Experiments in the Classroom: Examples of Inductive Learning with Classroom-Friendly Laboratory Kits.

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Abstract

The educational literature is full of examples of the effectiveness of inductive and hands on learning. Laboratory experiments are clearly an excellent place to encourage this type of learning. However, it would be beneficial to mix laboratory material with classroom presentations and problem solving in a more flexible approach than a traditional separate laboratory and lecture allows. We have recently been developing some laboratory kits, designed to be used in a standard classroom.

In this paper we review the conceptual basis of using classroom laboratory kits and examples of our recent developments and experience with these kits. We are developing this approach for teaching process control and for teaching simple RLC circuits to Chemical Engineering students. In process control we are developing kits using the LEGO® RCX® brick and quick disconnect piping that allow students to experience a full design, build and test sequence. In electrical circuits we have simple snap together circuit kits that allow students to gain hands on experience with simple electrical principles in the classroom.

Using these kits in the classroom allows for a range of contemporary learning approaches to be applied including inductive learning approaches, Kolb's experiential learning cycle and problem-based learning.

Introduction

In most engineering courses and curriculum the classroom and the laboratory are separated in both time and space. Even when the laboratory is part of an individual course, it is still generally separate from the classroom portion of the class. This separation is usually necessary due to the difference in resources and time required for the various laboratory vs. classroom course activities. In addition, this separation has often resulted in excellent classes and laboratories. However an opportunity is being missed. As many of us seek to teach inductively, to teach using the structure of experiential learning cycles and to teach with an awareness of varied student learning styles, mixing lecture and laboratory is advantageous.

The use of laboratories is one of the distinctive features of engineering. Wankat and Orevitz[1] suggest several goals that laboratories can meet including motivation and problem identification, discovery, induction, experience with equipment, real world type experiences, the opportunity to build/test and experiences that are memorable. These are all goals valuable to most of our courses. In fact they are often the key elements missing from lecture.

Wankat and Orevits[1] note, "Laboratory experiments appear to be most effective when the solution is not known ahead of time." However if there is too much separation between the students working on an unknown problem and them finding a solution, it can lead to frustration. A laboratory in the classroom allows students to see a problem and be quickly led toward a solution.

In many cases instructors begin to bring the laboratory into the classroom through demonstrations or maybe a trip to the laboratory.[2, 3] The use of a clinic approach brings the classroom into the laboratory. At Lafayette College, we have begun experimenting with self-contained laboratory kits to make hands on laboratory experience a part of lecture. We are finding this approach particularly helpful in implementing proven teaching approaches such as inductive learning, experiential learning cycles and sensitivity to varied learning styles. In this paper we briefly review the use of laboratories in these teaching approaches and present four strategies with examples of how we are attempting to bring laboratory exercises into the classroom.

Experiments and Inductive Learning

The inductive approach to teaching and learning is to begin with particulars and build to generalities. This is "backwards" from how we often naturally teach starting from general principles and then applying them to particulars. The inductive approach is the way most things are discovered and clearly how an infant learns, but it is not the way most courses are taught. It, therefore, requires we think differently about how we approach the classroom.[1-6]

Experiments are an excellent way to provide concrete particulars to begin inductive learning.[1] Hesketh, Ferrell and Slater[2] recommend the following sequence in using experiments in inductive learning:

1. Prelab Handout - Students are given a handout to peak interest that asks them to hypothesize about qualitative outcome.
2. Data Collection – Students complete experimental work consisting primarily of data collection with graphical analysis.
3. Discussion – Students identify key patterns and experimental relationships.
4. Lecture – Students are presented with key quantitative relationships.
5. Homework – Students are asked to complete calculations based on the laboratory data

This inductive approach contrasts with the usual deductive approach where we would generally start with the last two steps and then follow up with an experiment. Completing the experiment in class facilitates using this type of sequence. Having quick classroom experiments would allow the instructor to apply this exponential inductive sequence to more topics over a semester than if it were always necessary to wait for a convenient laboratory period.

Dahm[3] also describes the use of an inductive approach in teaching about distillation based on a hierarchy proposed by Haile.[7-11] This approach is more complex and utilizes an excellent mixture of exploratory calculation, example operation and the use of a process simulator in teaching distillation. Once again an experiment is used in the early stages. A distillation column for the classroom is beyond our capabilities but applying Haile's hierarchy to other problems could be facilitated by classroom experiments.

A clear and helpful critique of traditional teaching approaches can be found in Thomas Magliozzi's "The New Theory of Learning".[12] Magliozzi is best known as one of the hosts on the NPR radio show "Car Talk" but he was also for many years a professor of management. He starts off describing the weakness of the traditional lecture model of instruction noting, "Listening does not lead to understanding; doing does lead to understanding."[12] He also provides a popular level description of a problem-based style of inductive learning under the title, "The backwards learning theory." Of particular interest is his emphasis on the ways a problem can provide motivation to increasing learning. Experiments as a starting point for the discussion of various topics provide a way to set up this "backward" and "doing" based learning.

Experiments and Experiential Learning Cycles (e.g., Kolb Cycles)

The concept of using experience in education is not a new one. John Dewey discusses the needs and nature for experiential learning in his still timely work *Experience and Education.*[13] Many learning cycles have been suggested. These learning cycles vary from two to five or six steps but essentially all include active and reflective components.

Figure 1 depicts the four-step Kolb cycle of experiential learning, one of the most widely considered in engineering education.[14] This cycle consist of Concrete Experience, Reflective Observation, Abstract Conceptualization and Active Experimentation. While the cycle can begin at any step, it is generally begun with the concrete experience step.[1] All four steps are required for complete learning to occur. Experiments can be used in the first step, Concrete Experience, and in the last step, Active Experimentation. These steps can also be carried out by other means but physical experiments allow a high level of student control over their educational experience.[15]

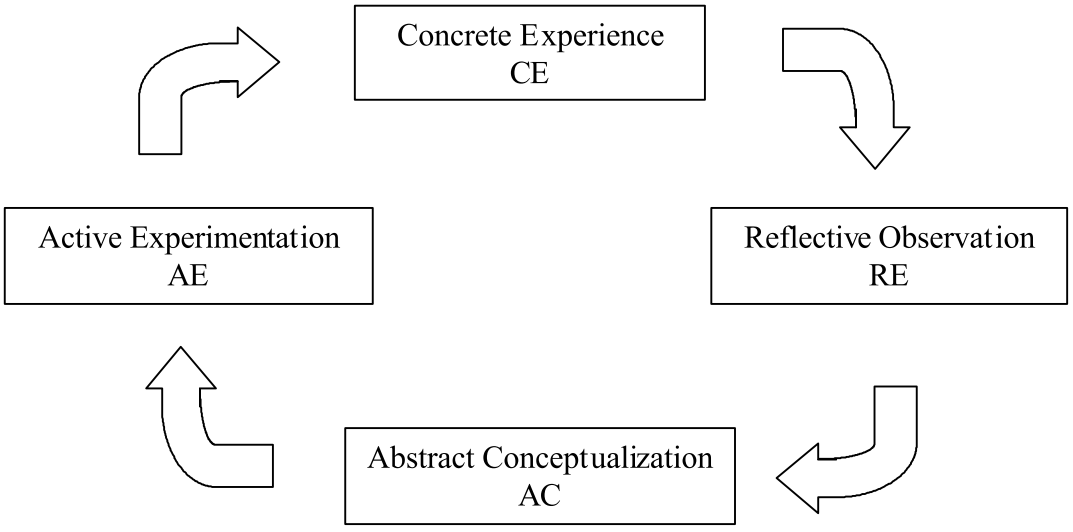

Figure 1: Kolb's Experiential Learning Cycle

Experiments and Learning Styles

The combination of laboratories with the classroom setting also allows for a natural balancing of learning styles. The issue of learning styles has been brought to the engineering education communities attention in the past many years by Professor Felder's work.[5, 6, 16] His approach to learning styles uses several dichotomous axes: the active vs. the reflective learner, the sensate vs. the intuitive learner, the visual vs. the verbal learner and the global vs. sequential learner. There is a need to address both poles of each of these dichotomies. Overgeneralizing a bit, experiments provide concrete experiences that appeal to the active, sensate, visual and global poles. Setting in a classroom allows for more reflection, intuition, verbal and exploration of the problem. This approach of setting experiments in the classroom tends to naturally balance the different learning styles.

Strategies for Implementing Laboratories in the Classroom

Below we outline four strategies for using the advantages of experiments in the classroom. These strategies start with demonstrations and dry labs thought experiments and progress through conducting class in a different type of setting. In each case examples are given for using each strategy.

Strategy 1: Experimental Demonstrations: Demonstrations have long been used in the science classroom, particularly on the introductory level. They can provide those particulars needed to begin an inductive process. Their key disadvantage is that the students are still spectators. It is crucial that some active exercise is used so that the students do not remain simply passive observers. Dahm uses a demonstration of a distillation column as a starting point for his inductive process based on Haile's hierarchy.[3] He wisely follows up with a cooperative learning type discussion. This is essential to the successful use of demonstration in inductive teaching.

In our introduction to engineering course we include an introductory discussion of fluidized beds and in an associated laboratory conduct a variation on the fluidized bed coating experiments developed at Rowan University.[17] To introduce the topic in class we do a demonstration of a fluidized bed using a bed of Rice Krispies®. The Rice Krispies are too large for smooth fluidization; they are Geldart type D particles.[18] However, their large size allows the motion in the bed to be seen and they follow many of the same gross patterns that smaller particles would.

The Rice Krispies bed is first used to simply show what a fluidized bed is. They are then used in a Kolb type learning cycle to understand the concept of minimum fluidization and the concept that in a fluidized bed there is a balance of the upward drag measured by the pressure force and the downward force of gravity. For the initial concrete experience step, a simple demonstration experiment is carried out where the pressure is measured for various flowrates and a fluidization curve is developed showing the climbing pressure in the packed bed region and the essentially constant pressure in the fluidized bed region. An example curve is shown in Figure 2. The second step, Reflective Observation, actually begins while the experiment is being conducted. Students are asked to notice the changes in the bed as the experiment was being conducted. They generally easily note that there is a change in the pressure curve from climbing to level and that the change occurred when the particles began to move vigorously. A mixture of student discussion and lecture presentation of some basic theory forms the Abstract Conceptualization step. The final step of Active Experimentation takes place in the regular laboratory where students carry out the experiments on the fluidized bed coating systems. In this example we have brought some of the laboratory into the classroom but left the final detailed experiments to the actual laboratory session.

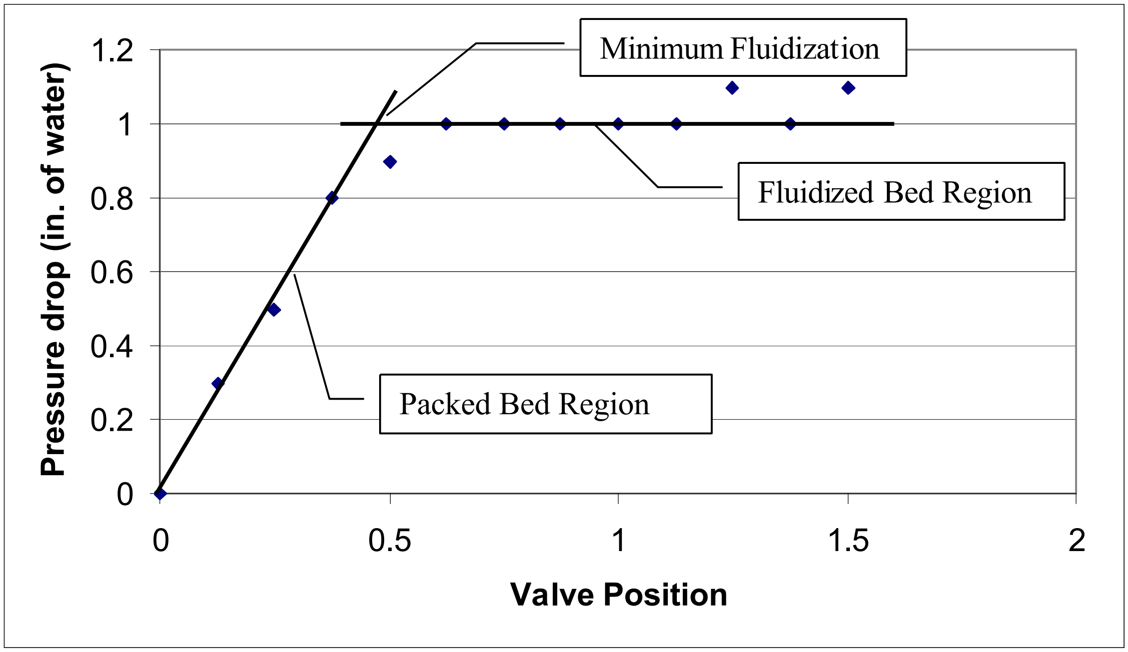

Figure 2: Fluidization Curve for Rice Krispies Fluidized Bed.

Strategy 2: Dry-lab (Thought) Experiments: Sometimes it is possible to obtain many of the benefits of an actual lab by simply having students think through the laboratory process. This can be done when students have some relevant previous laboratory experience to draw upon.

We use this approach to introduce basic descriptive statistics, particularly standard deviation, in our first chemical engineering laboratory. The laboratory course has a lecture attached. During the first lecture students are broken into small groups and each group is handed a sample of 8-12 acrylic balls, nominally ¼ in. in diameter and the discussion question shown in Figure 3.

The students are asked to begin by discussing the first two questions in their groups. We then collect their ideas as a class and come up with an agreed upon experimental design and the type of data that will be generated. We ask them to return to their groups and consider the third question. We again collect ideas from these cooperative learning groups. They generally have quickly arrived at using the mean and have some crude ideas about summarizing variability.
We discuss as a whole class and work our way to understanding that (1) we need some type of sum of differences from the mean; (2) we need to make all those differences positive or they will always sum to zero. This can be done several ways but they are steered toward squaring the deviation so that it is positive, and (3) we need to normalize this so that the resulting number is

not sample size dependent. (Each group has a different number of balls so this is a real issue in the problem presented them.) This last step does require some explanation by the instructor of why the normalizing by degrees of freedom (n-1) is the correct option. Once they have gotten this far, the idea of taking the square root is simply presented, and the class has arrived at the definition of a sample standard deviation. In their subsequent laboratory session, students will carry out the measurement experiment and calculate means and standard deviations using a variety of tools (e.g. computer software and calculator).

We have received a sample of some plastic balls that we are considering using for experiments in Wurster coating. Wurster coating is a fluidized bed coating process where the exact <u>size</u> and <u>density</u> of the particles used is important. Your job is to estimate the size and density of balls from this potential source. Discuss in your group

(1) What is the goal of this experiment?
(2) What experiment you would do?
    i. What would you measure?
    ii. What technique would you use to make your measurements? What tools would you need?
    iii. How would you take the measurements (order , number, organization)?
(3) How would you summarize the resulting data?

Be prepared to discuss your results with the class.

Figure3: Discussion problem for dry lab experiment discussion on mean and standard deviation

This approach allows the students to move from a particular concrete example to a general measure of variability (the standard deviation) by a simple inductive approach. Along the way, there is the opportunity for students to begin to think about many of the important issues raised by random variables.

Strategy 3: Simple experiments in a traditional classroom: A key limitation of Strategies 1 and 2 is that they are still a step away from involving the student in concrete experience. Strategy 1 (demonstrations) does not allow students direct contact or control of the experiment. Strategy 2 (dry labs) requires that students have some previous experience to be able to think about an experiment. By actually bringing experiments into the classroom we can increase the level of student involvement and often motivation. In addition, experiments provide an excellent way to introduce new concepts. Piergiovanni[19] provides a series of examples of simple inexpensive classroom based experiments to introduce various mass transfer unit operations in another paper at this conference. She uses a variety of completely separate experiments.

However a key approach we have been moving toward recently is the development of simple classroom experimental kits that allow students to carry out multiple experiments related to a topic. The kit approach has several advantages. Kits provide the instructor with a range of experiments that are ready to go whenever they are best suited to the educational situation. They minimize the amount of time that students need to spend learning new equipment, and they help students experience the connectedness of various aspects of a course. Kits are not possible in all cases but can be developed for many situations.

In the lecture portion of one of our laboratory courses we introduce our students to simple RLC circuits at approximately the level of the Fundamentals of Engineering exam. In teaching this class we have found that our students have very little "feel" for electrical circuits and discussing them on the blackboard seems both abstract and irrelevant to these students. We are turning to a hands-on inductive approach to solve this problem. We are developing simple experimental kits for students to conduct RLC experiments in class. For these kits we are using an educational toy "Snap Circuits" and an inexpensive multimeter.[20] These "Snap Circuits" kits include a range of resistors, capacitors, inductors, switches and LEDs and a battery power supply all of which literally snap together using simple clothing snaps. The circuit components are mounted on small plastic pieces that have the usual circuit symbol imprinted on them. The "Snap Circuits" sets are available from Ocean State Electronics for approximately $45 each.[21]

Table 2 is a list of initial experiments we are using. When we discus Ohm's Law students can take a range of resistors and see what happens when the voltage is varied. When examining simple resistive networks, students can measure the total resistance and work toward how to calculate the equivalent resistance. The kits also allow us to illustrate basic principles. Many more experiments are possible with these kits.

Table 1: Initial Experiments in the RLC Kit

1. Ohm's Law
2. Resistance networks
• Series
• Parallel
• Combined
3. Capacitor charging and discharging time constant
4. Capacitance network
5. Inductor network
6. Homemade capacitor (aluminum foil)

Strategy 4: A classroom designed for combined experiments, lectures and problem solving
Here we are seeking to take a step further and organize a course from the start to be a mixture of laboratory and classroom time. This requires developing the laboratory kits, preparing the room for this approach and choosing an appropriate time configuration for the course. Thinking about the space allows consideration of a room designed from the start for cooperative group learning including the laboratory work. The time schedule for the course can be adjusted to allow a longer block of time for completing experimental and group work.

Our key area of work in classroom laboratory kits has been in the development of extensive kits and a new classroom environment for our Process Control Class. This is meant as a development and proving ground for ideas and materials that have much broader application. We have set up a new classroom for small classes of approximately 20 students. The classroom has four group worktables. Each worktable includes a PC for the groups to work with. The course meets two times per week for two hours each time. The setting and timing allow a great deal of flexibility to run the entire course using non-traditional approaches to student learning. The course is taught as an ongoing mix of experiments, problem solving, discussion and mini-lectures. We are also considering experimenting with other time arrangements.

We are developing new laboratory kits for this class using the LEGO RCX brick as the computer interface. The RCX brick contains a Hitachi microprocessor and includes three 10 bit A/D inputs and 3 D/A outputs. We have purchased and developed various sensors and a control valve that interfaces with the brick. Process piping is provided by 3/8 inch brass tubing with quick release fittings. The control system is programmed on the computer using LabVIEW and ROBOLAB[22] softtware. We have developed software that provides a pseudo stepper motor operation for the control valve and control by a discrete PID velocity algorithm. More details on the physical system are covered in another paper.[23]

Our initial kit includes level and flow measurement and control capabilities. We are working on adding temperature and mixing control. In the future this equipment could easily be used for a range of fluid flow experiments in addition to process control. The kits require only 110 volt power, a bucket of water and a computer to function. So it has been relatively easy to adapt a classroom to these kits. The materials to assemble this level and flow kit are less than $1000 not including software. The basic design of these kits is available and we are working on commercial distribution.

To insure the safety of students using water near standard electrical power we take several precautions. The only full power in the actual process portion of the kit is the submersible pump, which is naturally safe around water. The other power is kept physically separate from the water. Finally all of the equipment is plugged into a GFCI protected extension cord.

These kits are helping bridge the gap between industrial and academic control. The kits are used the very first day of the class to demonstrate what control is, the components and terminology of control systems and some of the problems faced in controlling processes. The kits also are helpful in making some key concepts more concrete (e.g. proportional offset). They help students gain experience with the many abstract concepts in control theory. The kits allow students to conduct process reaction curve experiments and develop first order plus dead time models. They also provide opportunities to illustrate a variety of process control problems such as control loop interact and dead time. Students can work on implementing solutions to those problems. As students gain more experience the kits also allow students to actually practice control system synthesis, not just analysis. They can conceive of a control system and then have the ability to build the process and the controls.

The kits allow us to start most topics in the course inductively with concrete experience from working with these kits. It is very easy to proceed through a Kolb cycle where students carry out Reflective Observation. We then can use a mixture of discussion, problem solving and mini-lectures to engage in Abstract Conceptualization. Students can then continue the cycle by Active Experimentation either with the kits or through additional problem solving exercises.

One of the nicest aspects of these kits is how excited the students are to work with them. Most students are instantly interested in working with LEGOs, helping overcome the common problem in process control classes of low student motivation.

Conclusion

Laboratory and classroom experiences form a natural complement. Reducing the barriers between the two can help facilitate inductive learning, the structuring of experiential learning cycles and the diversity of teaching approaches needed to reach diverse learning styles. In addition classroom laboratory exercises help set up active experiences that give students more control of their learning experience.

The use of multi-experiment kits is helpful in presenting a unified and efficient set of active learning experiences in the classroom. The key example of our work in this area is the development of flexible kits for process control experiments. These kits can be used in any classroom as long as 110 volt power and personal computers are available. They allow students to design, construct and test both the simple process and their control systems.

To take full advantage of these process control kits we are redesigning the time structure and room set up for this course. Setting up a room with work groups instead of rows and planning a longer class period allows both laboratory and classroom experiences to be completed in one class period. The initial response by both students and faculty to this effort has been extremely positive.

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References:

1. P. Wankat and F.S. Oreovicz, *Teaching Engineering*, New York, McGraw-Hill, 1993.
2. R. Hesketh, S. Ferrell and C.S. Slater, "The Role of Experiments in Inductive Learning," *2002 ASEE Annual Conference*, session 3613 (June 2002).
3. K. Dahm, "Use of Process Simulation and McCabe-Thiele Modeling in Teaching Distillation," *2002 ASEE Annual Conference*, session 3513 (June 2002)
4. R. Felder, D. Woods, J. Stice and A Rugarcia, "The Future of Engineering Education II. Teaching Methods that Work," *Chem. Eng. Ed.*, 34(1), 26-39 (2000).
5. R. Felder and L. Silverman, "Learning and Teaching Styles in Engineering Education," Engr. Education, 78(7), 674-681 (1988).
6. R. Felder, "Author's Preface – June 2002 [to reference 3]", http://www2.ncsu.edu/unity/lockers/users/f/felder/public/Papers/LS-1988.pdf, accessed December 2002.
7. J. Haile, "Toward Technical Understanding: Part 1. Brain Structure and Function," *Chem. Eng. Ed.*, 31(3) (1997).
8. J. Haile, "Toward Technical Understanding: Part 2. Elementary Levels," *Chem. Eng. Ed.*, 31(4) (1997).
9. J. Haile, "Toward Technical Understanding: Part 3.Advanced Levels," *Chem. Eng. Ed.*, 32(1) (1998).
10. J. Haile, "Toward Technical Understanding: Part 4. General Hierarchy Based on the Evolution of Cognition," *Chem. Eng. Ed.*, 34(1) (2000).
11. J. Haile, "Toward Technical Understanding: Part 5. General Hierarchy Applied to Engineering Education," *Chem. Eng. Ed.*, 34(2) (2000).
12. T. Magilozzi, "The New Theory of Learning," n.d., http://cartalk.cars.com/About/Rant/r-rlast15.html, accessed December 2002.
13. J. Dewey, *Experience and Education*, Collier Books (1938).

14. D. Kolb, *Experiential Learning: Experience as the Source of Learning and Development,* Prentice-Hall (1984).
15. D. Wyrick and L. Hilsen, “Using Kolb’s Cycle to Round Out Learning,” *2002 ASEE Annual Conference,* session 3612 (June 2002).
16. R. Felder, “Reaching the Second Tier: Learning and Teaching Styles in Engineering Education,” *J. College Science Teaching*, 23(5), 286-290 (1993).
17. R. P. Hesketh, C. S. Slater, S. Farrell, and M. Carney, “Fluidized Bed Polymer Coating Experiment,” *Chem. Eng. Ed.* **36**(2) 138 (2002).
18. D. Geldart, "Types of gas fluidization" *Powder Technology* 7: 285-292 (1973).
19. P. Pergiovanni, “Simple, Low-Cost Demonstrations for UO II (Mass Transfer Operations),“ *2003 ASEE Annual Conference* (June 2003).
20. Elenco Electronics, Inc (Wheeling , IL), Electronic Snap Circuits, http://www.elenco.com/, accessed March 2003.
21 Ocean State Electronics & Computers (Westerly, RI), www.oselectronics.com, accessed March 2003.
22 M. Portsmore, M. Cyr, and C. Rogers, “Integrating the Internet, LabVIEW™, and LEGO® Bricks into Modular Data Acquisition and Analysis Software for K-College,” *2000 ASEE Annual Conference*, St. Louis, MO (2000).
23. S. Moor, P. Pergiovanni and D. Keyser, “Design – Build – Test: Flexible Process Control Kits for the Classroom ,” *2003 ASEE Annual Conference* (June 2003).

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