AC 2007-517: IMPROVING ENGINEERING LABORATORY EXPERIENCE THROUGH COMPUTER SIMULATIONS AND COOPERATIVE LEARNING

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Improving Engineering Laboratory Experience Through Computer Simulations and Cooperative Learning

Abstract

Engineering laboratory experience has been widely recognized as valuable for students to develop a solid understanding of a variety of important engineering concepts taught in classroom lectures, especially those involving manufacturing engineering and technology. The Accreditation Board for Engineering and Technology (ABET) requires that graduates of manufacturing programs must receive and demonstrate proficiency in laboratory experiences. Specifically, ABET 2000 states, "graduates must be able to measure manufacturing process variables in a manufacturing laboratory and make technical inferences about the process."

This paper presents a new pedagogical model that we recently developed from our teaching practice. In this model, real-world laboratory experiments and computer simulations are integrated with each other. It is described in detail how the new model works, using an example of student laboratory assignments and results. The paper also presents a modified-jigsaw cooperative-learning approach that we developed and that is proven particularly useful when dealing with large classes. There exists a long-standing misconception that laboratory experiences become impractical as class sizes grow in numbers. Our modified-jigsaw approach requires the instructor to meet with only a portion (one-fourth in our case) of the class, making a laboratory experience manageable even as class enrollments reach 100 or more students. The paper describes the logistics of the modified-jigsaw approach along with a specific example of student laboratory assignments. Our new pedagogical model and modified-jigsaw approach make a positive difference in the way students gain fundamental understanding of engineering concepts and applications.

Introduction

Developing innovative and effective instructional strategies to improve engineering and technology education has long been an important issue of research and practice [1-4]. Researchers and educators in our engineering and technology education community have made a tremendous amount of effort over the past decades to address this issue and have developed a wide variety of pedagogical models and approaches, such as multimedia and web-assisted lectures [5-6], real-time visualization [7], comprehensive and high-quality course design [8], and cooperative learning [9,10].

Among these existing instructional strategies, engineering laboratory experience has been widely recognized as an effective pedagogical practice that plays a significant role in developing and reinforcing students' understanding of a variety of important engineering concepts taught in classroom lectures [11-14]. Engineering laboratory experience has been integrated into such methods as active learning, cooperative learning, project-based learning, problem-based learning, and research-based learning in various engineering disciplines.

Engineering laboratory experience has been particularly emphasized when it comes to the teaching of manufacturing engineering and technology courses that involves numerous real-world examples and applications. The Accreditation Board for Engineering and Technology (ABET) requires that graduates of manufacturing programs must receive and demonstrate proficiency in laboratory experiences [15]. Specifically, ABET 2000 states, "graduates must be able to measure manufacturing process variables in a manufacturing laboratory and make technical inferences about the process."

Moreover, under the umbrella of its Manufacturing Education Plan (MEP), the Society of Manufacturing Engineers (SME) Education Foundation is making an aggressive push with North American industry and universities and colleges to ensure that new graduates acquire the appropriate knowledge and skills to become effective contributors in the manufacturing workforce and more importantly, to "hit the ground running" once they leave school. In a series of industry workshops and surveys that included manufacturing representatives from Fortune 500 enterprises (such as Ford Motor Company, General Motors, The Boeing Company, 3M Company, Motorola, and Caterpillar) and medium- and small-sized companies, the MEP has identified 16 competency gaps that need to be closed between industry's manufacturing workforce needs and what is provided by current educational programs. In all surveys and workshops conducted by the MEP since 1997, "hands-on experience in at least one specific manufacturing process" has been consistently listed among top five high priority competency gaps [16].

It is clear that the question is not whether we teach using engineering laboratory experiences; rather, the question is what hands-on instructional strategies generate the maximum possible educational outcomes, and also make a sustained, substantial, and positive difference in the way students learn? Traditionally, learning through engineering laboratory experiences is conducted in the following way: Students receive laboratory assignments, conduct experiments, and then turn in their lab reports to the instructor. Our years of teaching experiences have shown that this traditional approach may not stimulate and motivate students enough for critical thinking and problem solving to occur.

This paper presents a new pedagogical model that we recently developed from our teaching practice. In this model, real-world laboratory experimentations and computer simulations are integrated with each other. It is described in detail how the new model works, using an example of student laboratory assignments and results.

The paper also presents a modified-jigsaw cooperative-learning approach that we developed and that is particularly useful when dealing with large classes. There exists a long-standing misconception that laboratory experiences become impractical as class sizes grow in numbers. By using our modified-jigsaw cooperative-learning approach, meaningful laboratory experiences can be delivered even as class enrollments reach 100 or more students. The paper describes the logistics of the modified approach with a specific example of laboratory assignments.

Finally, the paper introduces our on-going effort to extend the new pedagogical model and the modified-jigsaw cooperative-learning approach to other engineering courses. Concluding remarks are made at the end of the paper.

New Pedagogical Model

Over the past years, we have initiated a pilot program teaching a manufacturing course entitled "Advanced Topics in Metal Cutting." From that course, we developed and implemented a new pedagogical model in which learning through engineering laboratory experiences is conducted in an integrated and cyclic way, as shown in Figure 1.

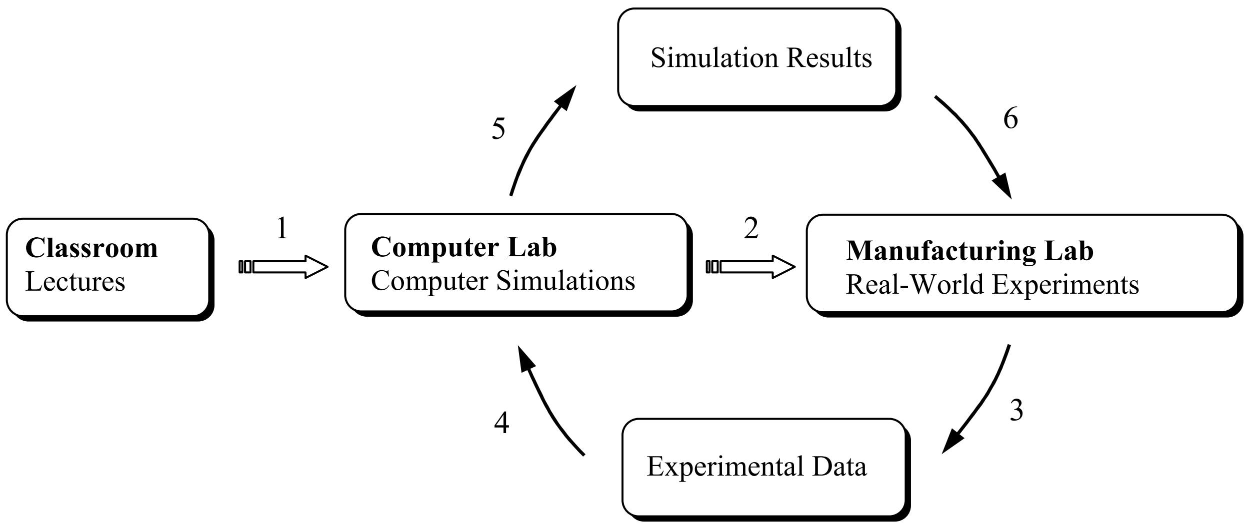

Figure 1. A new pedagogical model for stimulating cognitive learning through engineering laboratory experiences

In detail, the students gain their hands-on laboratory experiences in the following six steps:

Step 1: From classroom to computer lab. Using the knowledge they have learned from classroom lectures, students solve a particular machining problem (for example, the prediction of the cutting forces) by using a computer simulation program that we designed. The computer simulation program is deliberately designed not to be stand-alone, but require some experiment data (e.g., the chip geometry) as inputs.

Step 2: From computer lab to manufacturing lab. Students do the first-round of experiments to measure the required experiment data (e.g., the chip geometry); or, students compare the computer-simulated results with experiment data.

Steps 3 and 4: From manufacturing lab to computer lab. Students collect the experiment data and enter the experiment data into the computer simulation program; or, students modify the computer program to match the experiment data.

Steps 5 and 6: From computer lab to manufacturing lab. The computer simulation program predicts the cutting forces. Students do the second-round experiments to validate the predicted cutting forces. Based on the analysis of theoretical and experimental results, students provide suggestions to modify/refine the mathematical model used in the computer simulation program.

The above-described learning process combines computer simulations with real-world experiments and has received very positive feedback from students. All involved students commented that their learning experience was "very enjoyable and rewarding." Quantitative course evaluations, administrated at the end of the semester, showed that our unique teaching method did help improve students' understanding about fundamental machining concepts and complex machining phenomena.

Example of Student Laboratory Assignments

To further illustrate how our pedagogical model works, an example of a student's work is provided in this section. This example involves using computer simulation to study how the tool geometry and cutting conditions affect the cutting forces in metal cutting.

Step 1: The computer simulation program was developed based on the well-known Lee and Shaffer's model of chip formation [17], shown in Figure 2. Lee and Shaffer's model [17] is simple in its mathematical form but can only predict "dimensionless" cutting forces because the model does not take the work material property into consideration. By integrating Johnson-Cook's material model [18] into Lee and Shaffer's model [17], the computer simulation program that we designed can predict the dimensionalized cutting forces. The student chose a commonly employed aluminum alloy 6061-T6 as the work material to study.

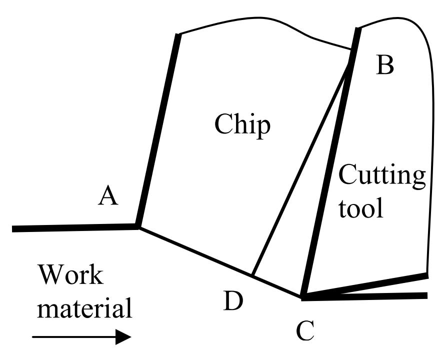

Figure 2. Lee and Shaffer's model of chip formation [17]

The output of the computer program is the resultant cutting force. The inputs include the tool rake angle, the cutting speed, the uncut chip thickness, the work material property, as well as the tool-chip friction on the tool rake face. The tool-chip friction is represented by a friction parameter τ/k that varies between 0 and 1.0. The larger τ/k, the heavier the tool-chip friction.

The student used the computer simulation program to study how the tool-chip friction τ/k affects the resultant cutting force. Two values of τ/k (0.80 and 0.85) were chosen for a range of uncut chip thicknesses. The results are plotted in Figure 3. As seen, the resultant cutting force increases with increasing tool-chip friction.

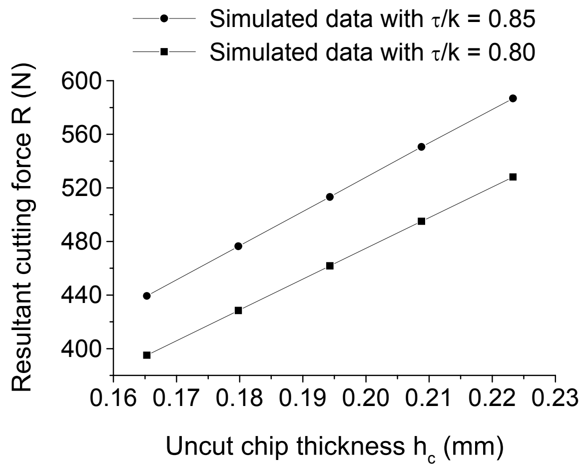

Figure 3. Step 1: Computer simulation

Step 2: To examine how accurate the theoretical predictions are, the student performed cutting experiments using the instrument and equipment that we have in our manufacturing laboratory. Orthogonal tube-cutting tests were performed on a CNC turning center. The work material was aluminum 6061-T6 and flat-faced carbide tools with the working rake angle of 5^o were employed. The cutting forces were measured by using a Kistler type 9257B three-component dynamometer, a Kistler type 5814B1 multichannel charge amplifier, and a computer data acquisition system (LabVIEW).

Figure 4 shows the experimentally measured cutting forces under a range of uncut chip thicknesses. From Figure 4, the student noticed that although both the computer-simulated results and the experiment results show the same varying trend for the cutting forces, there existed a big gap between them.

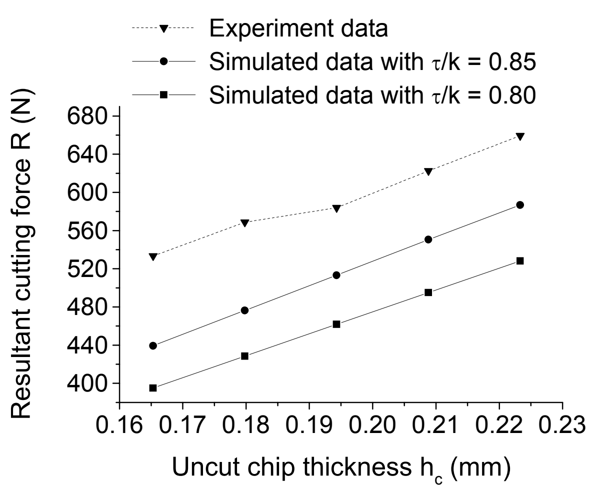

Figure 4. Step 2: Laboratory experiments

Steps 3 and 4: To make the computer-simulated data matches the experimental data, the tool-chip friction τ/k must be changed to a reasonable value. Therefore, the student adjusted the value of τ/k in the computer simulation program. After several tries, the student found that the best match could be achieved when τ/k = 0.90, as shown in Figure 5.

Steps 5 and 6: The student did cutting tests on other cutting conditions and compared the computer-simulated data with the experiment data. The purpose is to study the limitation of the theoretical model and obtain more hands-on laboratory experience.

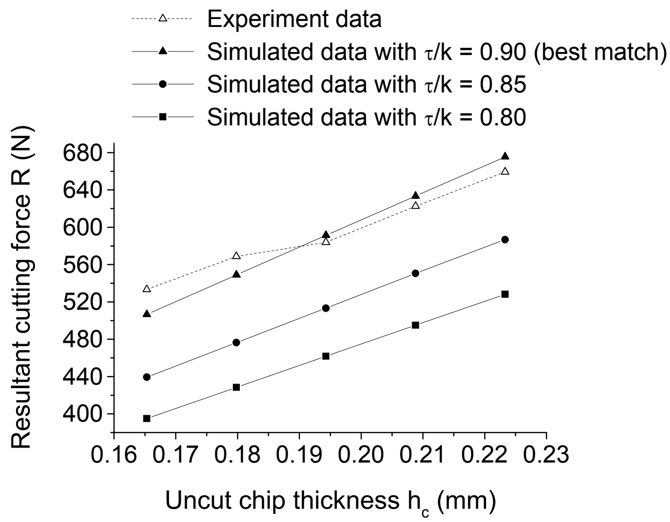

Figure 5. Steps 3 and 4: Modifying the computer program to achieve the best match

Through the above-described six steps, the student developed a solid understanding of why the tool-chip friction plays such a critical role in metal machining as well as how the cutting forces vary with cutting conditions. During this valuable learning process, the student also developed experimental skills on how to measure the cutting forces using state-of-the-art instruments and equipment.

Cooperative Learning

During the past twenty years, researchers have conducted extensive meta-analyses to determine the effectiveness of cooperative, competitive, and individualistic instructional strategies on learning. The findings associated with this research have typically been classified into areas of student achievement and findings other than achievement such as attitudes and motivation towards learning. In achievement measures, students in cooperative-learning environments consistently performed as well, or outperformed students in competitive and individualistic learning environments. "However, the degree to which this potential was realized depends in part on how the cooperative-learning structure was organized" [19]. Support for cooperative-learning approaches grows stronger as students engaged in higher-level learning skills especially problem-solving. In areas other than achievement, research findings also favored cooperative learning [19]. These areas related to attitudes and motivation play an important role in engineering education as they relate to student retention and the engineering freshman experience.

Implementing a cooperative-learning environment is more than just placing students in groups. In addition, initial ground work is necessary because students have little or no experience working in cooperative groups. Like teaming, individuals may initially feel uncomfortable sharing their ideas and working closely and relying on others. To be considered a cooperative group, they must have a goal that is important to each member. There must exist a positive interdependence among members of the group; success of each member depends on the success of the other members. In addition, each member must be held accountable for their individual responsibilities in the group; there are no "free rides" [20].

A variety of cooperative-learning approaches, such as the jigsaw approach, exist [1-4, 20]. In the jigsaw approach, each group member learns a portion of the content and teaches their portion to the rest of the group. After each person shares and teaches their portion, all of the group members will have learned the content. To accomplish the group's goal, everyone must do their job—learn their material, teach the others, and learn from the others. The success of each member is dependent on the success of the other members. In addition, for their portion of the content, each group member is viewed as the expert. This will greatly enhance the self-esteem and motivate the individual. Group scores are often used as a portion of the overall student assessment.

A Modified-Jigsaw Cooperative-Learning Approach

We developed and implemented a modified-jigsaw approach in our teaching of a college-wide design course. Compared to the conventional jigsaw approach described above, our modified approach only requires the instructor to meet with one-fourth of the class and thus making a laboratory experience manageable even as class enrollments reach 100 or more students.

The course in which we implemented the modified-jigsaw approach is titled "Introduction to Engineering Design." This course is evaluated on its ability to attract and retain freshman engineering students. To meet this goal, an exciting, creative, and meaningful laboratory design experience is required. However, a long-standing problem is how to offer such an experience when the course can often exceed 100 students. To solve this problem, we utilized the modified-jigsaw cooperative-learning approach for the laboratory portion of the course. Since the cooperative-learning approach has many similarities with the use of engineering design teams, our solution has a double benefit. The following paragraphs explain in detail how the modified-jigsaw approach works.

The class is divided into teams of four (team members A, B, C, & D). Each week one member from each team (e.g., team member A) attends the laboratory session. Each week's laboratory session has a detailed tutorial-based lesson. Students attending the laboratory session partner up and share a lab station. After attending the weekly session and with the detailed tutorial-based lesson, each team member A meets with their respective team and teaches the lesson. Each team completes a design-based homework activity that applies the content covered in the lesson. The following week, team member B from each team attends the new laboratory session—first turning in last week's homework, and second, taking a short quiz on last week's lesson. This process continues through the semester ending with a laboratory exam and a more robust design project. Using this modified-jigsaw approach, we are able to deliver meaningful laboratory experiences to large classes with only twelve laboratory work stations.

The following two details need to be paid special attention to ensure the success of the modified-jigsaw approach. 1) In our experiences, students are initially reluctant to work in teams. Teaming has become part of the formal content in the course including concepts such as the importance that teams play in the engineering design process, the growth stages of teams, leadership structures, and the assessment of teams and team members. Teaming activities include initial teaming activities, development and signing of team contracts that include grievance procedures, and the formal assessment of team members three times during the semester. 2) If the selected "student instructor" is inexperienced, team members who are relying on that student to teach them may have a less than rewarding experience. This effect must be minimized by having the inexperienced student instructor take a detailed tutorial-based lesson. If necessary, a student could learn the content individually. The positive aspect is team members work together to learn the material, complete the assignment, and prepare the next student for the following lab and quiz. A well-functioning team develops a sense of camaraderie.

Example of Weekly Laboratory Assignments

After determining a laboratory experience was important for the Introduction to Engineering Design course, we selected a content area common to the various fields of engineering. We chose data acquisition and control technology. A simple I/O board was developed for the course and LabVIEW was selected as the programming language. Initial lessons covered the I/O interface and programming digital outputs, leading to programming of digital inputs, and followed by multiple inputs and outputs. Each lesson introduced several new concepts and programming commands. Concepts and commands included the binary numbering system, port addresses, timers, for loops, case structures, sequence structures, and basic electro-mechanical devices.

Utilizing the modified-jigsaw approach, one student from each team attends the laboratory session. Concepts and examples from a detailed tutorial-based lesson are taught. This student meets with their team members during the week and teaches the lesson and guides the team through the lesson's homework assignment. A typical weekly homework assignment required the delivery of ping pong balls from a feeder at various rates depending on the settings of two inputs. The assignment read:

> As a group, write a program to feed ping pong balls at various rates depending on the setting of two inputs or switches. Use inputs 2 and 4, and outputs 3 and 5. Wire output 3 to the lower solenoid on the ping pong ball feeder and output 5 to the upper solenoid. If input 2 is high and input 4 is low, deliver a ball every 2 seconds. If input 2 is low and input 4 is high, deliver a ball every 4 seconds. If inputs 2 and 4 are both high, deliver a ball every 6 seconds. If both inputs are low, do not deliver any balls.

A typical program using LabVIEW to control the I/O board and external devices is shown in Figure 6. The input address 889 is read and Boolean expressions are used to control outputs through address 888 using a case and sequence structures. After several lessons and a basic understanding of the hardware and software, students are given more open-ended challenges where they must design, build and program a solution.

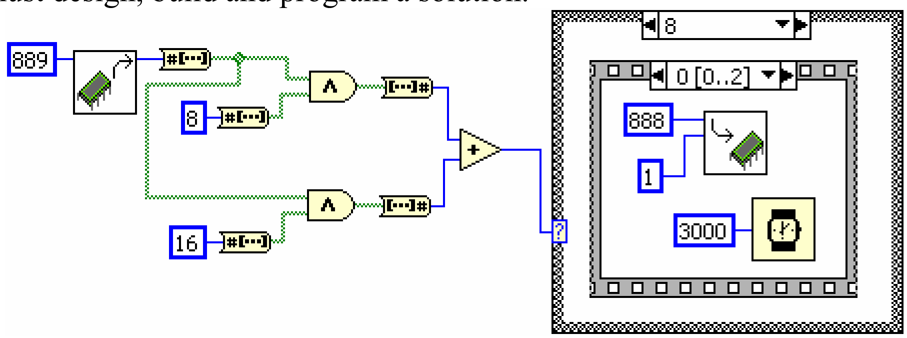

Figure 6. Typical LabVIEW program used with I/O interface

At the conclusion of the course, the students were given a Likert survey concerning curriculum strategies and activities. Approximately 47% of the students strongly agreed, and 42% agree with the statement, "the teaming or cooperative-learning aspect used in the laboratory activities was a good and useful experience." Only 5% disagreed, with no students strongly disagreeing with the statement. In addition, students commented throughout the course they enjoyed the cooperative group aspect when they missed a class or needed extra help.

Our On-Going Efforts

At present, we are making efforts to extend the above-described new pedagogical model and modified-jigsaw cooperative-learning approach to other engineering courses, especially to an undergraduate course titled "Machining Theory and Applications." (This course is different from the "Advanced Topics in Metal Cutting" course that we introduced before.) The objective of the Machining Theory and Applications course is to provide students a fundamental understanding of metal machining principles as well as fundamental analytical and experimental skills. The course covers almost all fundamental aspects in metal machining, such as the cutting forces and temperatures, the machining vibrations, and tool wear and tool life.

The reason we select the "Machining Theory and Applications" course is that machining is one of the most common and accessible manufacturing processes to which many engineering students are exposed. It is taught in numerous U.S. universities and colleges either as a stand-alone course or as an integral component of a manufacturing course. In addition, it is taught not only in mechanical, industrial, and manufacturing engineering programs, but also in many applied manufacturing technology programs across the country.

At present, we are developing three computer simulation learning modules for students, each module covering a major aspect of machining. These three modules include:

Learning module A: Force, temperature, and chip formation. The student learning goal is to predict how the work material, the tool geometry, and the cutting conditions affect the cutting forces, the cutting temperatures, and chip formation in metal machining.

Learning module B: Tool wear and tool life. The student learning goal is to predict how the cutting conditions, the cutting forces, tool and work materials affect tool wear and tool life.

Learning module C: The machined surface roughness and residual stress. The student learning goal is to predict how the cutting conditions, the tool geometry, and tool wear affect the surface roughness and residual stress of machined parts.

For each learning module, a set of criterion-referenced learning objectives as well as a table of test specifications for developing and weighting test items at various levels of the cognitive domain are being developed. Cooperative-learning activities are being designed for real-world experiments and are integrated into computer simulations using the described pedagogical model.

Concluding Remarks

We have presented in this paper a new pedagogical model that aims to integrate computer simulations into real-world experiments. In this model, learning through engineering laboratory experiences is conducted in an integrated and cyclic way, which makes a positive difference in the way students gain understanding of engineering concepts and applications. We have presented the framework of the model and use an example of student work to further demonstrate how the model works. We also present a modified-jigsaw cooperative-learning approach that is suitable for providing engineering laboratory experiences for large classes that involve 100 or more students. A specific example of weekly laboratory assignments is also presented to demonstrate how the modified-jigsaw approach works. Student evaluations to our work are overwhelmingly positive.

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