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A Multifaceted Approach to a Fluid Power Laboratory Course

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Introduction

This paper addresses the design of a fluid power laboratory course that utilizes a diverse breadth of learning activities. The laboratory includes a variety of exercises such as the use of simulation software, modularized hydraulic trainers, full-scale industrial systems, fabrication, and teardown analysis of fluid power components. Cycling through these various types of stations allows students with a diverse range of learning styles to experience the course topics in ways that are most conducive for each.

Course structure

Curricular placement

The Department of Engineering Technology at The University of Dayton requires Fluid Power in the junior year for mechanical and manufacturing engineering technology students. This requirement includes a three credit-hour fluid power lecture course and an accompanying one credit-hour laboratory course. This paper addresses only the laboratory course which is structured into 14 lab sessions that meet once weekly for 160 minutes each. It is limited to 18 students per section, all of whom are registered for the complementary lecture course. The laboratory is an integral part of meeting a subset of the ABET learning outcomes ranging from standard testing to written communication.

Facility and support

This lab course utilizes one laboratory classroom that is dedicated to machine control activities including hydraulic, pneumatic, and electrical machine controls. The room is approximately 25 feet by 50 feet and provides three-phase power, a supply room, worktables, hydraulic simulator stands, and benches with industrial hydraulic power units.

Course content and materials

Fluid Power at The University of Dayton is taught with a focus on industrial application of commercially available components. Students take a separate course in fluid mechanics that deals with more detailed analysis of general fluid systems, but the fluid power course uses commercially available components and manufacturers' data. The text for the fluid power lecture course is Industrial Hydraulic Manual, now in its 6th edition from the Eaton Corporation. No additional text is required for the lab. Each student is given a small technical reference handbook published by Womack that contains many hydraulic standards, basic data on standard piping and tubing, tables of data for standard actuators and other reference material. The instructor obtains these from a local supplier of industrial hydraulics and provides them to the students at no cost.

Grading:

Students receive a grade in this one credit hour lab course that is separate from the three credit hour lecture course grade. The grade for lab is determined by student performance on quizzes and logbook submissions.

Students generate extensive logbooks adhering to specifications provided at the beginning of the term. This is not a bound logbook with fixed pages where students make entries. Rather it is a three ring binder with one tab for each session of the course. Students insert class notes, hand drawn circuit diagrams, calculations, annotated photographs, annotated data sheets, computer simulation printouts, and other materials. Color printouts are required to show circuit simulations and photographs from lab. Any papers that are computer-generated or reference materials such as manufacturers' data sheets must be annotated to be included in the logbook. Rubrics are used to evaluate the logbook four times throughout the semester. Each rubric has some common and predictable elements throughout the term, but additional items are added each time as audit checkpoints for very specific items from particular sessions and these are not published before logbooks are collected.

Students take five quizzes throughout the semester, each designed to take about twenty minutes at the beginning of lab sessions. Quizzes include terminology, calculations, open-ended design, and analysis. In addition, the quiz typically contains one element that reinforces the need to keep logbooks updated such as "take out the sheet from your logbook showing the design modified for regeneration and attach that to your quiz."

Reasons for a multifaceted approach

This laboratory course has many different learning outcomes that are dependent on different types of experiences. Additionally, students in the course have diverse learning styles and preferences. To achieve success then, laboratory experiences and learning modes need to be varied.

Substantial work has focused on learning styles and student engagement. Much of that work suggests that meeting these objectives with a diverse student body is best achieved with a diverse approach to laboratory sessions. Specifically in the area of fluid mechanics, one published report[1] indicates that the addition of one additional mode of learning resulted in improved student engagement and performance. Another institution reported[2] that in the study of fluid flow, the inclusion of one additional learning mode improved student learning to statistically significant levels. Another paper[3] specifically "highlights the need for a range of learning modes in engineering education, appealing to a diverse set of individual learning styles."

Some students may connect most naturally with the computer simulation exercises while others may learn more by taking apart valves and pumps and examining the internal components. Some concepts are learned well through guided step-by-step exercises on pre-built modules, but another type of learning takes place through more open and undefined work on full scale industrial systems.

This approach differs from many typical labs that are built on a single platform, such as following one guide for a given educational system that takes students through a weekly series of scripted exercises.

Varying the type of activity and the associated learning styles to enhance learning outcomes is supported by a substantial body of research. Exact terminology varies, but the value of labs in general are supported by this same research. Aural/auditory learners can do well in a traditional lecture course. Most students in engineering disciplines, however, can achieve deeper learning in a mode that is more visual/tactile. These students benefit from working in a laboratory course and hooking up equipment. Seeing, touching, and running these systems greatly enhances the learning and leads to deeper learning outcomes that allow students to apply what they have learned. The multi-faceted approach presented in this paper simply takes this a step further and addresses even more styles within the lab to connect to more students and in deeper ways. The logic-based learner can do extremely well, for example, working independently on a computer simulation of a system without other distractions. Other activities are more conducive to the social learner and yet others are better aligned with the students who prefer a kinesthetic learning activity. Even as a semester progresses there is reason to change activity types as students are able to move from a level of basic understanding to more open-ended activities that allow for more self-direction and creativity, leading to a stronger ability to apply the concepts after graduation.

Elements of the lab

While the lab meets only weekly, each of the 14 sessions is two hours and forty minutes in length. This provides enough time to divide each session into three separate “stations.” With this number of separate activities, there are many opportunities for variation of not only topic, but also learning mode. This variety makes for a more active and interesting lab course and allows opportunities to connect to wide range of student learning styles.

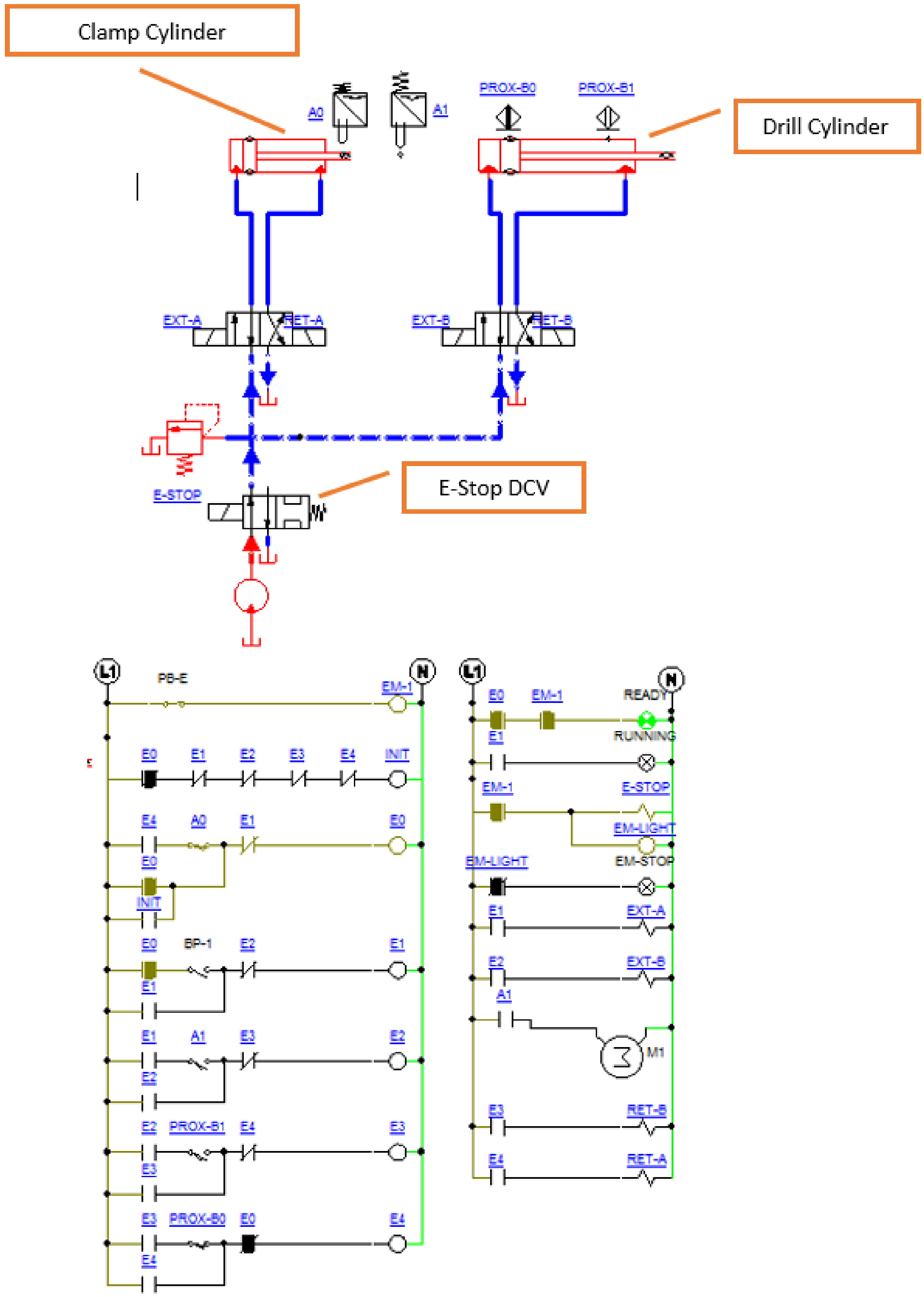
In our particular case, there are 18 students enrolled. Students are formed into groups of three and after a brief introduction to the lab session, each group spends about 45 minutes at each station before rotating to the next. Note that for 18 students in groups of three, there are six groups, so the laboratory needs to provide two sets of each station. Below are some of the main categories of activities with an explanation and sample of each:

Computer Simulation

The laboratory utilizes software called “Automation Studio” by Famic Technologies. The software is a commercial design tool and not a simply an educational package. The educational element, however, is very natural and has proven to be a tremendous asset to this course. There is substantial support for the software including online training videos. The software has proven to be a great learning tool for many students who are comfortable with computer software and enjoy working in a drag and drop environment, but might initially be intimidated by oily hoses and mechanical connections. A typical station provides a brief description of a desired machine operation and asks the students to develop a design that performs in this manner. Students design a system and then run the simulation to see how it performs. They then troubleshoot, modify, and iterate.

The University purchased a site license of the software providing access for up to 36 simultaneous users. Students download the software to their personal computers at the beginning of the semester. Anytime they open the program it automatically checks for a valid and available seat license, and then allows the student to use the software. With our arrangement, students must be on campus to have this access. The software supports any hydraulic component and design encountered in the class. The design can be tested at any point by calling the program to simulate the system. The program is excellent at showing what will happen with the design that the student has entered based on the efficacy of the design. A typical result for a student logbook is shown in Figure 1.

Figure 1. Typical logbook entry for simulation exercise, showing a screenshot that a student printed out for inclusion in the logbook. In the actual software, full motion animation shows the operation of the circuit.

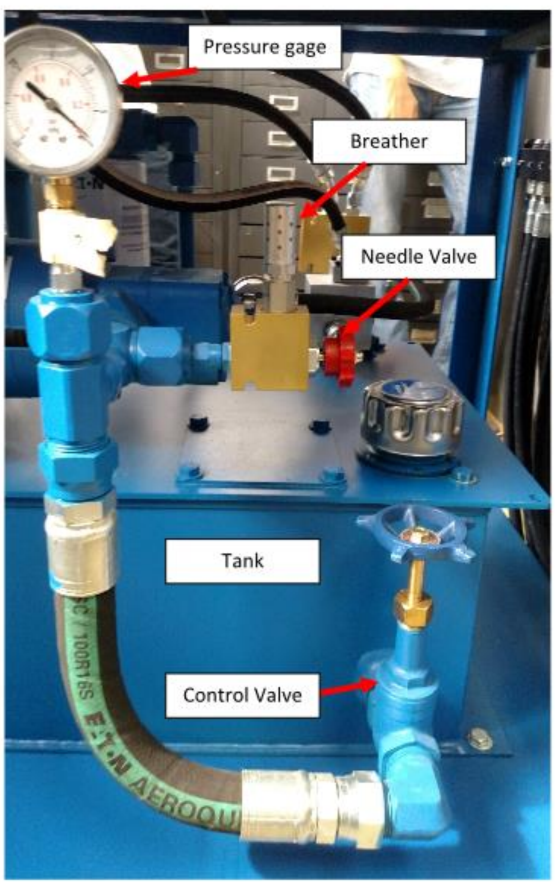


Trainer Stands

The lab also utilizes two trainer stands that include commercial components neatly mounted and labeled on a panel with quick connect fittings. These trainers were purchased from Eaton Hydraulics, and are specifically packaged for use as a training aid. They are double-sided units that allow two identical sets of controls and actuators to run from a single power unit located on the base of the unit. The trainers include cylinders, a hydraulic motor, pressure control valves, a check valve, directional control valves, gages, and flexible hose for making connections. Manuals with a series of workbook exercises are included. These modularized and neatly labeled units demonstrate a variety of circuit designs and are excellent for teaching in a very structured, step-by-step approach. The workbook offers closed-end training modules that resonate with students who like the hands-on experience but need a closed set of parameters with specific instructions. The trainers do not offer much in the way of open-ended learning or mathematical/analytical/theory work. These units, for example, have a fixed 500 psi system pressure that is not designed to be adjusted. When teaching this lab, it is very easy to see the students who most connect with this approach. These students really want a visual and tactile experience, but also enjoy the comfort of a guided experience and very specific questions that are answered in a workbook type format. Figure 2 shows a student logbook entry from an exercise on the trainer.

Figure 2. Entry from student logbook for trainer station. It shows an annotated photograph the student took along with the student's explanation of that particular exercise.

Station 1: Cavitation and aeration



When the pump is turned on oil will flow from the tank to the pump, through the suction line. The control valve must be fully open or else the pump will starve and oil can experience cavitation because the pump is creating a partial vacuum that could cause the oil to start boiling/vaporize. The needle valve is connected to a breather and the valve must remain closed or else there will be too much air in the suction line and the pump will experience aeration. Aeration can also happen when there is a leak in the suction line and aeration will cause the pump to wear out. The pressure gage measures the partial vacuum that is created in the hydraulic suction line. The partial vacuum can be prevented by putting the tank above the pump and letting gravity deliver oil to the pump. Cavitation can be prevented by having a big, fat, straight suction line going to the pump.

Sight gage is used to indicate the fluid level in the tank and the temperature of the fluid.

Industrial benches
The lab includes three sets of benches built from actual hydraulic power units that were used in industry. The power units are connected to overhead electrical bus and are full scale systems. Next to the hydraulic power unit is an open bench and nearby is a multitude of components available for use on these systems. Pressure control valves, actuators, and conductors are fitted with quick-connect fittings to allow for a wide range of designs. Students adjust system pressure up to 2000 psi and fully control the operation of their circuits. The systems allow for the measurement of rpm, current, voltage, pressure, flow and other parameters just as in an industrial system. They allow for a creative approach and seem very representative of systems that graduates will face in industry. These systems most readily connect with the kinesthetic learners and social learners as these stations require substantial discussion, decision-making, and physical work. Figure 3 shows a setup on the industrial bench.

Figure 3. Photo of industrial bench from a student logbook. Students each include photographs of the general work environment along with more specific and labeled photographs of circuits and components.

Fabrication stations

Some stations give students exposure to the type of work that skilled trades will need to perform to build and maintain systems designed by graduates. It is important to gain an appreciation for this skill set, and this experience also allows students to learn about the various options available to a designer. Note that this lab does not develop proficiency in the use of tools as that is not a required outcome of the program. Throughout the course of a semester students will generate pipe threads, bend and flare tubing, and make fitted connections. Note that all other hydraulic circuit stations are equipped with flexible hose and quick disconnects so students do not gain this experience elsewhere. Some students really enjoy the experience of actually making something from raw materials and enjoy the opportunity to work with unfamiliar tools. Figure 4 shows a typical logbook entry for this type of a station.

Figure 4. Typical logbook entry for fabrication station. In this station students were given a simple fixture and then cut, bent, flared, and fit ¼” steel tubing to the fixture.

Tear downs

Some stations provide a commercial component such as a pump or a directional control valve at a workbench with the basic hand tools that it takes to disassemble that component. A typical exercise is to begin by noting all information from the nameplate of the component and then access the manufacturer's data sheet for it. Early in the semester, this information is posted to the University learning system software, but later students must find it on their own. Students then observe all external features, photographing and noting details. Typical external features include ports, mounting, mechanical interfaces, and electrical controls. Students then "decode" the model number from the nameplate, cross-referencing it to the data sheet and noting all characteristics that should be expected. Once complete with the external features and the background research, students use the tools provided and begin disassembly. Students must take multiple photographs showing exploded assembly views and annotate these. Naming each component and commenting on the major ones proves to be a valuable assignment. Students notice the tolerance, fit, and surface finish issues associated with these components.

Tactile learners really value these stations. Some students are able to understand how a component works when viewing the cutaway illustrations provided in the text, but others really do not have a full understanding until they have held those components in their own hands. These stations are among the most popular of the semester as many students report that seeing the inside of these components really allows them to internalize what was being taught in the lecture portion of the course. Figure 5 shows a typical student logbook entry for a teardown station.

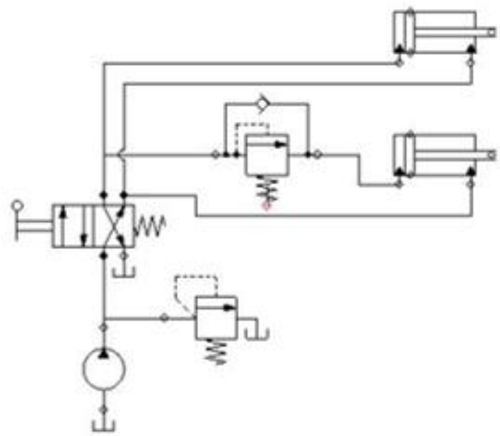
Figure 5. Typical logbook entry for teardown station. Students analyzed the internal construction of a pressure control valve, comparing it to the data sheet from the manufacturer.

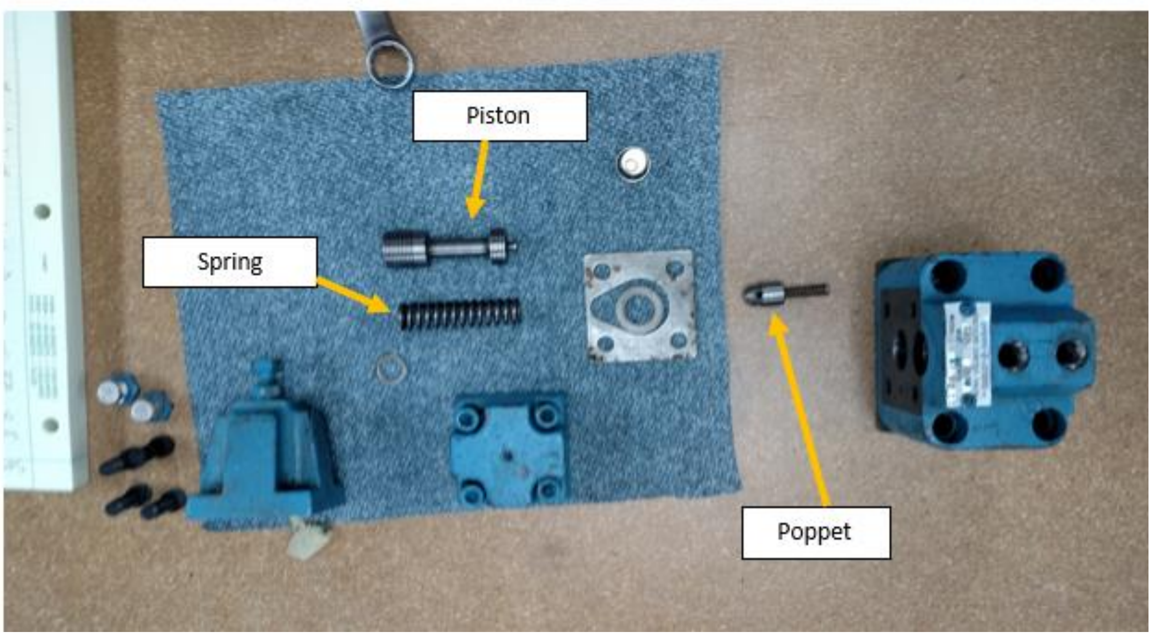
Station 1: Analysis of a Pressure Control Valve

Model Number: RCG 03 B2 23

This model number specifies that the valve is a gasket mounted sequence valve with an internal check valve, normaly open, 3/8 inche nominal pipe bore, internally piloted, externally drained, with a max pressure of 500psi and a flow rate of 30gpm.

The piston inside the valve shifts up once a certsin pressure is reached. The piston pushes against a spring. The resistance of the spring determines the pressure required to push the piston open.





Commercial system reviews

It is helpful for many students to see the overall goal of hydraulic design so that they get a bit more excited about working through the details. For this reason, in the beginning of the semester, groups of students visit working hydraulic systems. One station is the visual inspection of a forklift while a licensed forklift operator operates the various actuators and allows students to interact with it. Each group also visits the hydraulic lift on the receiving dock and can see, for example, single-acting cylinders in a scissors mechanism. A visit to the stage riser in the campus theater can be helpful because it shows the way in which the orchestra or the sets for a play can be raised or lowered with a hydraulic system. Some learners need to see the "big picture" before the study of components is helpful.

Standard fluid testing:

Some stations throughout the term are dedicated to standard testing. Students can actually experience fluid properties, but also become familiar with the detailed specification of ANSI or ASTM standards. Viscosity testing, for example, ranges from fairly quick and simple tests to extremely tedious procedures. Properties such as pour point and flash point are fun for students and are much better in lab than they are in lecture. Again, the likelihood of retention and ability to apply concepts are greatly enhanced with these laboratory experiences.

Outcomes

Using this broad set of student laboratory experiences seems to exhibit many benefits.
Student feedback on the course is positive. Students gain an appreciation of the hands-on skills required to implement and maintain engineering designs. They come to better understand the skilled individuals who perform these crafts and upon whom all graduates will rely. Troubleshooting skills are also developed, and in varied ways as students work on virtual circuits, predefined exercises, and full-scale industrial systems. By the end of the course students have worked with full-power large-scale industrial systems. They seem to recognize the significance of this relative to a small breadboard with a maximum of twelve volts, but rather a large horsepower system with high pressures and voltages, making the element of safety more readily apparent. In addition, students enhance their documentation skills through a well-developed and substantial logbook with documentation, annotated photographs, descriptions of results, and the results of quizzes used to assess student learning. Experiencing the disassembly of a valve or pump and actually seeing the size of a poppet or feeling the stiffness of a spring gives students a deeper understanding of the course materials. Experiencing the significance of the details of a long model number better prepares them for applications in industry.
Very early in the term students, as students experience this more open approach to lab, they also come to understand that mistakes are welcomed. They come to understand that a perfect design rarely happens on the first try and come to expect that design is an iterative process and troubleshooting is a critical skill. Surprises are encouraged, and happen often as students set a valve to 2000 psi but then see no pressure on the indicating gage. They gradually become more comfortable with variation and ambiguity and the fact there are not forms to complete and no template to follow.

Constraints and limitations
This model for a laboratory course in fluid power, like any model, has its deficiencies and constraints. This approach does necessitate an amply equipped facility. Adequate space, equipment for double-tooled stations, industrial components and equipment, are all necessary. In this case, these resources have been acquired over many years. The budget also must provide for software, some limited technician help, and student support. For these reasons, cost and infrastructure can be an issue for some institutions.

This approach does not provide a great deal of time developing any one skill. These are BSET programs and graduates are not technicians. For this reason, students only develop basic familiarity with such skills as tube flaring and pipe fitting, for example. They do not graduate with a proficiency in hands-on technician skills. For some two-year programs, this required outcome would necessitate a different approach.

This multifaceted lab also takes more time for administration and planning. It is substantially easier for an instructor to step through a series of activities from a standard trainer workbook or a computer simulation package. Similarly, this model is more challenging for the students as well. There is more ambiguity and less continuity than a single approach that is consistent through the semester. This approach actually causes some serious stress for the student who has an implicit mental model for labs that the student role is that of a recipe-follower. These students are plagued with questions such as “What are you really looking for?”, “Exactly what are we supposed to do?”, “What should this part be called?”, and “How many pictures do we have to have?”.

Another weakness in the current system is that quizzes are not hands-on, but only written. It would be best if quizzes re-created the stations and required an assessment of hands-on ability. At this point, that type of exercise is only incorporated into the final quiz due to time, space, and equipment constraints.

Perhaps the most significant caveat at this point is that this model has not been in place for a long time, and results are based on qualitative feedback rather than quantified outcomes assessment. No formal assessment has been done with control groups. The pedagogical method aligns with available research, student feedback is quite positive, and learning seems to be improved, but this has not been proven with research-based metrics and controls.

Summary:
The goal of any laboratory is to facilitate a better understanding of theory and practice. With planning and support, laboratory courses can be modified to include a multi-faceted approach that varies the student learning experiences and supports a range of student learning styles. In the case of a fluid power laboratory course, faculty should consider, for example, not only a typical trainer stand with accompanying worksheets, but also disassembly, computer simulation, and more free-form exercises. In so doing, students may experience a broader range of skills and learn in more varied and deeper ways. Modifying the course does not mean that each activity presented here needs to be included. If your lab currently operates in a single mode, such as stepping through a manual for a set of trainers or a workbook with a particular simulation software, consider breaking away from this default operation. Simply consider, within your own set of constraints, how you might diversify the activities, and hence the learning modes to increase student interest and student learning.