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Innovative solutions to overcome educational lab limitations

Project to design air duct simulator benefited students on both sides

By Farman A. Moayed

Students Alex McDaniel (left) and Bukola Ogunyemi help produce the components to create the miniature ventilation model.

Some teaching universities and institutions face budget cuts and reduced enrollment, which makes it a challenge to fund their educational labs and other facilities. Many cannot offer enough opportunities for undergraduate students to get involved in research projects and mostly rely on their educational labs to provide the necessary experiential learning opportunities.

Such universities sometimes face problems upgrading lab equipment or buying new instruments to expand the scope of experiments in their labs. In such circumstances, faculty can become creative – developing undergraduate projects in which students can participate to design, fabricate and test new equipment that later can be used to perform experiments in a lab.

This article describes how a low-budget but funded undergraduate project was used to benefit the industrial hygiene lab of the Safety Management program at Indiana State University. Three undergraduate students were recruited for a summer internship project to design, procure materials and equipment, fabricate and evaluate a miniature ventilation kit that was later used in the industrial hygiene lab to teach ventilation and air duct design. Anecdotal evaluations from students in the industrial hygiene lab indicated that experimenting with such equipment helped them better understand the concept of ventilation and air duct design.

The benefits of lab courses in education

Lab courses play an important role in student learning, especially in technology and applied sciences programs. A well-structured lab with adequate equipment can enhance learning, problem-solving and critical thinking skills. Experts generally believe that labs and lectures likely pursue different learning objectives.

One common method of classifying learning objectives was introduced in 1956 by Benjamin Bloom, Max D. Engelhart, M.D., Edward J. Furst, Walker H. Hill and David R. Krathwohl ("Taxonomy of Educational Objectives: The Classification of Educational Goals"). Educational objectives were categorized in three domains: cognitive, affective and psychomotor (see Figure 1).

The cognitive domain deals with the recall or recognition of knowledge and development of intellectual abilities and skills. The affective domain covers objectives that describe changes in interest, attitudes and values, and the development of appreciation and adequate adjustment. The

FIGURE 1

Classifying learning objectives

A summary of domains in Bloom's Taxonomy.

Cognitive domain	Affective domain	Psychomotor domain
Knowledge	Receiving and attending	Gross motor skills
Comprehension	Responding	Fine motor skills
Application	Valuing	Coordination of body movements
Analysis	Organization	Nonverbal communication behavior
Synthesis	Characterization by a value	Speech behavior
Evaluation		

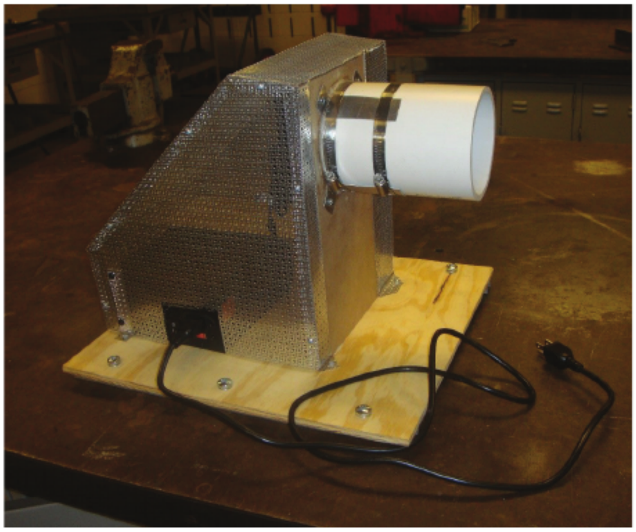
third domain, psychomotor, is about the manipulative or motor-skill area that appears to lose its importance in engineering and technology education, yet the success of students and graduates conducting experiments depends on it. On one end of the spectrum, the lecture portion of courses mostly covers the cognitive domain; on the other end, the lab portion predominantly covers the psychomotor domain.

Educational labs and undergraduate projects, which are a different form of experiential learning, allow students to explore different applications of the knowledge they have acquired during the lectured classes and understand the limitations of the techniques, equipment and methods. Undergraduate students involved in research or technical projects show more confidence in understanding the scientific and technical concepts of their field and have improved critical thinking and problem-solving skills compared to their counterparts who do not participate in such experiential learning activities.

The main difference between experiential learning in conventional educational labs and undergraduate projects is that the tasks (experiments) are already structured, the equipment already chosen and all students need to do is use the given resources and solve a problem. However, in a typical undergraduate project, students are expected to get involved in the process, design and equipment selection. The faculty adviser describes the goal or desired outcome and provides limited and necessary information. The faculty also need to have a certain level of supervision.

A majority of literature regarding undergraduate projects is research-focused, though similar concepts can be considered and used for nonresearch projects. There are three distinct models that faculty members and students can collaborate on undergraduate projects: traditional, consultant and joint-creation models.

Faculty can use the first model to define a project and develop the methodology and allow undergraduates to participate. In the second model, students conduct the project independently with faculty members as consultants and to provide guidance. The third model is where both undergraduate students and faculty members start a project together and collaborate throughout the process. Obviously, depending of the nature of the project, the level of student involvement and how the project relates to the professor's career goal, each model has its own advantages and disadvantages.



The fan component of the miniature ventilation kit.

Background on safety management

The Safety Management undergraduate program in Indiana State University was created around 1973, shortly after the U.S. Congress passed the Occupational Safety and Health Act (OSHA) in 1971. The goal was to educate and train experts to help industries improve. Over time, the program grew in size and content. A graduate program was created and the content of both undergraduate and graduate programs transformed to serve the needs of general industry.

The curriculum covers a variety of technical topics – safety legislation, accident prevention, fire protection, industrial hygiene, occupational toxicology, system safety analysis, hazardous material management, human factors and ergonomics – as well as administrative and management topics on industrial safety and training programs. Some of the courses had levels of experiential learning components such as term projects, group assignments and, in case of the industrial hygiene course, an educational lab.

The industrial hygiene course covers a wide range of topics such as identification and exposure evaluation of chemical and physical hazards and assessment of commonly practiced engineering control methods in industry. Students are required to understand and use different quantitative and mathematical methods for exposure evaluation and control methods assessment. The lab component was meant to help students understand the scientific and technical aspects behind the evaluation methods while getting familiar with relevant measurement equipment and instruments.

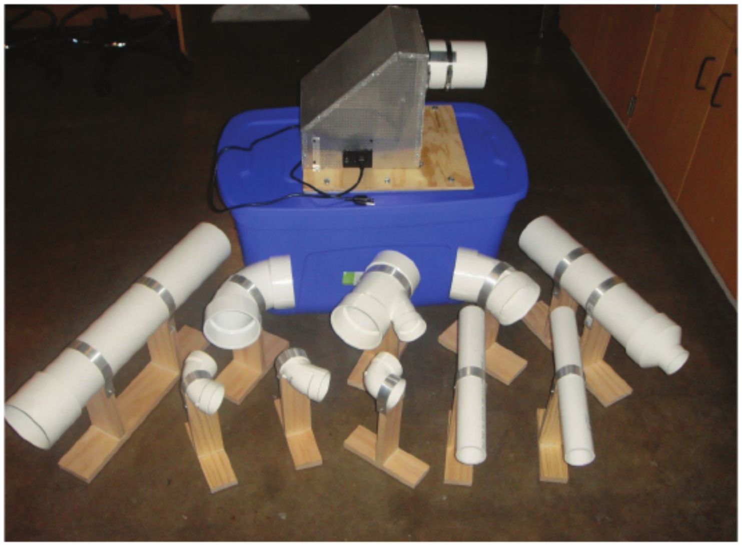
However, when the safety management programs were moved to the College of Technology (COT) in 2010, a significant portion of lab equipment was left behind, and some that was transferred was defective, obsolete or insufficient to teach necessary skills. Gradually, with the help of the COT, new equipment was purchased, and though the current situation is not perfect, the program has enough lab equipment to cover important topics.

Statement of problem

Among engineering control methods discussed in the industrial hygiene class, ventilation and the basics of air duct design were topics considered challenging for students. It seemed students had difficulty understanding why and how the airflow, air pressure and velocity changes after components such as elbows, change of diameter and diverging wye. The industrial hygiene lab did not have the right equipment to experiment or even demonstrate the effect of each component on airflow.

In 2015, as professor for the industrial hygiene course, I came up with the idea of building a miniature ventilation kit for the lab. The idea was to build a lab kit made of different parts commonly used in ventilation systems that students can use to create different air duct configurations and use a few measurement instruments to measure airflow, air pressure, velocity and conduct basic computations. This would provide a firsthand experience about how each parameter changes from one component to another.

The project needed to go through several phases to be completed. The first was funding. A proposal was submitted for an internal grant of $2,000 and awarded in summer 2015. This was used to purchase 4-inch and 2-inch PVC pipes, 90- and



Components of the miniature ventilation kit.

Research on learning

The author references information from these authors' research on classifying learning objectives to enhance problem-solving and critical thinking skills.

- H.B. Yu, "Promoting Chemistry Learning through Undergraduate Work Experience in the Chemistry Lab: A Practical Approach," *Journal of Chemical Education*, 2014
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- Samir Al-Ghadhban, Ali Muqaibel, Ghassan Alregib and Ali Al-Sheikhi, "Seeding Undergraduate Research Experience: From Georgia Tech to KFUPM Case Study" 2018
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45-degree elbows, diverging wye and convertors, a 4-inch fan and power supply, digital monometers, airflow meters, metal plates and wood. The funds were also used for power and hand tools, hardware and personal protective equipment such as protective eyeglasses, steel-toed boots and gloves.

The second phase was recruiting students for the project. Three seniors, one international and two domestic, expressed interest. Only one of the domestic students had some experience using different power or hand tools. All three enrolled in a summer internship course to count their work as a requirement of their program and be covered under the university liability plan.

The third phase of the project was design and fabrication. An abstract design of parts and components were provided by the instructor and students were supervised and guided to use the materials, tools and their own creativity to fabricate each part. The college allowed access to wood and metal fabrication workshops and equipment such as table saw, band saw, metal plate bending and sheer cutting machines. This phase was the longest portion of the project and lasted about a month and a half.

The following general criteria were established and followed during the design and fabrication phase of the final product:

- It should be safe for users.
- It should not generate noise.
- It should not generate vibration.
- It should have a stable stand.
- It should be easy to operate, assemble and disassemble.

None of the participating students majored in engineering, nor had they taken courses in design or project management. The first three phases of this project were a significant opportunity for students to learn from their

FIGURE 2

The measurement model

The configuration used for the evaluation of the ventilation kit.

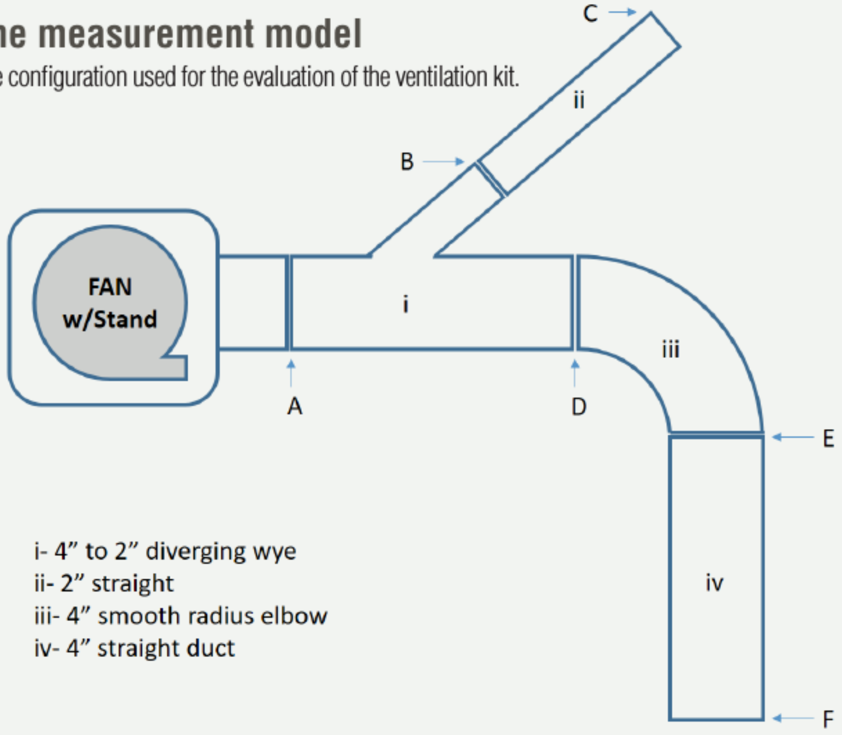


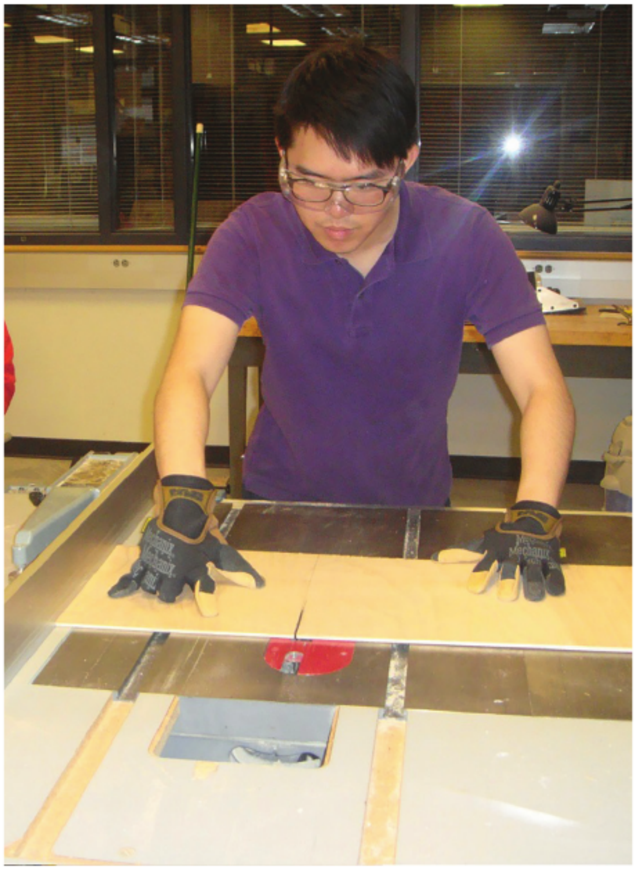
FIGURE 3

Data produced by model

Measurements of static pressure and air velocity before and after the modification.

Point of measurement	Propeller fan		Centrifugal fan	
	Average static pressure* (in. H_2O)	Average air velocity* (m/s^2)	Average static pressure* (in. H_2O)	Average air velocity* (m/s^2)
A	0.012	2.1	0.241	8.1
B	0.008	0.8	0.095	4.5
C	0.001	0.6	0.088	4.4
D	0.000	0.0	0.181	7.0
E	0.000	0.0	0.178	7.0
F	0.000	0.0	0.163	6.9

The assembled model allowed for the evaluation of the miniature ventilation kit performance.



Min Jun Jang measures components for the model.

mistakes, such as distinguishing differences between PVC and CPVC pipes and to how safely use machinery and tools in workshops.

The fourth phase of the project was documentation. Students learned the basics of technical drawing in a two-day crash course, then were supervised to create technical drawings of all parts and equipment they fabricated during the summer.

This phase was actually more challenging to them than the fabrication phase. Drawing three-dimensional objects on two-dimensional papers seemed to be difficult to non-engineering students, and drawings of metal plates before being bent appeared to be challenging.

Evaluating the outcome

The first step of evaluation of outcome was to evaluate if the lab kit functioned as intended. The team used the ventilation kit to create different configurations of air ducts to see if the changes in air pressure and velocity were measurable (see accompanying photos).

Very quickly it became clear that the fan installed on the stand was not powerful enough to generate adequate airflow and air pressure; whenever a component was added to the configuration, such as an elbow or diverging wye, the airflow dropped close to zero with the first component and almost zero with any additional component.

Initially, the fan was selected based on the level of noise it generated. One criteria was to keep the noise level of the ventilation kit as low as possible; therefore, the fan selected in the design phase was very quiet but with low power. The team needed a compromise and replaced the quiet fan with a more powerful centrifugal fan from a used hand-dryer.

The ventilation kit was evaluated for the second time and the results were promising. Both the airflow and air pressure were measurable at every point in every air duct configuration. Figure 2 shows the configuration that was used for evaluation; the average of measurements of static pressure and air velocity before and after the modification are presented in Figure 3.

After the ventilation kit was used as an educational tool in the industrial hygiene lab, a quick survey was conducted to see how students evaluate the new experiment. The results showed significant satisfaction that the ventilation kit had helped them understand the concept of ventilation and air duct design. ❖

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