Integrating Virtual Lab Simulation Software into an MET Program

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Abstract

The Mechanical Engineering Technology (MET) program of the Purdue University College of Technology promotes itself as a hands-on, minds-on program that incorporates lab activities into most of its classes. The MET program on the main campus at West Lafayette has outstanding resources, but the similar programs that belong to the statewide system and mission do not have access to such outstanding resources. A good example is the sophomore-level class in fluid power. At the MET program in Columbus, Indiana, this class often has 10–15 students, with only one semi-functional fluid power bench to conduct lab sessions. During these sessions, students are divided into groups of three or four and asked to conduct a lab exploring a variety of fluid power topics. While one group is working, the instructor has historically struggled to find a meaningful task for the rest of the class. Also, the dynamics of the group performing the lab is not always ideal, with one member doing most of the work while others watch.

Trying something different, the instructor for this class has recently incorporated software that creates a "virtual lab" environment for the students. In this specific case, 15 copies of the software have been purchased. This allows everyone in the class to perform the same experiments, as available on the hardware, in a virtual environment on their computer monitors. All students are required to conduct the lab exercises and submit lab reports. No longer do students have idle time waiting for lab benches to become available. This paper will detail the use of this fluid power software, plus other virtual lab environments that could extend the reach of the MET program beyond its traditional boundaries.

Introduction

The Purdue University College of Technology Statewide System was created to extend Purdue's existing technology programs across the state to help meet Indiana's need for trained technologists and technicians. The statewide system represents a direct academic and administrative extension of the College of Technology at the West Lafayette campus. The same quality education that is offered on the Purdue University campus in West Lafayette is available in 10 other locations throughout Indiana, including the Columbus/SE Indiana area. Due to limited resoures, however, the MET program at the Columbus location is unable to provide students with the same laboratory opportunities that exist at the main campus. Many of the MET courses have two delivery options: first, the class may be taught as two hours of lecture and two hours of lab per week, or second, the class may be structured as simply three hours of lecture per week. In many cases, the Columbus statewide location chooses to deliver the class as three hours of lecture per week, but most would agree that the majority of students learn better from hands-on, minds-on activities than from simply listening to a lecture.

This work details the efforts of faculty at the Columbus location to bring this hands-on, minds-on element of lab activities to MET students, using virtual lab simulation software rather than real hardware. Having real hardware as on the main campus would be the ideal situation, but faculty at the Columbus location are forced to be innovative in providing similar experiences for their students given the lack of resources. Virtual lab software can be purchased in sufficient seat numbers for less money than a single hydraulic bench. This often means that every student in the class is required to conduct the lab activity, which increases learning, decreases lost time due to group changeovers, and eliminates the possibility of one dominant team member who does it all or one team member who relies on others and does nothing. Additionally, this significantly increases safety in dealing with high pressure fluid. Students are also required to write their own lab report, increasing opportunities to practice verbal communication and to satisfy a critical program outcome in communication.

Additionally, an element of Purdue University's strategic plan involves engaging all Indiana citizens with the ultimate goal of developing a better-trained workforce, especially in manufacturing. According to a study commissioned by the Indiana Chamber of Commerce, "In the twenty-first century, 60 percent of all jobs will require skills that are possessed by only 20 percent of the current workforce. In Indiana, an estimated 960,000 to 1.23 million employed Hoosiers have literacy skills below the minimum standard for successful employment in a knowledge-based economy" [1]. Clearly, Indiana's current workforce is lacking the proper skills for a manufacturing economy. The College of Technology created the statewide system more than 40 years ago to provide technology education opportunities throughout the state of Indiana. With virtual lab software, students can perform lab activities without supervision (there is no safety hazard) and can potentially perform lab activities in remote locations, extending the reach of the program throughout Indiana.

Satisfying Program Outcomes

The real question to be answered by the faculty of the MET program in Columbus is not whether the virtual lab software is better or worse than working with real equipment but whether using the software improves student learning and satisfies MET program outcomes. Several classes with the dual-delivery option are currently offered with the lecture-only format, due to a lack of lab resources. In the absence of real hardware, does the virtual lab increase student learning, satisfy program outcomes, and meet core learning objectives of each of the classes?

The Accreditation Board for Engineering and Technology (ABET) programs makes no specific statement regarding simulated laboratory activities. The issue for ABET is whether the program has satisfied the outcomes it has defined. Some closely related statements include the following:

> "An ability to design and conduct experiments as well as analyze and interpret data." [2]

> "Use the techniques, skills, and modern engineering tools necessary for engineering practice." [2]

All of the examples of virtual lab activities included in this paper satisfy the first statement above and some of the elements of the second statement. For the MET program at Purdue Columbus, the virtual lab activities supplement the lectures rather than replace physical lab activities. Limited financial resources prohibit the program from constructing and developing outstanding physical lab facilities in all areas, whereas the virtual lab software costs significantly less and does satisfy program outcomes.

However, the MET program at Purdue Columbus does use physical hardware in many classes, meaning that the use of virtual lab software represents only a small part of all lab activities. Specifically, the MET program has two refrigeration/heat pump trainers, a heat exchanger trainer, a hydrostatics bench, a process control trainer, PLC trainers with peripheral benches, structural trainers, hardness testers, a tensile testing machine, heat treating and tempering ovens, an aluminum foundry for sand casting, machining and welding equipment, and a new mechatronics apparatus. While the introduction of virtual lab software has provided many benefits at a reduced cost, physical lab facilities still dominate the MET program.

The first program outcome of the MET program in Columbus is that students will,

> Apply knowledge, problem solving techniques, and hands-on skills in the areas of product development, manufacturing processes, materials specification, fluid power, energy systems, and continuous improvement.

There are enough hands-on activities, as demonstrated above, to provide hands-on skills to MET students. However, the MET program in Columbus has little, if any, equipment in fluid power, measurement science, and robotics. Supplementing these topics with virtual lab software is a viable option and has worked well. As new equipment has been added, such as the mechatronics, the virtual lab software has been used to prepare students for working with the physical equipment. Specifically, the virtual robotics software from Amatrol™ simulates the same robot used on the Amatrol™ mechatronics, and students can practice moving and positioning the robot in the virtual lab prior to using the actual robot.

Review of Virtual Lab Activities

Other engineering and engineering technology programs use virtual lab software to supplement their learning activities. In his work, Tebbe [3] developed a refrigeration simulation program that "mimicked the physical operation of the equipment with realistic data outputs." Tebbe found several advantages in using the simulation of the real equipment. Typically, students finished the activity in less time than using the real equipment. By eliminating the potential danger involved when dealing with high pressure equipment, the simulation activity was safer and further eliminated the need for supervision of the students while using the real equipment. Basically, the students did not need to be supervised to complete the activity, making it more convenient and adaptable to distance education. Tebbe's conclusion is that a virtual lab "provides advantages in terms of pedagogical approach, cost, and access."

Another paper [4] details the efforts to create an Advanced Virtual Machining Laboratory (AVML). In this work, a CNC milling machine is simulated and is available online. The program simulates the cutting process by showing the cutting tool motion, incorporating the machining sounds, and displaying in-cut part geometry and chip formation. The manual control interface is simulated by using the controller software. Actual material-removal processes using a milling machine can be verified with this tool before cutting real metal.

Pedagogical values identified in the paper were that a process that normally takes hours or days can be simulated in minutes; any number of students can be trained at any time; the activities are safe and students are never turned loose on unsupervised real equipment; students are trained on the AVML and then tested on the actual machine at the end of the semester; and the virtual lab activity is available to disabled students. Additionally, in the current economic environment where technology changes rapidly, virtual lab software saves money by not having to invest in expensive equipment that may be outdated in only a few years.

Other examples of virtual lab implementation include a stress and deformation tool [5] that combines a computer-aided solution with a pneumatic actuation system that is controlled via the Internet. This coupling of simulation and real testing maximizes student learning. A PLC virtual learning system [6] comprises an intelligent tutoring system and a simulation with animation technologies. In this instance, the simulation tool is used as a pre-laboratory activity to familiarize students with the technology prior to touching real equipment that poses an electrical hazard. The intelligent tutoring system is comprehensive in PLC topics, motivational, and always available. Typically, this system presents the content, provides an educational simulation incorporating the animation to demonstrate how the instructions work, and then allows interactive practice by the student. This type of activity may be highly individualized because each student works at his or her own pace and is a good supplement to classroom lecture activities. The authors of this paper evaluated students before the lecture, after the lecture, and after the virtual PLC module. Although there were no data to support their conclusions, the authors did state that the PLC module caused significant improvement in learning.

An interesting work employing simulation used the virtual tool to assist in the understanding of basic phenomena in fluid mechanics [7]. The author's contention is that any activity that aids in the visualization of abstract concepts will foster understanding. They utilize a constructivist view of learning that maintains that learning is not just the acquisition of facts, but the construction of knowledge achieved by students building on what they already know. Based on this view, virtual lab activities are effective in encouraging learning, particularly since the activity will build on lecture material.

This view was confirmed by a study [8] conducted at the University of South Florida in 2005. The central question explored was if computer simulation is as effective as physical lab activities in teaching college-level electronics. Students were tested on knowledge retention, as well as their attitudes about the virtual activity. Post-activity test scores and lab completion time differences were quantified for students who were randomly assigned to either the simulation group or the physical testing group. Concept tests were given during the fifth and eighth weeks of the semester and were graded by the course instructor and a second instructor who was not familiar with the study.

The results of the study were that the simulation group performed higher on the post-activity concept tests after both the fifth and eighth weeks and that the simulation group used significantly less time to complete the labs. Surveys of the students revealed that the simulation group had a more positive attitude about the lab activity; they also found the activity less abstract, more interesting, and less time consuming. The overall conclusion of the study was that simulation programs for lab might prove more effective at higher levels of cognitive learning, and regardless of whether the students are using hardware or software, they will learn the lesson. This study provided confidence that incorporating virtual lab activities into several classes in the MET program would improve learning and assist in meeting program outcomes.

Sophomore-Level Fluid Power Class

The first application of a virtual lab in the MET program at Purdue University in Columbus was in a Fluid Power class taught in the fourth semester of the two-year associate degree program and the four-year baccalaureate program. The details of the class are listed in Figure 1. Note that the class can be taught in “Class 2, Lab 2” or “Class 3” configurations. This means that the class can be three hours of lecture per week or two hours of lecture plus two hours of lab per week. As a result of these two configurations, implementing a lab into the class is not required; however, most faculty members would agree that hands-on, minds-on lab activities would be beneficial in this class.

Prior to 2002, the only lab activities incorporated into the class were an activity to identify various hydraulic and pneumatic fittings and an activity that involved cutting a rubber hose using a hydraulic-assisted cutter, which demonstrated force multiplication. A hydraulic circuits demonstrator, which used a differential manometer to measure pressure differences in copper piping of different thicknesses, was added in 2003. In 2004, the MET department added hydraulic and pneumatic benches from a local high school and tried to incorporate them into the class. Experience quickly demonstrated that the benches were missing some key components that limited their usefulness. Additional challenges emerged because only two groups could work on the machines at any one time, leaving half of the class disengaged until their group’s opportunity to perform the experiment. The instructor saw this as inefficient and investigated other opportunities.

In 2006, the instructor implemented virtual lab software called LVSIM – HYD, which is developed and sold by Lab-Volt Systems, Inc. Figure 2 displays the work environment typical of LVSIM and includes a table, power unit, a pressure, various electronic devices used for motion control, several hydraulic components, and a cut-away view of a valve that shows real-time flow through the valve. Hydraulic circuits are assembled in the virtual environment in the same way as they would be in the physical environment. Students may place manifolds, relief valves, linear or rotary actuators, flow control valves, pressure control valves, pressures, flowmeters, directional control valves, and various electronic and magnetic devices to control the circuit. Hoses are connected between components by using the mouse. The power unit has an operational on/off switch to start the flow of oil. Cut-away views of nearly all the components allow users to observe when oil is flowing back through a relief valve or how the flow is directed through a directional control valve based on the manual lever position. Cut-away views of more complex valves, such as pressure-compensated flow control valves and sequence valves, allow the user to obtain an increased understanding that is not available with physical equipment alone.

MET 230 - Fluid Power

Class 2, lab. 2, cr. 3, or class 3, cr. 3. Prerequisite: MET 111 or PHYS 218; corequisite: MA 221.

This course consists of the study of compressible and incompressible fluid statics and dynamics as applied to hydraulic and pneumatic pumps, motors, transmissions, and controls.

Upon successful completion of this course, the student should be able to:

1. *Design fluid power systems* with off the shelf components.
2. *Mathematically analyze* fluid power systems for proper operation.
3. Demonstrate understanding of operational theory of *pressur* vs. *flow* relationships in hydraulic systems.
4. Demonstrate understanding of operational theory of *pressur* vs. *flow* relationships in pneumatic systems.
5. Demonstrate understanding of application of *the conservation of energy equation* to fluid power systems.
6. Demonstrate the operation and function of working fluid power systems.
7. Demonstrate application of compressible and incompressible fluids in dynamic and static fluid power systems.
8. Demonstrate conventional solenoid control valve vs. servo control valve technology application to motion control circuits.
9. Use application software for analyzing, documenting, and presenting the results of technical work.

Figure 1: Description and expected outcomes of a fluid power course

With the virtual lab software, 15 students can work simultaneously on building hydraulic circuits and conducting experiments. To have this happen with physical equipment would require an investment greater than $100,000. A more modest investment would only provide two or three machines, requiring that the students work in groups. Experience from previous assessments from this class of MET program outcome number four—teamwork—revealed that often only one or two members of the group really perform the hands-on work of the lab activity. It is possible that the inactive members of the group were taking data and, therefore, responsible for generating a lab report for the group. While this division of labor might encourage teamwork and be typical of an industrial environment, it does not facilitate outcomes involving technical understanding and written communications. With the virtual lab software, each student is required to perform the lab and prepare a report summarizing the details, outcomes, and data gathered from the lab experiment. This is a critical benefit of all the virtual lab software implemented by the MET department of the Purdue University College of Technology in Columbus, Indiana.

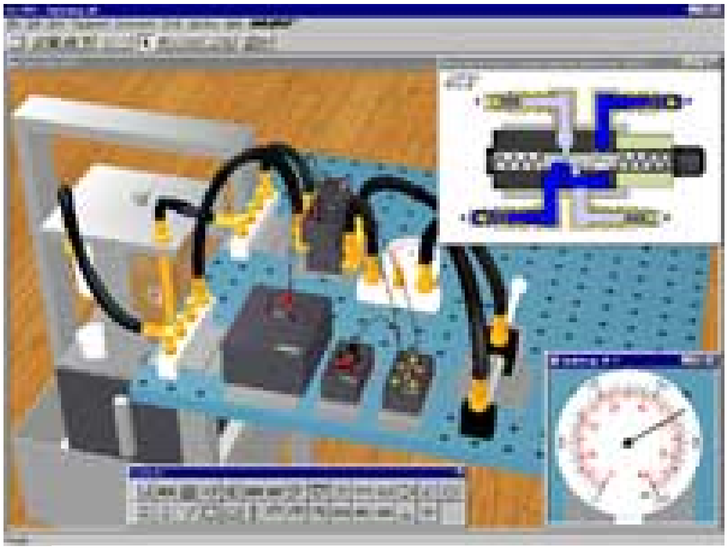

Figure 2: The interactive environment for LVSIM, a hydraulics virtual lab

Interestingly, Lab-Volt includes the same experiment manual in both physical equipment and virtual software sales. And, this is appropriate, since the same experiments conducted with the physical equipment can be done with the virtual software. The only real differences are handling of the equipment and using the quick-disconnect hoses to attach the components together. The student still must understand how to place the various components to create a functioning circuit, to acquire the proper data, and to produce the desired actuator movement. Individual lab experiments in the basic fluid power course have studied the following:

- Pressure limitation
- Pressure and force
- Force and velocity
- Work and power
- Cylinder control
- Cylinders in series
- Cylinders in parallel
- Regenerative cylinders

These activities are described in detail in the manuals supplied by the manufacturer.
The virtual fluid power software is also used for the advanced fluid power course, MET 334. This is an elective rather than required course and focuses on the control of fluid power. The following components are included in the virtual software and are utilized extensively in lab activities of the advanced fluid power course:

- DC power supply
- Pushbutton station
- Limit-switch assembly
- Relay
- Time delay relay/counter
- Pilot-lamp station
- Pressure switch
- Magnetic proximity switch
- Diffuse reflective photoelectric switch

The final project for this class the last time it was offered was to design a drilling system that used a hydraulic clamp to hold a workpiece in place during a drilling operation. The drill was simulated by an electric motor. Several of the electrical components were required for the system, and students had to develop a ladder diagram for the assignment.

Not Quite Physical Equipment

While the virtual software described above has many of the important features of real equipment, there are some critical deficiencies. First and foremost, the virtual hydraulic trainer cannot simulate pressure losses due to friction or leakage. So, lab activities designed to demonstrate these losses cannot be done. However, the MET program does have a single fluid circuit demonstrator that has four pipes with different diameters. Various valves are used to isolate the flow through the different pipes, and pressure taps are used with a differential manometer to measure pressure differences. In the past, students in groups of three or four would work on the equipment one group at a time, while the instructor looked for creative ways to entertain the other students. Now, the other students are engaged with the hydraulic virtual lab while waiting to use the real equipment. In this way, again, the virtual lab does not replace the real equipment but works together with the real equipment to improve the overall lab experience of the student.

Troubleshooting problem circuits where the instructor has inserted faults cannot be performed on the virtual lab either. Still, on complex circuits like those employing regeneration, students using the virtual lab have to troubleshoot those circuits if they are not working properly. The virtual hydraulic lab does contain pressure gauges, flowmeters, tachometers, and a voltage probe that can all be used to troubleshoot basic and electrically-controlled hydraulic circuits.

Significantly Lower Cost

The hydraulic virtual lab software was purchased from Lab-Volt for $4,085 in April 2006. This included 15 seats of the software, which is managed from a central server. Individual seats can be

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checked out on machines throughout the facility. All of the 15 seats are permitted to add operational pressure gauges, flowmeters, and tachometers to the hydraulic circuit. More users are allowed to engage the software but are unable to make pressure, flow, and speed measurements. These other users could construct a circuit including those measurement instruments, wait for and add one of the 15 licenses, and then test their circuit. This is not the perfect situation, but it works.

In 2003, the MET program in Columbus investigated adding two hydraulics trainers to its inventory of lab equipment. At this time, the vendor, a leading educational equipment supplier in Massachusetts, quoted a unit price of $18,267 for the basic trainer with an additional $9,080 for the electro-hydraulics option, which is necessary to match the capabilities of the virtual lab software. This $27,347 configuration would have served only one group at a time. To purchase enough of these to let 15 students work individually would have required an investment of more than $400,000. Realistically, to employ even five of these machines to serve five groups of three students each would have cost more than $136,000.

Not surprisingly, purchasing the hydraulic virtual lab software represents a much larger “bang for the buck” than purchasing real hardware. Given the limited resources of the MET program in Columbus, however, it has been an effective investment. Still, engineering technology programs promote themselves as hands-on programs, and virtual lab software is best used to supplement real laboratory equipment. As mentioned previously, the MET program in Columbus has much lab equipment in other areas, and the virtual lab activities represent only a minimal amount of all lab activities. And, ultimately, a mix of virtual lab software and real hardware in all fields is the desired objective.

Safety and Convenience

Of the numerous advantages of using the virtual lab software for fluid power, safety and convenience are at the top of the list. With physical equipment, students and instructors are required to wear gloves, coats, and safety glasses or helmets with face guards. The danger of high pressure oil always exists, and it leads to tentative behavior by the students that wastes time during lab assignments. Accidents, such as a failed quick-disconnect coupling, lead to dangerous situations and unfortunate messes. None of these are a concern with the virtual lab software. As mentioned previously, others have reported that virtual lab activities take less time, and the experience here has been no different. Also reported in the study at the University of South Florida [8] was that virtual lab activities actually improved knowledge retention more than physical lab activities, and students engaging in virtual lab activities reported a more positive attitude than those in physical lab activities. Since the MET program does not have actual fluid power equipment, these types of comparisons are not possible in this work.

Virtual Measurement Systems

Additional virtual lab software has been implemented in other classes. The Measurement Tools I software developed by Amatrol™, Inc., is designed to allow the user to learn how to use various measurement devices such as calipers and micrometers. Also embedded in the software is what Amatrol™ terms the "Learning Activity Packet," which is similar to the virtual tutor mentioned previously. These LAPs consist of objectives, activities, skills, and self-review sections that could stand alone as a learning activity and allow users to proceed at their own pace. At the Purdue University MET program in Columbus, the virtual lab software is used to supplement the introductory materials class, a required class, and two electives. The first elective is called "Improving Data Quality" and focuses on calibration. The second elective is "Metrology" and includes learning to use measurement devices as core learning objectives.

The software includes shafts, plates, disks, and blocks of various sizes that are measured with each of the measurement tools—machinist's rules, tape measures, dial and digital calipers, micrometers, and dial indicator assemblies. Where possible, the tools include both English and metric versions to provide experience in both unit systems. Figure 3 displays the environment in the Measurement Tools virtual lab, showing a dial caliper measuring the width of a plate. Students also use the caliper to measure the diameter of the holes and the length of the plate. The virtual caliper is operated similarly to a real caliper.

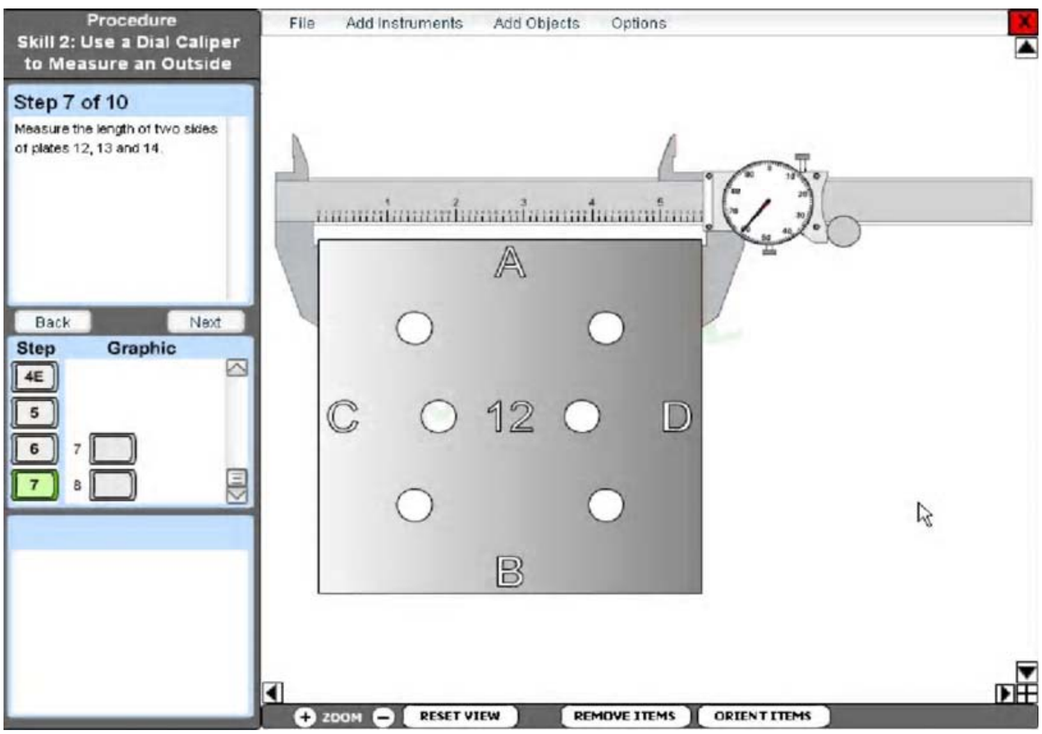

Figure 3: A graphic from the Measurement Tools virtual environment from Amatrol, Inc., showing a dial caliper measuring the width of a plate

Figure 4 demonstrates measuring the length of a shaft with a micrometer, and Figure 5 shows the zoomed view that is available to read the micrometer. The Learning Activity Packets available with the virtual lab software contain excellent descriptions and graphics on how to properly use and read the instruments. Many exercises are included in the packets to provide necessary repetition to acquire the skills. An excellent exercise included is that the 10 shafts, three disks, three plates, and gauge block are measured by all of the available instruments, and all of the measurements are compared in a single table, revealing the accuracy and tolerance of each of the instruments.

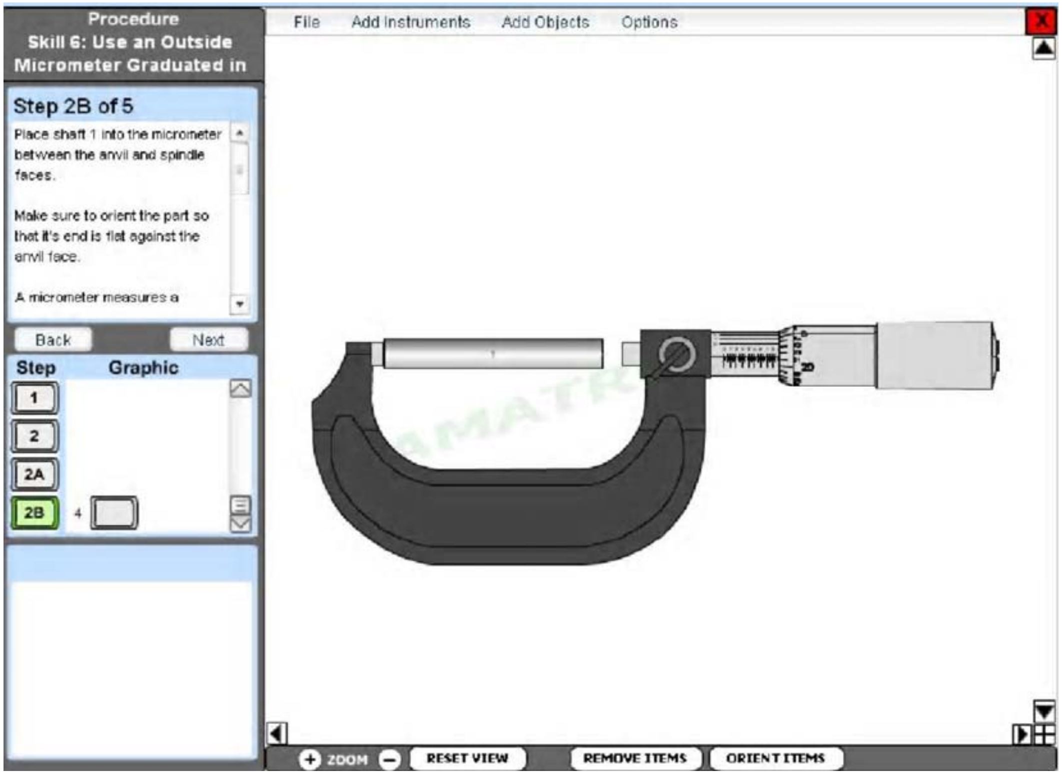

Figure 4: A micrometer used to measure the length of a shaft in the Measurement Tools virtual lab

Additionally, the Measurement Tools software includes dial indicator gauges and provides lessons and exercises to introduce students to the use of these gauges. Figure 6 provides an example from the software showing a dial indicator. Ideally, the students should be tested at the end of the semester using real measuring equipment to assess if students have acquired the skills, as is done by Javidi, et al. [8]. Currently, this is not happening due to the lack of equipment. However, the MET program has submitted several proposals that would provide funds to add real instruments and equipment. In fact, Amatrol™, Inc., the developer of the software, also manufactures a Measurement Tools work bench that works with the software to provide a more effective learning experience.

Virtual Robotics

Another virtual laboratory activity that the MET program at the Purdue University in Columbus has implemented is the programming of a robot. The MET program received funding to purchase a Mechatronics system from Amatrol™, Inc., that included a Pegasus robot. Also purchased from Amatrol™, Inc., were six licenses for their virtual robotics software. This software was implemented in an introductory manufacturing processes class to provide beginning students an experience in manufacturing automation.

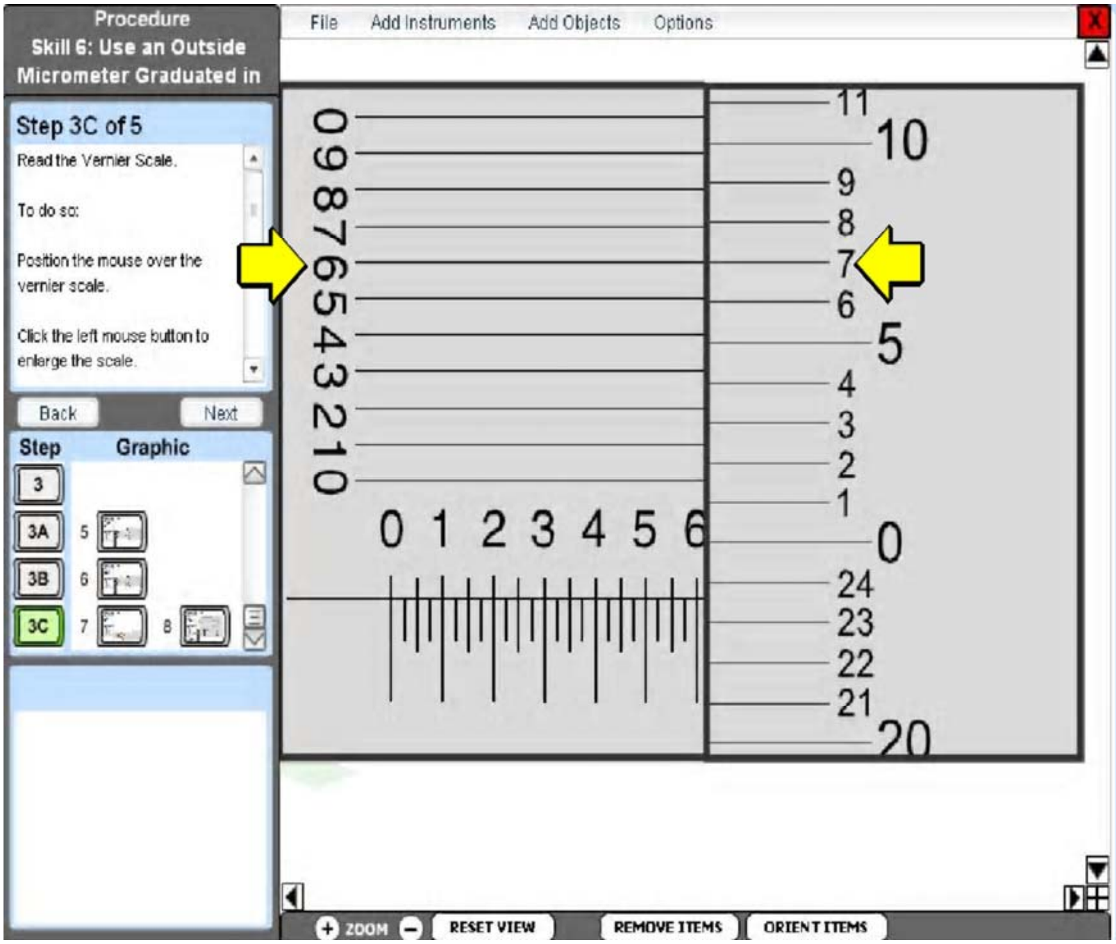

Figure 5: A view available within the virtual lab to read the micrometer

The software, the teach pendant, and a virtual robot are all part of the simulation. The student may position the robot with the teach pendant and then use the points in the robotic software to position the robot automatically. With the Mechatronics system, the software is used as training for subsequent use of the actual hardware. The equipment was just received this spring, so it has not yet been implemented in this way. The virtual lab software, though, has been utilized in the introductory class.

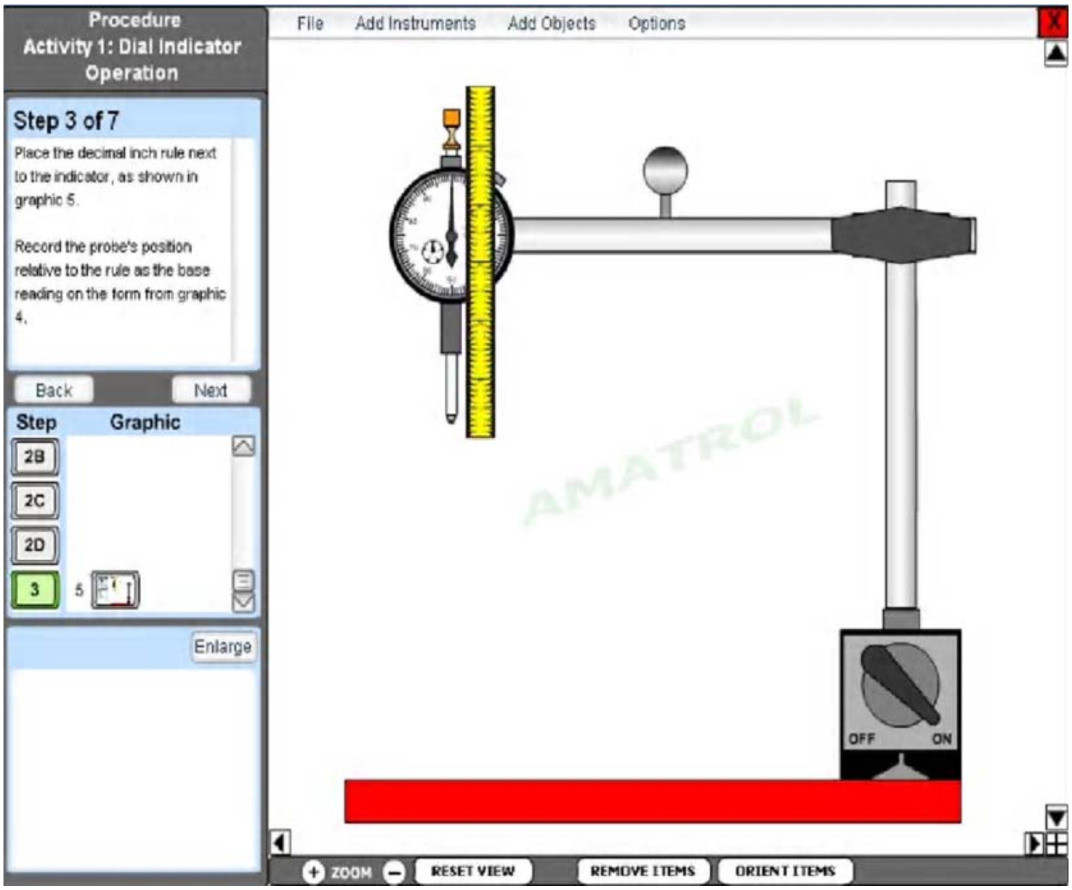

Figure 6: The Measurement Tools software showing

Conclusions

The MET program of Purdue University in Columbus, Indiana, has implemented several virtual laboratories into its program to provide students with a laboratory experience. These virtual labs do not replace physical labs since, in the classes discussed, no equipment currently exists. Although the classes may be taught without a lab component, the MET program is designed to be a hands-on, minds-on program, and all efforts to provide a lab experience are explored. In the examples herein, virtual labs are incorporated into two fluid power classes, a metrology class, and an instrumentation for automation class. In each case, the virtual labs helped to satisfy the outcomes of the classes and fit well into the course. All students were required to do the lab activities and submit reports. This was compared to the previous experiences of the faculty, where only a few students would do the hands-on activity while others would write the lab report. However, using the virtual lab required all students to do both.

Ideally, sufficient lab equipment would be available to provide a quality experience for all students. For the Purdue University at Columbus MET program, however, the resources are not available to do this. The virtual labs provide an alternative. With recent funding and submitted proposals, the MET program plans to purchase enough physical equipment to allow students to be tested after learning the skill in the virtual lab. The work by Javidi et al. [8] demonstrated that learning laboratory skills in a virtual environment is effective, as well as safer and more efficient. The use of virtual labs will continue, and the future plan is to supplement it with enough hardware to provide a quality lab experience.

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Biography

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