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A Fluid Flow Experiment Utilizing Computer Aided Laboratory Instruction

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Abstract

Experiential discovery laboratory exercises and computer-aided instruction (CAI) are both effective pedagogic means for complex science learning. The combination of these two techniques into computer aided laboratory instruction (CALI) has the potential for being a highly effective teaching method with several attractive side benefits. These side benefits include: significantly reduced supervisory and grading workload, reduced laboratory equipment cost, and reduced laboratory space. These side benefits are achieved through unattended, open laboratory operation and computer grading of the laboratory exercise. Only one laboratory station is required, and students can conduct the experiment whenever the equipment is available.

This paper reports initial progress on the development of a CALI experiment using the LabView™ G programming language. The objective of this experiment is to determine the relationship between pressure drop and fluid flow rate for water flowing through capillary tubes and orifices. The total CALI experience consists of:

- Completing a computer-administered qualifying test,
- Diagramming the flow circuit on the computer screen,
- Selecting appropriate virtual instruments,
- Placing and connecting the physical hardware,
- Sampling and logging data, and
- Completing a computer-administered post-test.

Initial results show enhanced understanding of the relationship between pressure drop and fluid flow rate by students performing the CALI experiment. Observation of the students during the experiment indicated a positive benefit from the hands-on experience of their handling and connecting the physical hardware. CALI participants evidenced greater awareness of the function of the various components than did the control group performing a comparable, traditional, laboratory experiment.

I. Review

Extensive testing[1] has established that interactive engagement of the students significantly enhances both conceptual understanding and problem solving abilities of the students in introductory physics courses, "… it appears that present interactive engagement courses are, on average, more than twice as effective in building basic concepts as traditional courses …".

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Felder[2] has indicated that incorporating a variety of educational approaches to effective learning in engineering courses is extremely beneficial to the students. In addition, Felder[3] has determined that effective pedagogy, as applied to laboratory experiences, should have the student learn by discovery.

A review of literature relating to CAI for laboratory courses and to intelligent tutoring systems was performed on the ERIC and EI Compendex Web databases. The trends in CAI relating to laboratory assisted instruction were: eliminating laboratory hardware by running simulations, logging data, searching databases, performing calculations, performing analyses, and looking up reference information. Dozens of references were found covering each of these approaches. Examples are shown in [4], [5], [6], [7], [8], [9], and [10].

The efficacy of both CAI and experiential discovery laboratory exercises in education leads to the supposition that the combination of the two can be a highly effective teaching method. However, this combination is not widely reported. Indeed, only one reference was found that specifically dealt with using a computer application to both conduct a laboratory experiment and interact with the laboratory hardware. D'Souza, Scott, and Stone[11] describe ". . a computer controlled vibration laboratory that is inherently safe and does not need an instructor. The laboratory is controlled through the computer which protects both it and the student. Results are collected and analysed by the computer. Most importantly the laboratory has been designed to behave in a different manner from the theoretical models developed in lectures and students are expected to criticise their lecture models."

II. Problems Associated with Conventional Laboratory Instruction

While there is widespread agreement among both engineering teaching faculty and industry advisers that experiential discovery laboratory exercises are beneficial for students, the trends have been to fewer laboratory courses and replacing physical laboratory exercises with computer simulations. The reasons for this can be mainly traced to the costs for time, equipment and facilities associated with providing physical laboratory exercises. Almost all laboratory exercises require considerable time and resources to develop, setup, and maintain. They require significant amounts of special purpose, high cost space to operate, and they require large amounts of time to properly supervise the laboratory exercise and grade the resulting laboratory reports. Increasing the experiential discovery factor of laboratory exercises only exacerbates these requirements.

One laboratory exercise for an undergraduate laboratory course in the Department of Mechanical Engineering at the University of Wyoming is a fluid flow experiment to determine the flow resistance characteristics of orifices and capillary tubes.

III. Description of the Conventional Fluid Flow Experiment

In the conventional experiment a constant head tank supplies fluid pressure to a manifold that is connected to three flow resistance elements: a sharp edge orifice, a round edge orifice and a capillary tube bundle. The students can direct the flow to one of the three elements using low loss valves. The fluid, water in this case, flows through one of the elements and into a downstream manifold that is connected to a constant back-pressure device. The fluid is then exhausted into a reservoir where it is pumped back into the constant head tank. Varying the height of the constant head tank controls the pressure at the upstream manifold. The upstream and downstream manifolds are connected to adjacent manometer tubes. This allows the students to obtain the pressure drop across the active flow element. The volumetric flow rate is obtained by capturing the effluent in a graduated container over a timed interval. In this manner, the data for relating pressure drop and flow rate is obtained. The conventional apparatus is shown in Figure 1.

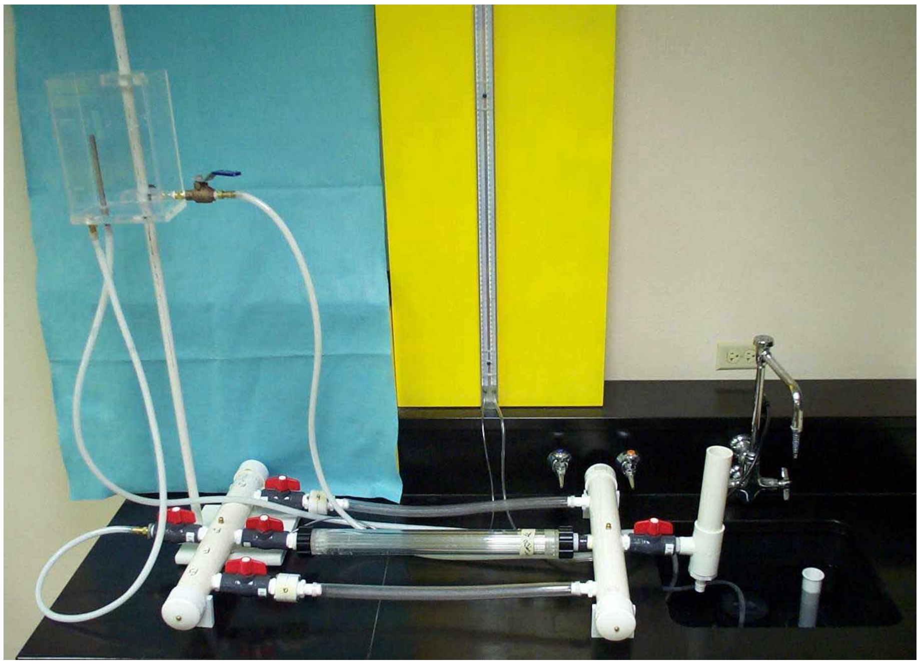

Figure 1. The Conventional Apparatus

Originally six sets of apparatus for this experiment were constructed at a cost of about $2,000 to $3,000 per station. The facility needed to conduct the experiment is a standard laboratory sink with 12-15 square feet of counter space and approximately 125 square feet of floor space for each station. Utilities needed are water, drain, and electrical power. The setup time for the experiment is about 2-3 hours per station. Therefore, the experimental apparatus is assembled before the students perform the exercise, thus limiting the experiential discovery component to operating the experimental apparatus. The tear down time is about 1-2 hours per station, since the apparatus must be dried to prevent biological and physical fouling. The students perform the 2-hour experiment in pairs, while a course instructor and teaching assistant supervise the laboratory session. Grading of the resulting laboratory reports averages approximately 2-3 hours per student. Assuming a class size of 30 students, somewhere between 90-125 man-hours are required for this single experiment. This time does not include maintenance time on the equipment. The experimental equipment requires approximately 0.3 cubic meters of storage space for each station, or 1.8 cubic meters total, when not in use.

This particular experiment requires relatively simple, inexpensive apparatus and has modest space and utility requirements. In contrast the corresponding requirements for classroom instruction are about a fifth of the space and a few hundred dollars in equipment per student. The man-hours required per student classroom hour are similarly less. This disparity between laboratory and classroom requirements is the driver for the trend toward fewer physical laboratory exercises and more computer simulations.

IV. Combining CAI with Experiential Discovery

The combination of CAI with experiential discovery laboratory exercises promises to increase the benefits of experiential discovery while mitigating the drawbacks of costly time and resource requirements. Laboratory exercises using CAI can be unattended and open for extended periods. Consequently, a single laboratory station can serve an entire class. The computer monitors the students' progress, and the exercise is graded concurrently. These features lead to significantly reduced equipment, space and time requirements, while giving the student flexibility in scheduling laboratory time, more hands-on experience with the equipment, and immediate feedback on performance.

Figure 2 Rack Mount Computer with Instrument Patch Panel

The UW Department of Mechanical Engineering, through an internal grant, has applied CALI to a variation of the laboratory exercise described above. A computer application, CA-Lab, was developed using the LabView™ G programming language. The fluid flow apparatus of the conventional experiment was adapted for the CA-Lab experiment to allow quick setup and tear down and to protect both the students and the equipment from injury during the experiment. Instrumentation was added, and an industrial, rack-mount computer was fitted with a data acquisition (DAQ) card and connected to a patch panel for making the instrument connections. The rack mount computer is shown in Figure 2. The objective of the experiment is still to determine the flow resistance characteristics of orifices and capillary tubes.

V.   Description of the CALI Fluid Flow Experiment

In the CALI version of this fluid flow experiment the student must first complete a computer administered exam covering the principals involved in the fluid flow experiment and develop virtual schematics of the apparatus. Following these exercises, the student then selects appropriate hardware from an equipment cabinet and connects the hardware to achieve a flow

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circuit comparable to the conventional experiment, but having computer connected instrumentation. The student assembles the actual equipment and makes the instrumentation connections by referencing the virtual schematic. With the CALI approach only one flow resistance element is connected at a time. A standpipe is used to provide a constant pressure head on the upstream side, and a micrometer pinch valve on the Tygon™ tube supply line, connecting the standpipe to the flow resistance element, controls the flow. The flow rate is measured with an oval-gear flowmeter, and the associated pressure drop across the flow resistance element is monitored with a differential pressure transducer. The outputs of the two transducers are connected to the DAQ card in the computer. An accumulator is inserted between the flow resistance element and the oval-gear flowmeter to isolate the pulsation generated by the flowmeter from the flow resistance element. Two views of the student-assembled configuration utilizing the round edge orifice are shown in Figure 3.

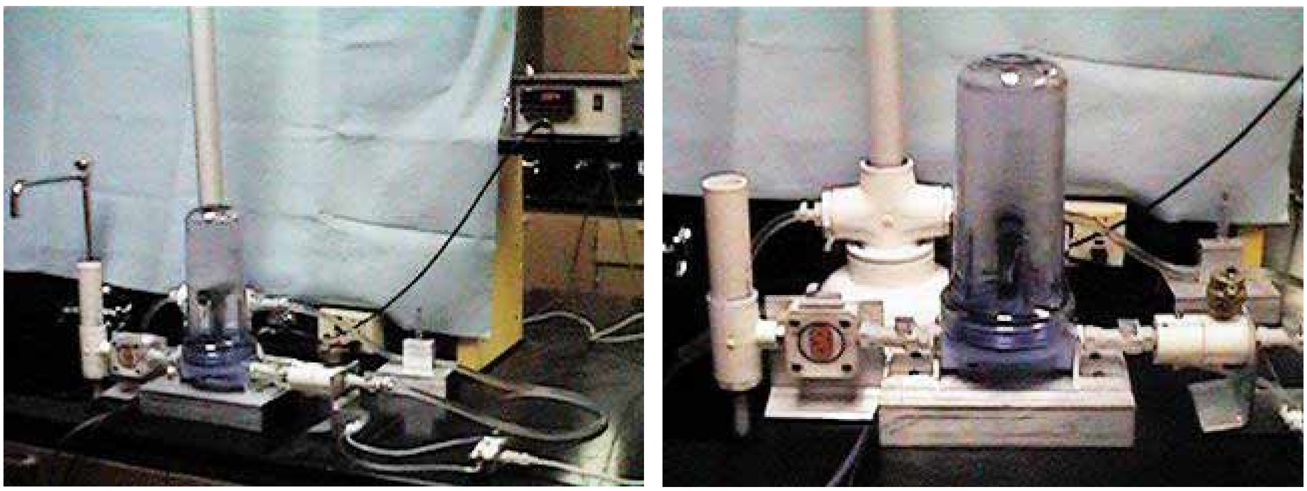

Figure 3 The CALI Experimental Apparatus

One station of laboratory apparatus was constructed at a cost of about $3,000. The rack mount computer and the DAQ card added approximately $3,500, although the computer is general purpose and is already being used for a variety of other experiments and projects. The facilities needed to conduct the experiment are one standard laboratory sink with 12-15 square feet of counter space and the same floor space, approximately 125 square feet, as is needed for the conventional laboratory setup. The same utilities, water, drain, and electrical power, are also needed. Setup and tear down times are approximately the same as for one conventional laboratory station. The total time required for this laboratory is approximately 10 man-hours for a class size of 30 versus the 90 to 125 man-hours required for the conventional laboratory. When not in use, this experimental equipment requires approximately 0.2 cubic meters of storage space exclusive of the rack mount computer. The computer occupies about 0.6 cubic meters.

VI. The CA-Lab Program

To the extent possible, CA-Lab is structured as a general-purpose laboratory instruction application with specific laboratory exercise documents stored in text files or standard picture formats. The student must log into the program with a password issued by the instructor, and then the CA-Lab program guides an individual student or team of students through the laboratory procedure. The steps a student must complete for the CA-Lab program exercise are as follows:

1. After logging into the CA-Lab program, the student reviews an information and instruction screen describing the experiment and giving general instructions for using the program. Other instruction screens are interspersed throughout the program for the various sections.
2. Following the initial instruction screen, the student completes a qualifying pre-test. This series of screens presents questions and problems designed to help the student understand the experimental processes and select appropriate equipment for the experiment. At the end of the pre-test, the student is shown the pre-test score and given the opportunity to retry for partial credit the questions not answered correctly.
3. Next, the student is required to make virtual diagrams of the flow system for each of three different flow elements. To help the student select the appropriate equipment for the experiment, on-screen “Equipment Cabinet” and “File Cabinet” icons are available. By clicking on the “Equipment Cabinet” the student is presented with a screen showing icons for each piece of equipment. Clicking on the information button near each equipment icon opens a specification sheet document for that particular piece of equipment. The equipment specification sheets can also be accessed through the “File Cabinet”. In addition the “File Cabinet” contains reference documents, laboratory handouts, report templates, and any other documents pertinent to the experiment. From the information presented, the student must select the proper equipment from a larger than needed selection set. For example, three different pressure transducers and two different flowmeters, all having different ranges, are available. The selected equipment must then be connected in the proper order. A virtual diagram includes the connections from the measuring instruments to the computer patch panel. The student’s scores for the three virtual diagrams are displayed following the completion of the diagrams, and the student is given the opportunity to repeat for partial credit any diagrams with low scores.
4. After the fluid flow system has been diagramed, the student is asked to select the appropriate virtual instruments to display the experimental data on-screen from a larger than needed selection set. The required virtual instruments are flow and differential pressure strip charts and an X-Y graph of pressure versus flow rate for the sampled data. The score for the selection of the virtual instruments is displayed, and the student is again given an opportunity to re-do the selection for partial credit, if inappropriate choices were made.
5. In the next step the student must place and connect the experimental hardware. To help with this process, a general virtual diagram from Step 3 is displayed. Clicking on various parts of the diagram will open screens that show pictures of the selected equipment or connection and display textual hints to assist the student with the setup. The equipment

connections were designed using robust fluid quick couplers, physical constraints and natural affordances to minimize the risks of injury and damage. These principles were also used in designing the instrument connections to the patch panel on the industrial computer. The patch panels connectors are coded by type to prevent inappropriate connections from being made. However, the student must select the proper DAQ channel to make a functional connection.

6. After setting up the equipment, the student performs the experiment and collects the experimental data. The strip charts for the differential pressure across and the flow rate through the flow resistance element show the system conditions as the student adjusts the flow control pinch valve. The student must take a minimum of ten measurements of the pressure drop across the flow resistance element versus the flow rate by clicking an on-screen “SAMPLE” button. The data points are displayed on the X-Y graph. The collected data is compared to the expected data for a given flow resistance element, and the quality of the data set is scored. Warnings are issued if the data falls outside a selected error band. The student can re-do data sets with poor data quality. After a data set is completed, the student saves the data sets to disk for further processing in a spreadsheet program.
7. The final step is a post-test to determine the student’s grasp of the experimental data. The student can repeat any incorrect questions in the post-test for partial credit.

VII. Beta Testing of the CA-Lab Experiment

To test the efficacy of the CA-Lab experiment, a class performing this experiment was divided into a test and a control group, and the performance of the two groups was compared. The groups were selected by ranking the class members by overall, incoming, grade-point average. Starting from the lowest grade-point average, every third student was selected to run the CA-Lab experiment. This procedure identified thirteen CA-Lab experimenters and thirteen pairs of students for the conventional laboratory exercise from the class of 39 students. The conventional laboratory students had an average grade point average of 3.02 and the CA-Lab students’ grade point average was 2.94, with a standard deviation of 0.57 for both groups. Although the CA-Lab group’s grade point average was lower than the conventional lab group’s average, the difference was not significant. The CA-Lab students arranged for three-hour time blocks to run the experiment throughout the second week of October 2000. The conventional laboratory exercise students attended regularly scheduled laboratory periods during that week.

The CA-Lab students were observed while they conducted the experiment. Bugs in the CA-Lab application caused some difficulties for the first three students. Although all three students were able to complete the experiment, these problems resulted in incomplete scores. The identified bugs were corrected before the remainder of the students performed the CA-Lab experiment. The final two students experienced difficulties with a power connector for the flowmeter and also had incomplete scores.

VIII. Evaluation of the Initial Results

To evaluate the effectiveness of the CA-Lab experiment, three testing measurements were made. First, a 10-point essay question related to the function of a common part of the experimental apparatus for both experiments, the constant back-pressure device, was included in a quiz administered in the week following the laboratory exercise. Second, a 70-point quiz based entirely on the fluid flow laboratory was administered after both groups of students had submitted all required laboratory reports. Finally, a 20-point computational/judgement essay question relating to the flow characteristics of the capillary tube bundle used in the laboratory experiment was included in the final exam for the course. The final exam was given in the second week of December 2000. The laboratory exercise grades were not considered, since the two grading systems are not comparable. Analysis of variance between the mean scores of the two groups was used to determine the significance of any differences.

The first quiz question resulted in an average score of 2.68 for the conventional laboratory students and 3.31 for the CA-Lab students, with 3.82 and 3.92 standard deviation respectively. The fluid flow laboratory quiz resulted in an average score of 53.13 for the conventional laboratory students and 50.38 for the CA-Lab students, with 11.11 and 7.76 standard deviation respectively. Neither of these tests demonstrated a significant difference between the two groups.

The test question on the final exam showed conventional laboratory students scoring an average 13.17 points on the question and CA-Lab students scoring an average 16.92 points on the question, with 5.80 and 2.61 standard deviation respectively. These results did show a significant difference between the averages of the two groups at the 95% confidence level. While these results are by no means conclusive, they do suggest that the CA-Lab experiment did impart greater long-term understanding of the flow characteristics of the capillary tube bundle than did the conventional experiment.

These results plus the fact that the CA-Lab application was being beta tested and has considerable room for improvements indicate that the CA-Lab application does indeed have potential for significantly increasing students' complex learning.

Observations of the students performing the CA-Lab experiment indicated many students lacked familiarity with physical apparatus. Two of the more extreme examples of this were one student's failure to realize that the reservoir must be filled with water before the experiment could be run, and two students trying to plug the quick connect for the pressure transducer into the vent of an automatic air release valve. Several students exhibited anxiety in working with the apparatus and with the instrument connections. One student expressed a fear of being electrocuted by the submersible pump (A GFI outlet was installed to prevent such an accident), and one failed to make the ¼-turn lock on the common BNC connectors resulting in poor instrument connections. Another student left an air bleed valve on the differential pressure transducer open, creating a large puddle that soaked the student's books, calculator, and computation pad. It is apparent that more experience in handling physical hardware would give these students a greater appreciation of physical devices and processes, thus promoting the students' self reliance and helping prepare them for life-long learning.

IX. Future Work and Modifications

The principal shortcoming identified in this CA-Lab experiment was that the exercise took too long to perform, averaging about three hours and twenty minutes for those sessions where accurate times were obtained. Consequently, the students lost interest or hurried to make the real or imagined three-hour deadline. From those records with complete and accurate times, the average time spent on the pre- and post-tests was 71 minutes. When the CA-Lab experiment is again used, these two tests will be removed from the CA-Lab application and made into separate, Web-based tests. With this arrangement, the students will take the qualifying test on the Web at their convenience. Upon successfully completing the qualifying test, they will be issued a password for the CA-Lab program, and the CA-Lab application will then consist of only constructing virtual diagrams, selecting appropriate virtual instruments, setting up the physical apparatus, and collecting the experimental data. The students will take the Web-based post-test after completing the laboratory exercise.

Removing the pre- and post-tests from the CA-Lab application and making them Web-based opens new possibilities. Foremost among these is the possibility of using a well-developed application package such as AUTHORWARE™ for CAI. With this approach, it will be relatively easy to make a test context sensitive so that the test can focus on areas where the individual student's knowledge is deficient and give immediate feedback, both positive and negative. Other options are selecting a randomized set of test questions from a large pool and varying computational parameters each time a question is presented. These options will prevent students from obtaining specific answers to test questions from previous experimenters.

The Department of Mechanical Engineering is seeking additional funding to continue development of this concept. If successful, the CA-Lab application will be modified to add data analysis by the student into the application and to make the program more general. The goal is to have all the documents and control for the application contained in plain text files and spreadsheets. The instructor will then not be required to know the G programming language to use the CA-Lab application. Another feature that will be considered is allowing students to quit the program at certain junctures and later restart at that point.

X. Conclusions

The CA-Lab concept does have potential to deliver experiential discovery laboratory exercises with reduced time, space, and cost requirements, but more work remains to be done to perfect this concept.

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