2–disagree somewhat, 3– neutral, 4 –agree somewhat, and 5–strongly agree.

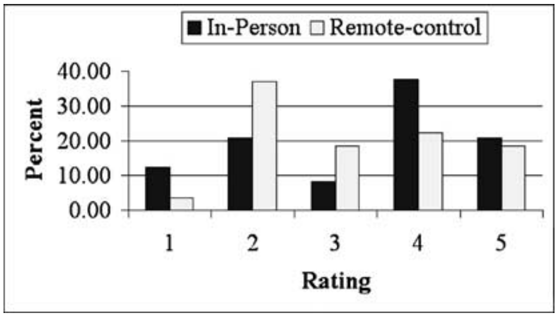


Figure 7. Please select a number between 1–5 that best matches your level of agreement with the statement, "I was concerned about making mistakes when running the experiment." where 1–strongly disagree, 2–disagree somewhat, 3–neutral, 4–agree somewhat, and 5–strongly agree.

The second question looked at the confidence level of students as they carried out the experiment (refer to Figure 7). Again simply looking at the mean value would give the impression that both students sets had about the same level of confidence (mean value remote control = 3.30, mean value in-person = 3.15). Looking at the percentage of students who "agree somewhat" or "strongly agree" with the statement, "I was concerned about making mistakes when running the experiment," more than twice the number of in-person students (58%) did, than remote students (28%).

A possible explanation for these survey results may lie in the very nature of the two sets of experimental apparatus. Remotely operated experiments require significantly more automation of the experimental apparatus than in-person labs. Consequently, in in-person labs students have more direct control of the equipment and may explain the higher level of confidence they have in their data. The manual nature of the operation, however, may lead to increased anxiety when running the experiment as there are more things that could be set incorrectly. This is despite the fact that a teaching assistant is in the room with the in-person students during the entire experiment. It therefore remains a challenge to developers of remotely operated laboratories to develop methodologies that increase the students' level of confidence in their data.

V. CONCLUDING REMARKS

The Internet now provides an exciting new medium through which students can obtain a laboratory experience by remotely interacting with experimental apparatus. We believe remote operation allows the introduction of more laboratories into the mechanical engineering curriculum, while addressing space and budgetary constraints. The results from this study show that there is no significant difference between the educational outcomes from students who performed the experiment remotely, versus those who carried out the experiment in-person. We hope that this study will be the first of many providing a direct comparison between these two modes of delivery, and as a result firmly establish remotely operated labs in engineering curricula as an equal partner to the current two dominant modes of laboratory experience: in-person and simulated laboratories.

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APPENDIX

Laboratory Report Grading Criteria
(150 points total)

I. Abstract (15 points): Statement of objectives (3 points): Important apparatus and methods (2 points); Statement of significant results (2 points); Cogent discussion of results (3 points); Conclusions (3 points); Spelling and grammar (2 points)

II. Introduction, Objective, Theory (20 points): Introduction of fundamental objective, motivation, and background (5 points); Identification of salient objectives (5 points); Explanation of physical principles (4 points); Derivation of fundamental formulae (4 points); Spelling and grammar (2 points)

III. Apparatus and Instrumentation and Procedure (20 points): Identification of important apparatus (5 points); Explanation of significant procedures (5 points); Necessary and sufficient use of figures (4 points); Proper presentation of figures (4 points); Spelling and grammar (2 points)

IV. Results and Discussion (40 points): Logical presentation and citation of figures (5 points); Succinct description of each figure (5 points); Relevant and cogent discussion of results (10 points); Proper presentation of figures (5 points); Presentation of calculations (5 points); Accuracy of calculation (5 points); Error discussion (3 points); Spelling and grammar (2 points)

V. Conclusion (10 points): Concise listing of significant conclusions (8 points); Spelling and grammar (2 points)

VI. Sample Calculations and Derivations (25 points): All Relevant calculations and derivations covered (10 points); Calculations and derivations correct (15 points)

VII. Presentation of Material (20 points): Cover page (2 points); Overall neatness and clarity of report (10 points); Appropriate appendices given (4 points); Appropriate references listed (4 points)

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