

## **Problem Based Learning of Data Acquisition and Computer-Based Control Applications in MET Courses**

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### 1. Introduction

This paper discusses how problem-based learning and computer-based applications can be used to enhance the students' learning experience in two 300-level courses in controls, instrumentation, and fluid power. MET 382 Controls and Instrumentation for Automation is a three credit hour course with a two-hour laboratory. Half of the time is allocated for data acquisition, and half for control applications. The second course, MET 334 Advanced Fluid Power, also a three credit hour course, includes analysis and testing of hydraulic and pneumatic systems. Both courses require practical skills to complete the laboratory assignments, which give students hands-on experience. Although every phase of developing the practical skills is important, we have found that hands-on experience in applying software to solve problems presents the greatest challenges in a laboratory environment. Practical experience with data acquisition and other computer applications is an important part of the engineering process.

Several software packages are used in both courses. In this paper we discuss two laboratory assignments, one for data acquisition with LabVIEW 6 software, and the other for fluid power calculations with the help of Excel software. We find that students benefit from developing proficiency in the software applications to solve technical problems. Employing an intensive, problem-based approach helps develop this proficiency in a limited time. We recommend that the students receive clear, consistent, and reasonably complete assignments provided by the laboratory instructor. It is important that the students continue through all phases of each assignment, and fully engage in solving problems as they encounter them. This paper discusses how we focused on the problem-based learning that could also be implemented for industrial projects.

Problem based learning (PBL)<sup>1,2,3,4</sup> is a response to educational research that has found that lecturing is arguably the least effective way to facilitate student learning. During lecture, students' level of attention drops significantly as the lecture goes on. Students tend to lose their initial interest. This is true also during the introduction to a laboratory exercise, which is intended to help students complete their assignments in the allotted time.

PBL was pioneered at Case Western Reserve University in the early 1950s, and is now used in over 80% of medical schools, and a growing number of engineering schools include it in their curricula. With PBL, students are empowered to self-direct their education to solve difficult problems that have been prepared for them by the instructor. PBL is an instructional method, which uses real world problems to facilitate students' critical thinking and problem solving skills, while accomplishing the course objectives. Students learn not only from the instructor, but also from the printed instructions. They may choose to use Internet, ask a team member, consult with other teams, or make their own experiment. They get involved and take responsibility for their learning. Instructor becomes mediator, counselor, consultant, and subject matter expert, guiding students as they solve their problems.

In this paper, we discuss how PBL can be applied to industrial projects, within the constraints of a laboratory. We found that the problem-based approach to the laboratory experiments made it possible to provide students with real-life experiences within the time and other constraints of a course. Both students and instructor benefit from this approach, which is pedagogically pragmatic and allows students to be exposed to the industrial practice.

It is important to remember where the class fits in its engineering technology curriculum. We have to look at the prerequisites for each class, and what are the expected outcomes. Furthermore, to what extent the students will be expected to use their skills in subsequent classes or in industry. The detailed instructions provided require students to complete specific assignments. Students were expected to solve problems as they encountered them.

Department of Mechanical Engineering Technology at Purdue University offers MET 382 Controls and Instrumentation for Automation course in data acquisition and control applications to undergraduate students. LabVIEW 6 software by National Instruments is used extensively for data acquisition. A fluid power laboratory is used to provide the equipment the students can use to collect data. This reinforces their expertise with the fluid power equipment, gained in MET 230 Fluid Power course.

Students worked in teams of two or three. The amount of problems the students were able to handle varied from team to team, and indicated how skilled they already were in solving similar problems. The expectations of solving their problems by the instructor also played the role in shaping their attitude to problem solving.

MET 334 Advanced Fluid Power, as well as MET 382 Controls and Instrumentation for Automation require a good command of Microsoft Office, especially Excel. In addition, 200-level courses in mathematics and physics are required. Our students had completed courses in product design and specifications, applied statics, materials, manufacturing processes, and computer analysis tools. Therefore, students enrolled in both courses were ready to apply their knowledge to controls, measurements, and fluid power calculations.

## 2. Advantages of problem-based learning

There are a number of advantages of using problem-based learning in a laboratory:

- The emphasis is on understanding, not memorizing, or completing without thinking, the laboratory procedures. This promoted discussions and collaboration among students, and faculty mentoring.
- The instructor also becomes more involved in students' work. He coaches, mediates, consults, and provides expertise. He is available when asked, or when he notices the need to be involved. Otherwise, the instructor remains on the side.
- Students feel responsible for providing answers to the problems provided in the laboratory instructions, and those they encounter themselves. They develop skills to solve these problems, and thus become more competent.
- Teamwork is encouraged, which helps develop interpersonal skills, which are of benefit in an industrial environment.
- Laboratory time is used efficiently, with all participants fully engaged in the learning process.
- Enables to expose weak spots in students' knowledge and address them right away.
- Teaches students take responsibility for their learning. Even with the instructor's help, students are required to understand and solve the problems.
- Provides instructor with a valuable feedback for selecting lecture topics.
- Students leave the lab more mature and confident about their skills. They know they can solve other problems when they encounter them in other classes, or later in industry.

## 3. Disadvantages of problem-based learning

Problem-based learning comes with the following disadvantages:

- Since PBL stresses quality, not quantity, of content covered, some of the material covered by textbooks may be omitted.
- Students may initially struggle with PBL when this approach is new to them. They may not be prepared to answer questions posed by the instructor, they may want the instructor to solve all the problems for them. They may tell the instructor "It is your job to tell me."
- It can be difficult and time-consuming to correct erroneous student reasoning, and keep students on track.

Student assessment is more difficult than traditional multiple-choice tests. It requires preparation of different assessment tools, such as oral examinations and presentations, peer and teacher assessment of class projects, and modified homework assignments.

#### 4. MET 382 Controls and Instrumentation for Automation

This course stresses hands-on experience in a wide area of topics, including programmable logic controllers (50% of time), data acquisition (35%), and industrial control (15%). In this paper we focus only on one 2-hour laboratory assignment for data acquisition.

The core learning objectives for this course are:

- Identify the components of a PC-based data acquisition system.
- Evaluate and select an automated data acquisition system based on the requirements (accuracy, repeatability, speed, etc.) of a given application.
- Use data acquisition software to collect and analyze data from a mechanical system.
- Evaluate and select sensors for a given application based on the sensor's accuracy, resolution, response time, and other relevant static/dynamic specifications.
- Identify common sensors for determining position, temperature, pressure, flow, and force.

##### 4.1. LabVIEW software programming

In order to give students real-life experience in data acquisition, we asked them to first configure the data acquisition system for temperature measurements, run it, test it, and answer specific questions about system accuracy. The laboratory assignments asked students to write programs in LabVIEW for virtual instruments, and run them. The assignments challenged the students to apply their skills in temperature measurements to other sensors. They connected the data acquisition system to a hydraulic stand and measured pressure and flow rate. They wired the sensors and calibrated them. Then they were asked to collect the data and write them to a file.

Students were required to complete all the above assignments without “formal” introduction to the exercises. They started right away on their assignments. The instructor was moving from one team to another to help them get started. Students needed to learn where the equipment and supplies were located in the lab, how to configure the data acquisition system, how to run the LabVIEW software, and how to write a program in it. Students received detailed instructions how to configure the channels for data acquisition, and how to run the software. Table 1 shows a sample of instructions (two out of seven pages) provided to students to help them start writing a program in LabVIEW for temperature measurements. Numerous problems arose for students when they misinterpreted the instructions, did not follow them, or did not configure the data acquisition properly.

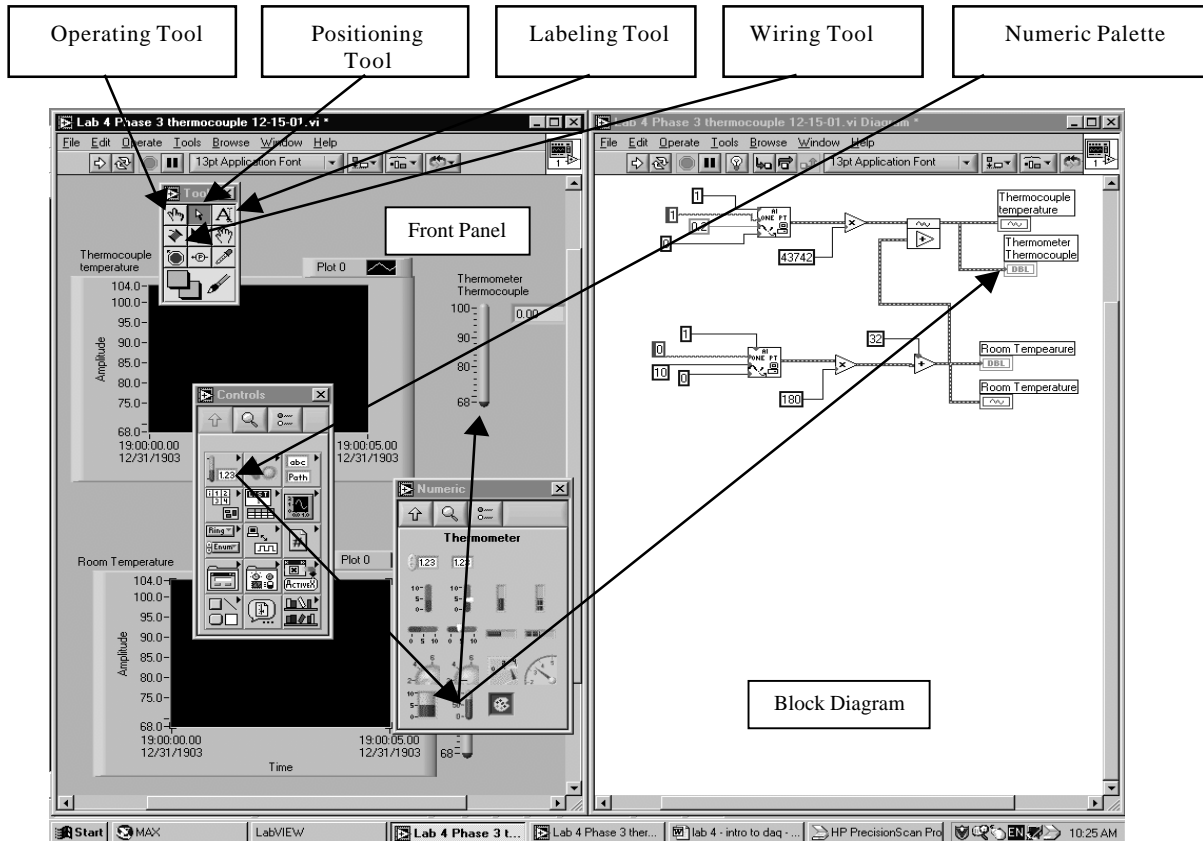
Figure 1 (see Table 1) shows the only screen capture of a finished LabVIEW program students received in their laboratory manual. Before fall 2001 semester we included more screen captures to guide students through their programming steps. We added more problems for students by removing the screen captures. This proved to be a step in the right direction because students focused more on the final result and paid more attention to written instructions.

**Table 1. Sample of instruction provided to students**

**Phase 3: Using LabVIEW® software for temperature measurements.**

**Background**

LabVIEW, or **L**aboratory **V**irtual **I**nstrument **E**ngineering **W**orkbench, uses a graphical programming language G, not a traditional, text-based, code. A LabVIEW program represents a *virtual instrument* (VI). The software comes with a large library of subroutines designed for data acquisition, analysis, and presentation. The program (virtual instrument VI) is built by adding icons (subVI's) to the block diagram and connecting (wiring) them.



**Figure 1. Screen capture of a finished virtual instrument students were expected to create by using LabVIEW**

**Getting started with a virtual instrument (VI) - Before beginning with a VI program**

- a) Connect one type T thermocouple to channel one of the signal conditioning box for a differential measurement, as described in the first part of Phase 2. You will have to adjust software in both the “Data Neighborhood” and “Devices and Interfaces” file folders. Don’t forget the dip switches.
- b) Run a test to check if the channel works properly. For purposes of this early test, temporarily configure the channel in software as a “type T thermocouple”. Be sure that the temperature graph trends upwards as the thermocouple heats up, otherwise you may have a polarity problem

- c) Launch LabVIEW (Start→Programs→MET Applications→National Instruments LabVIEW6→LabVIEW) and open a new VI. Save it in your directory as Temperature.vi.
- d) Choose pull-down menu →Windows →Tile Left and Right, to see both the front panel (left) and the block diagram (right side of screen). *The front panel is the user interface; it allows you to interact with the program. The block diagram is for wiring the icons together.*
- e) Use the pull-down menu Windows, or right-click on the front panel or block diagram, to make the palettes visible as shown on the previous page.

To get help, go to the pull-down menu Help and click “Show Context Help”

### **Adding sensors and graphs to a virtual instrument**

This set of instructions creates the display for two analog channels. Channel zero is for the built-in cold junction compensation. Channel one is for the thermocouple you installed.

- a) In the front panel, choose the →Positioning Tool, then go to →Controls →Numeric →Thermometer and drag and drop the thermometer indicator on the front panel. Type “Thermometer Thermocouple” before clicking again. Repeat the procedure for “Thermometer Room Temperature”.

- b) To show the digital display, right-click on the thermometer, go to →Visible Items →Digital Display.

*On the block diagram, numeric terminals represent the thermometers. The color of the terminals (and connecting wires) depends on the type of data:*

*Orange: Floating-Point Number      Blue: Integer Number*

*Green: Boolean                              Purple: String*

*The blocks placed so far are orange, which means their numeric values are represented by double-precision (DBL) data.*

- c) Go with the Positioning Tool to →Controls →Graph →Waveform Chart and drop it on the front panel. Type “Waveform Thermocouple” before clicking again. Repeat this for the Room Temperature Waveform Chart.
- d) Line up the corresponding labels on the block diagram (right screen) by left clicking on the orange DBL and dragging it to a new position below each thermometer block.

*The next several pages document how to create the portion of the program within the dashed lines in the previous figure. This dashed segment captures data from channel one. Once the programming for channel one is completed, this information can be copied and modified for use with channel zero.*

As you work through the following pages, your program should begin to look like the one shown at the beginning of Phase 3. Please use it for reference as you go through the remaining setup steps.

The assignment was to create a *working* virtual instrument (thermometer). As is the case with any prototype work, problems with the hardware and software were abundant. Often students did not know if their procedures were correct or if the problem existed where they assumed it to be, so they checked their work repeatedly, often to discover a solution to the problem somewhere else. Virtual instrument presented in Figure 1 is quite simple, but for a student who never programmed in LabVIEW, it was a challenge.

#### 4.2. Advantages of using LabVIEW programming for problem-based learning

- Students develop understanding of how data acquisition system works.
- Students develop their own and unique skills to solve hardware and software problems.
- The instructor has more time to assist students when they encounter overwhelming problems.
- Students learn data acquisition techniques and software applications to solve real world problems.
- Students take initiative to solve problems on their own without the help of instructor.

#### 4.3. Disadvantages

- Students may struggle with software and hardware for data acquisition.
- Learning how to use new software in two hours can be a challenge.
- Laboratory sessions require teamwork and outside of class preparation.
- Laboratory assignment may not be completed during the allotted time.

### 5. MET 334 Advanced Fluid Power

#### 5.1. Core learning objectives for MET 334 Advanced Fluid Power

The objectives of this course are:

- Develop student skills to apply the principles of fluid power studied in MET 230 Fluid Power course to predict performance of complex industrial and mobile hydraulic-pneumatic motion control systems.
- Develop student skills of analytical problem solving and selection of hydraulic and pneumatic system components to maximize system efficiency.
- Develop student confidence in applied analysis of fluid system dynamic performance and develop methods for practical system troubleshooting and analysis to correct operating deficiencies and malfunctions.

#### 5.2. MET 334 Hydraulic Cylinder Speed Control Analysis

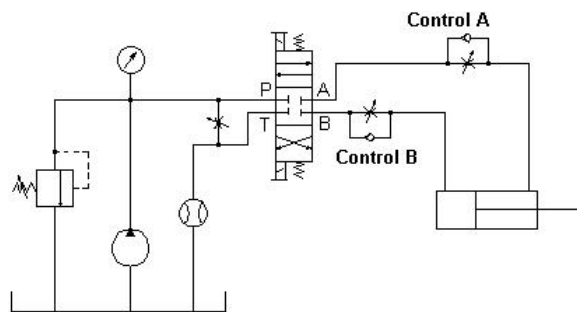
Like the previous course MET 334 Advanced Fluid Power offers a magnitude of opportunities to apply problem-based learning. The speed control exercise, presented in the following, is an example of taking an existing laboratory exercise with a hydraulic cylinder control, and applying data acquisition for advanced course work. In the existing laboratory exercise, students completed all calculations with a personal calculator. In the advanced course version, the exercise requires the student to complete the basic exercise for review, and add a spreadsheet

component to illustrate how the meter-out cylinder stalls under load. This helps students better understand how the speed control circuit performs over a wide range of parameters. Calculations with personal calculators did not allow for such approach due to time constraints. Objectives of this exercise were:

- To illustrate how cylinder velocity control is accomplished in a simple hydraulic actuation system.
- To set a meter-out non-pressure compensated flow control to achieve specified piston velocities in both extend and retract motions.
- To compute pressures, flows, and power losses in various parts of a circuit under velocity control.
- Calculate velocity for varying load conditions with non-pressure compensated flow control valves.

### 5.3. Procedure

In this laboratory exercise, meter-out flow control (Figure 2) was used. Meter-out control offers the most positive method of cylinder control under all types of load conditions. Non-pressure compensated flow controls are commonly used where varying loads are not encountered and precise velocity control is not required. Non-pressure compensated flow controls are much more economical than pressure compensated speed controls and system efficiency is equal. Application requires analysis to predict operating velocity versus cylinder loads to properly set the speed controls and predict overall system limits for velocity and loading profiles. The cylinder velocity is evaluated for varying load conditions and also overall-efficiency for increased loading until cylinder stall condition (Figure 3 & 4). The problematic system approach brings about unusual but important pressure conditions in the control circuit, which must be taken into consideration. These conditions are evaluated in this exercise.



**Figure 2. Speed control circuit**

To evaluate the system students first analyze the existing hydraulic system and then operate the system to establish base line data. All system parameters are documented including component specifications. Once base line data is collected students apply the information to spreadsheet analysis for predicting velocity versus cylinder load. Students balance forces and then apply the basic orifice equation for hydraulic systems to establish flow rate across the meter-out valve A or B as shown in Figure 2.



Load	Press. out	Flow out	Cylinder vel.	System eff.
pounds	psi	gpm	in./sec.	%
0	3191.69	1.49	1.11	0%
500	3094.63	1.47	1.10	3%
1000	2997.57	1.45	1.08	7%
2000	2803.45	1.40	1.04	14%
3000	2609.34	1.35	1.01	20%
4000	2415.22	1.30	0.97	27%
5000	2221.11	1.24	0.93	34%
6000	2026.99	1.19	0.89	41%
7000	1832.87	1.13	0.84	47%
8000	1638.76	1.07	0.80	54%
9000	1444.64	1.00	0.75	61%
10000	1250.53	0.93	0.70	68%
12000	862.30	0.78	0.58	81%
14000	474.06	0.57	0.43	95%
14700	338.18	0.49	0.36	99%

Figure 3. Example of student spreadsheet

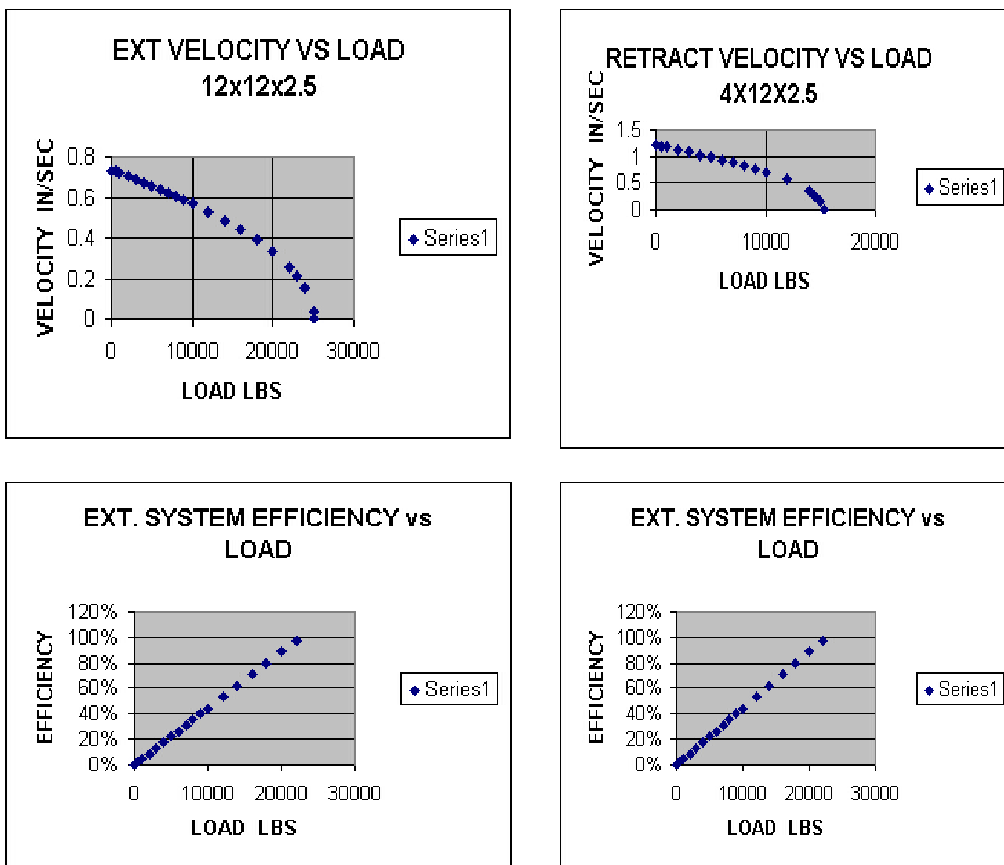


Figure 4. Cylinder plots of velocity and efficiency versus load

Students are left on their own to analytically establish the velocity and load limits. Students are required to design an Excel spreadsheet similar to the examples in Figure 3 & 4. Again students work in teams of two or three and must rely on fluid power fundamentals, spreadsheet skills and problem-solving approach skills to analytically predict cylinder speed for various system conditions.

#### 5.4. Advantages of using a hydraulic speed control experiment for problem-based learning

- Students develop understanding of pressure versus flow relationships.
- Students develop their own spreadsheet to predict velocity for any load condition.
- The instructor mentors students in system use but allows time for students to develop their own learning styles and work in teams.
- Students learn data acquisition techniques and software applications to solve real world problems.

#### 5.5. Disadvantages

- Students may struggle with linking software to spreadsheet applications.
- Learning to manipulate the software can be time consuming.
- Laboratory sessions require teamwork and outside of class preparation.

### 6. Conclusion

In both cases discussed, problem-based learning enriched students' learning experiences. They experienced more problems and took initiative to solve them. We observed that students showed more of their individual strengths than in the lecture-style approach. We found that detailed written instructions were necessary for LabVIEW programming in order to limit novelty of the software, to which students were exposed for the first time. Students still encountered numerous problems as they proceeded with their assignments and developed skills from identifying and solving them.

Limited instruction was given for base line data collection in the presented MET 334 laboratory assignment. Examples were given of velocity versus load characteristics for meter-out flow control of hydraulic cylinder circuits. Students' task was to apply their previous knowledge to develop velocity, efficiency versus load graphs for actual system parameters. This allowed the application of problem-based learning in which students developed their individual learning styles in a team environment. This approach showed accelerated learning and understanding of pressure-flow relationships in hydraulic motion control systems.

We observed a positive students' response to problem-based learning. They demonstrated satisfaction from problem solving and the opportunity to develop their own solutions. Students responded positively to the opportunity to apply previously gained knowledge of fluid power fundamentals and analytical skills to solve real-life problems.

Problem-based learning instruction was adapted to both courses presented in the paper. Furthermore laboratory instructors adjusted the instruction level to group and individual student competency. We did not find it necessary to create additional troubleshooting flaws to add challenge to the problem-based learning experience.

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