AC 2012-4760: IMPLEMENTING A VIRTUAL LABORATORY FOR A DIRECTED AND SYNCHRONOUS STUDENT LEARNING EXPERIENCE; COMBINING VIRTUAL AND REAL EXPERIMENTATION: AN EFFORT TO ENHANCE STUDENTS’ CONCEPTUAL UNDERSTANDING OF FLUID POWER

Dr. Larry Alfonso Villasmil Urdaneta, Rochester Institute of Technology

Larry Villasmil is an Assistant Professor in the Department of Manufacturing and Mechanical Engineering Technology at the Rochester Institute of Technology. He received his B.S.M.E. in 1988 from the Universidad Nacional Experimental del Tchira in Venezuela. After graduation, he joined Petroleo de Venezuela, working in several positions as a Rotating Equipment Specialist in the E&P division. He earned his M.S.M.E. in 2002 and Ph.D.M.E. in 2006 from Texas A&M University. His research interests include computational fluid dynamics, rotor dynamics and turbo machinery, industrial power generation and refrigeration, heat transfer, fluid power, education, and the use of technology in education. He teaches courses in the area of thermal and fluid sciences, such as fluid power, applied fluid mechanics, thermofluid laboratory, and wind power systems. He holds memberships in ASME, AIAA, and ASEE.

Dr. Rob Garrick, Rochester Institute of Technology

Robert D. Garrick, Ph.D., P.E., is Associate Professor in the Department of Manufacturing and Mechanical Engineering Technology at the Rochester Institute of Technology (RIT) and thermo-fluids curriculum Co-chair. Garrick worked for 25 years in automotive engineering research and holds seven U.S. patents.

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Implementing a Virtual Laboratory for a Directed and Synchronous Student Learning Experience in Fluid Power.

Abstract

Many Engineering Science and Engineering Technology programs include technical introductory courses that students traditionally struggle with, see Borrego\textsuperscript{1}. The Pneumatic and Hydraulics Systems course is one of many of this type that has a relatively high W/D/F rate (Withdrawals, D and F grades). Nevertheless, hidden in each student’s overall course grade is the fact that students typically do better in the laboratory portion of the class.

Since 2006, the syllabus, content sequence and delivery have been improved with success but students keep perceiving a ‘disconnection’ between the laboratory sessions and the lecture. This indicates that while they enjoy the lab sessions they find the lecture portion ‘hard’ and challenging. Beyond the student’s perception, the fact remains that not many students fully grasp the fundamental concepts and principles.

From a pedagogical perspective, there is a difference in the approach to education and learning between the laboratory session and the lecture session of the course (as all courses with a laboratory component). In the laboratory, small groups work together with pre-labs, notes and textbooks at hand, performing the experiments under the guidance of the lab instructor, where students tend to do better in group reports. In the lecture, the instructor has a more active and traditional leading role where a few students underperform on individual assignments and tests with closed notes while they tend to do well in group assignments and open notes/textbook opportunities.

Following the work developed by Zacharia\textsuperscript{2}, we are currently investigating the value of combining virtual experimentation (VE) and real experimentation (RE) in respect to changes in students’ conceptual understanding of fluid power. Like Electrical Circuits, Pneumatic and Hydraulics Systems is an abstract subject and its successful teaching relies heavily on the use of laboratory experiments. We formulated the hypothesis that current engineering technology students, hands-on oriented, who belong to the millennial generation (Sweeny\textsuperscript{3}), will significantly benefit from the combination of VE and RE allowing them to see the connection between abstract principles, equations and the real world applications in a collaborative manner.

Preliminary results in comparing student skills in pre-lab preparation, laboratory report grades and student survey indicate that incorporating a virtual experiment in conjunction with a real physical experiment appeared to be advantageous to student preparedness and the student’s understanding of the course material.
Introduction

Many Engineering Science and Engineering Technology programs include technical introductory courses that students traditionally struggle with, Borrego\textsuperscript{1}. At Rochester Institute of Technology, Pneumatic and Hydraulics Systems is one of many of this type in the College of Applied Science and Technology. This course has a relatively high D/W/F rate (historically about 23\%\textsuperscript{4,5}, see Figure 1. which causes the need for trailer sections. Nevertheless, hidden in single grades is the fact that students do significantly better in the laboratory portion of the course than in the lecture ($\alpha < 0.00001$ in one-tailed t-Tests comparing student laboratory and lecture grades in years when the laboratory and the lecture component of the course have been taught by the same instructor).

![Figure 1. Historic D, W and F in the Pneumatic & Hydraulic System course.](image)

Since 2006, the syllabus, content sequence, and delivery has been improved with success measured as increasing average grades, positive course evaluation feedback, and intended learning outcomes achievement. Nevertheless, end of class evaluations indicate that students keep perceiving a ‘disconnection’ between the laboratory sessions and the lecture, indicating that while they enjoy the lab sessions they find the lecture portion ‘hard’ and challenging. Beyond the student’s perception, the fact remains that not many students fully grasp the fundamental concepts and principles (observed as the need for unusual long introductions of those concepts and principles in upper level courses in the thermal and fluid sciences course sequence).

The observations and experiences with this course are not unique. As summarized by Zacharia\textsuperscript{2}, students of all ages and levels have difficulties understanding scientific concepts. Students have ideas and interpretations based on everyday experiences and language that often interfere with learning of the scientific models introduced during science classes, affecting their ability to assimilate the correct ideas. The students have constructed their knowledge about the physical world, their own interpretation for science terminology, and ‘reasonable’ explanations for how and why things work, over many years of experience. It should be expected that they would naturally ‘resist’ any contradiction or ‘discrepancy’ when presented correct but conflicting information.
In his review, Zacharia\textsuperscript{2} points to previous research that concluded that fostering conceptual change requires challenging students with ‘discrepant events’ to contradict their conceptions provoking a cognitive conflict that causes reflection and resolution. These discrepant events and significant experience can be provided both through the use of laboratory inquiry-based experimentation and through the use of virtual environments that support experimentation, such as interactive computer-based simulations. In either case, it is clear from Ma and Nickerson that hands-on experience is crucial for science learning and that lab-based courses play an important role in scientific education\textsuperscript{6}.

Hands-on labs or real experiments have been performed since the ‘beginning of times’. On the other hand, it is only recently that modern computer technology has made possible a new and rich learning environment, the simulation. Several authors in a review performed by Lee\textsuperscript{7} coincide indicating that information technology has changed laboratory education and the nature and practices of laboratories where remote and simulated labs are now common. In a context that is similar to the real world, instructional simulations are mostly used for student unguided discovery learning\textsuperscript{7}. In a review on learning with simulations, de Jong and van Joolingen\textsuperscript{8} highlight on discovery learning that scientific reasoning comprises the abilities to “(a) define a scientific problem; (b) state a hypothesis; (c) design an experiment; (d) observe, collect, analyze, and interpret data; (e) apply the results; and (f) make predictions on the basis of the results”\textsuperscript{9}.

Simulated labs offer the flexibility of designing multiple experiments, observing and collecting ‘instantaneous’ data and results (depending on the level of detail sought), and obtaining immediate feedback when making predictions and adjustment to the ‘models’. Simulations purportedly reduce the amount of time it takes to learn and create an active mode of learning that thereby improves students’ performance\textsuperscript{4}. As reported by Abdulwahed\textsuperscript{10}, simulations as virtual laboratories are also more cost-effective to implement and run, they are inherently safe and they are not constrained by time or space. Virtual labs can be an alternative or a complement to the hands-on laboratory, e.g. using them for preparing for the lab. Virtual labs in preparation sessions appear to have raised the conceptual understanding during hands-on labs\textsuperscript{10}.

### Instructional Approach

The participants of the study are 25 undergraduate students (22 male, 3 female). These students generally range in age from 19 to 24 with two non-traditional students (one is 32 and the other is 36 years old). The Pneumatic and Hydraulics Systems class is a technical introductory course of the thermal and fluids science area sequence. It is included in the curriculum of the Manufacturing and Mechanical Engineering Technology programs which are both five years in duration. The current curriculum of the Pneumatic and Hydraulics Systems course is based on the Problem Based Learning (PBL) pedagogical model\textsuperscript{11} application to technical education and actual classes are taught in a ‘technology rich environment’\textsuperscript{5}. Although the course is required and offered in the second year, the range of the current students varies considerably; 5 are in the 2\textsuperscript{ND} year, 8 in the 3\textsuperscript{RD} year, 5 in the 4\textsuperscript{TH} year and 2 in the 5\textsuperscript{TH}. One of the participants had taken the
course prior to the study. Given the small size, we decided to have the whole sample as an experimental group with previous years courses population as basis for comparison.

Curriculum Content

The Pneumatic and Hydraulic Systems course is also referred in other Colleges and Universities as Fluid Power (validated on individual searches through NFPA\textsuperscript{12} links). In our case, it is the first course to introduce the fundamental principles of conservation of mass and energy for a ‘moving’ fluid and the concepts of force, pressure (Pascal’s Law\textsuperscript{13}), and power (hydraulic power\textsuperscript{13}). Other areas of study are fluid logic and basic electrical control, pneumatic/hydraulic circuit design/applications, and hydraulic pumps/motors. Traditionally, while the lecture portion of the course concentrates in all content areas the laboratory component focuses on fluid logic and electrical control, pneumatic/hydraulic circuit design and applications.

Zacharia\textsuperscript{2} indicates that a conscious effort was made to preserve the same teaching method and teaching materials for both their control and experimental group, pointing to limitations of previous studies where the method of instruction was not controlled. As already mentioned above, the syllabus, content sequence, and delivery method has evolved while being improved with success since 2006. Nevertheless, such changes have been made within the ABET intended learning outcomes for the course and are comparable for the two previous sessions where the courses have been taught.

As a preliminary study, where we are interested not only on improving students’ conceptual understanding of fluid power but also on student success and student retention, we used Virtual Experimentation\textsuperscript{2} for all laboratory sessions. We looked at the individual and overall performance of the class on a single laboratory session or multiple sessions rather than a specific content module or topic.

Lab Material

Real Experimentation

Real experimentation involves the use of real equipment and components in a traditional fluid power laboratory. In our case, the experimentation is heavily oriented to pneumatics circuits for safety and cleanliness. The Pneumatics and Hydraulic Systems laboratory has one hydraulic bench and six identical pneumatic benches with similar components and materials. The hydraulic bench is of ad-hoc design with an on top of reservoir electric motor driven pump and a pressure relief valve with supplies and return quick connectors. The pneumatic benches are Neutrainer 200 training systems (SMC International training) adapted to the needs of the program. Students work in groups of 2 or 3 per bench conducting the same experiments per laboratory session under the supervision of a faculty member.
Virtual Experimentation

Virtual Experimentation involves the use of software capable of modeling the behavior and response of real equipment and components to conduct the laboratory experiments on a computer. In this study, the software Automation Studio™ (Famic Technologies Inc. 2011) is being used for this purpose. The software features a large number of virtual components available and gives the students and faculty not only the capabilities of replicating any laboratory session but any of the ‘complex’ circuits described in the textbook. Therefore, the students have at their disposal the ‘same’ parts and components available in the real laboratory. Circuits are created by dragging ISO (International Standard Organization) fluid power symbol icons into a ‘drawing’ board representing the hydraulic and pneumatic components and positioning them in the desired position in the circuit indeed creating an ISO diagram. On a ‘click’ of a button, the circuit is run and the feedback is color coding of high and low pressures in lines and the displacement of valves, switches and actuators. The software includes multiple sensors (also as ISO symbols) and plotting capabilities that feedback from the circuit operation to the students is similar ways or better ways than currently available in the real laboratory.

Lab Content and Schedule

Below we present the lab session schedule we are following in the current investigation. There are three sessions planned to be held in a computer lab to introduce the basic features of the software and discuss specific control and logic objectives of the circuits to be built during the course. There are seven sessions planned to be held in the laboratory to perform the real experimentation. The computer lab and laboratory sessions are alternated, as the experiments change in control logic and evolve in complexity.

<table>
<thead>
<tr>
<th>Lab</th>
<th>wk</th>
<th>Date</th>
<th>Experiment</th>
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<tbody>
<tr>
<td>1</td>
<td></td>
<td>1 Nov 30</td>
<td><strong>Lab Orientation and Introduction to Automation Studio.</strong></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>Dec 07</td>
<td>Basic Hydraulic System</td>
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<tr>
<td>2</td>
<td>3</td>
<td>Dec 14</td>
<td>Cylinder Control, Pneumatic Actuation.</td>
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<tr>
<td>3</td>
<td>4</td>
<td>Jan 11</td>
<td>Cylinder control, OR/AND gates – Cylinder Speed.</td>
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<tr>
<td>4</td>
<td>5</td>
<td>Jan 18</td>
<td>Position Sensing, Time Delay and Constructing a Flip-Flop from mono-stable components.</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>Jan 25</td>
<td><strong>Introduction to Ladder Diagrams in Automation Studio.</strong></td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>Feb 01</td>
<td>Cylinder Control, Electro-pneumatic Actuation – Limit and Pressure Switches.</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>Feb 08</td>
<td>Cylinder Control, Holding Relays – Safety Circuit.</td>
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<tr>
<td>7</td>
<td>9</td>
<td>Feb 15</td>
<td><strong>Cylinder Sequencing Logic in Automation Studio.</strong></td>
</tr>
<tr>
<td>7</td>
<td>10</td>
<td>Feb 22</td>
<td>Electro-pneumatic sequential cycling</td>
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To perform the laboratory activities, the students have at hand a lab manual containing the lab guide for each week session. Each guide includes the Learning Objectives, the Circuits to be constructed (experiment numbers), a Pre-Lab Preparation section, Written Results section (expected minimum content of the lab report), and the description and sequence of execution of each experiment as appendix. In addition, the students are given at the beginning of the course, a lab report format and a grading rubric.

Laboratory preparation can be performed in many ways, for instance, students can be asked to prepare by reading the manual and sketching a preliminary circuit for each experiment. Alternatively the lab manual preparation can be combined with using a simulated version of each circuit and experiment, a virtual lab\textsuperscript{10}. The virtual lab preparation is a suitable tool to visualize the experimental setting in a simplified way and to show results in a graphical way. Completing each fluid power circuit in a virtual environment makes the hands-on lab a reinforcement experience, indeed a second demonstration of the basic principles being taught that helps in forming and understanding concepts\textsuperscript{10}. As preparation for the lab session, we are requesting the students to construct the circuits in Automation Studio\textsuperscript{TM} and bring a print out with a brief explanation of how the circuits should work as a way to implement the combination of virtual and real experimentation\textsuperscript{2}.

Preliminary Results

Sketched Circuits

For the first lab, 17 of the 25 students submitted the requested print outs and electronic files as pre-lab preparation. From those 17, only 3 completed their circuits using Automation Studio\textsuperscript{TM} despite the fact that over the introductory session during the first week of classes we went over the basic commands of the software while practicing the circuit that was going to be built the following week. On the other hand, all 3 Automation Studio\textsuperscript{TM} submissions were functionally correct; meaning the circuit or circuits virtually built by each student performs as requested by the laboratory manual meeting the goals of the experiment. Figure 2 compares single frames of a student simulation and a faculty simulation for the basic hydraulic system circuit. Although the student circuit have some ISO symbols that do not represent the exact components we used in the real experiment one week later, the similarities between the two solutions cannot be questioned and even more when we consider that the laboratory manual only includes generic descriptions of the components to be utilized (as part of the learning by inquiry we encourage the students to get familiar, play and ‘discover’ the full functionality of the parts they will use in each lab).

For the second lab, 12 of the 25 students submitted the requested print outs and electronic files as pre-lab preparation. Surprisingly, from those 12, 7 completed their circuits using Automation Studio\textsuperscript{TM} without any faculty supervision. Similarly, all 7 Automation Studio\textsuperscript{TM} submissions were functionally correct except 1. The circuits virtually built by the students perform meeting the goals of each experiment. Figure 3 compares single frames of a student simulation and a faculty simulation for comparable pneumatic circuits. Again, the student circuit has an ISO
symbol or component we did not have in the real experiment as the student was not aware of the real components available in real laboratory at the time but such inclusion reflects that this particular student did some research looking into the suggested references and figured out the circuit components required to perform the desired function. Again, the two solutions are comparable although in this case we included the single student solution that is not fully functional as the directional valve is connected backwards preventing the full extension of the pneumatic cylinder.
Lab Grades

To evaluate if the introductory session with Automation Studio™, including the pre-lab preparation, has any impact in the understanding of the basic principles of the operation of basic hydraulic systems, we compared the scores of the first laboratory reports of the current participants and previous sessions of the course, see Figure 4. It is apparent that a significant drop in grades occurred in the current session. This outcome is contrary to what we expected. Nevertheless, these grades are significantly affected by the quality and degree of completion of the lab reports and not necessarily reflect the understanding of the basic concepts. When the grades for the current session are scrutinized further, the top 10% of the students performed comparable with previous sessions while the bottom 50% performed significantly worse ($\alpha < 0.045$, one-tailed t-Test on a similar year). As inferred by some student’s comments, it is apparent that current students expect more directions and instructions to execute tasks and might resist the idea of inquiry and discovery learning.

![Figure 4. Laboratory Report Scores for week 1 of the current course session (8) and previous sessions (no Automation Studio™).](image)

Student Survey

A student survey was used to understand how the virtual experiment environment helped the students to understand the material and accomplish the laboratory experiment. The students responded on a five point likert scale (very easy, somewhat easy, fair, somewhat difficult, very difficult) that the Automation Studio™ virtual experiment software was in general fair to use with a normal distribution centered on fair with a few students (<25%) responding that the software was either very/somewhat easy, or very/somewhat difficult. 85% of the students responded that the use of Automation Studio™ contributed to their understanding of the fluid
power circuit operation in the lab. This very positive response correlated with the instructional initiative of improving student performance in the laboratory. The students also responded on a five point likert scale (very effective, reasonably effective, satisfactory, not very effective, and ineffective) if the completion of the Automation Studio™ Virtual experiment contributed to their understanding of the fluid power circuit. 91% of the students responded that the virtual experiment was either very effective or reasonably effective in contributing to their understanding.

Conclusion

The sample used for this instructional approach consisted of students across multiple years of the program with one student who was repeating the class. The pedagogical approach in the class was to implement a pre-laboratory virtual experiment experience to improve student performance in the laboratory class and to improve student conceptual understanding of the subject. From the study results we found that students who completed the virtual pre-laboratory assignment were able to obtain a fully functional virtual experiment independent of faculty supervision. Laboratory report grades of the using the virtual laboratory software as compared to the previous sections of the class showed a decrease in laboratory grades. Further investigation into the graded reports appeared to indicate that the lower grades may be correlated to decreased report organization and report writing skills as compared to previous sections of the class. Student comments also indicated that the students using the virtual laboratory software were not always open to a discovery or inquiry learning approach in approaching the software to explore different solutions. From the student survey the students responded that the software learning curve was ‘fair’ and not overly excessive or overly simplistic. The vast majority (85%) of the student responded that the pre-laboratory virtual experiment contributed to their understanding of the fluid power circuit operation, and 91% of the students responded that the virtual experiment was effective in contributing to their understanding of the course material. Overall, we concluded that incorporating a virtual experiment in conjunction with a real physical experiment appeared to be advantages to student preparedness and student contributing to the student’s understanding of the course material.

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