AC 2009-284: A PROJECT-BASED ACTIVE AND COOPERATIVE LEARNING APPROACH TO IMPROVING MANUFACTURING ENGINEERING EDUCATION

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A Project-Based Active and Cooperative Learning Approach to Improving Manufacturing Engineering Education

Abstract

This paper describes a project-based active and cooperative learning (PB-ACL) approach that was developed to simultaneously address four industry-identified competency gaps that need to be closed between industry's manufacturing workforce needs and current educational programs. The four competency gaps include 1) a specific manufacturing process, 2) business knowledge, 3) oral and written communication, and 4) teamwork. In the PB-ACL approach, students form various project teams with three or four students on each team. Each student is assigned different responsibilities. Each team works on a semester-long manufacturing project that includes three well-integrated tasks. A representative example of student projects is given to show how the PB-ACL approach works. A Likert-type and open-ended questionnaire was developed to assess student learning outcomes. Assessment results showed that more than 80% of the surveyed students gained positive experiences from the PB-ACL approach.

Introduction

As competition in the global economy becomes increasingly fierce, industries set higher and higher expectations and requirements for engineering students [1-4]. In close collaboration with numerous industrial partners and universities and colleges in North America, the Society of Manufacturing Engineers Education Foundation has reported 15 competency gaps [5] that need to be closed between industry's manufacturing workforce needs and current educational programs. These 15 competency gaps are grouped into four categories including:

- A specific manufacturing process: machining, welding, casting, forging, etc.
- Integration systems skills: business knowledge, manufacturing systems, supply chain management, international perspective, and product/process design
- Technical skills: engineering fundamentals, materials, manufacturing process control, quality, and product/process design (co-listed in the "Integration system skills" category)
- Professional skills: oral & written communication, teamwork, project management, problem solving, and personal attributes

Addressing these competency gaps requires effective instructional strategies, such as active learning and cooperative learning. Active learning is generally defined as any instructional strategy that actively engages students in the learning process [6-9]. It is built upon an experimentally-proven cognitive learning theory [10], which states that if students become active participants instead of passive listeners during the course of knowledge acquisition, they can recall information and learn course materials better. Cooperative learning is generally defined as any instructional strategy in which small heterogeneous groups of students work together to achieve a common learning goal [11]. Simultaneous interaction and equal participation among students occur in cooperative learning. Active and cooperative learning have been widely adopted in many engineering and science disciplines, such as manufacturing [12,13], engineering design [14], and computer science [15,16]. Active and cooperative learning also take a wide variety of formats, such as project-based learning [17,18] in which students are actively engaged in the learning process by forming student teams working on a specific project.

In a recent effort to address those industry-identified competency gaps to improve manufacturing engineering education, the author of this paper developed a project-based active and cooperative learning (PB-ACL) approach and implemented it in an upper-division manufacturing engineering course: Machining Theory and Applications. In the PB-ACL approach, students form various project teams with three or four students on each team. Each student is assigned different responsibilities. Each team works on a semester-long project that includes three well-integrated tasks. The PB-ACL approach simultaneously addresses four competency gaps including 1) a specific manufacturing process – machining, 2) business knowledge, 3) oral and written communication, and 4) teamwork.

This paper provides a detailed description about the PB-ACL approach. A representative example of student projects is given to show how the PB-ACL approach works. A Likert-type and open-ended questionnaire was developed to assess student learning outcomes, or in other words, if the PB-ACL approach was effective in addressing those four competency gaps. Assessment results showed that more than 80% of the surveyed students gained positive experiences from the PB-ACL approach in terms of those four competency gaps. Major conclusions are summarized at the end of the paper.

A Project-Based Active and Cooperative Learning (PB-ACL) Approach

Figure 1 shows the overall framework of the project-based active and cooperative learning approach. This approach consists of three well-integrated tasks. Task 1 focuses on developing a computer software program for machining simulations. Task 2 focuses on developing the associated business plan. Task 3 focuses on the written and oral presentation of the project.

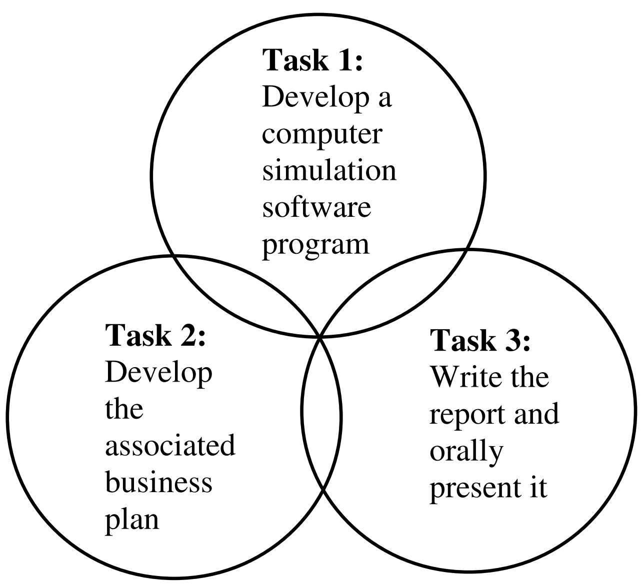

Figure 1. Overall framework of the project-based active and cooperative learning approach

Table 1 shows how each competency gap is addressed by different project tasks and what instruments are used to assess student learning outcomes. The results of assessment will be described in detail in a later section of this paper.

Table 1. Project tasks and assessment instruments

Competency Gaps Addressed in This Paper	Tasks That Are Designed to Address the Gaps	Instruments of Assessing Student Learning Outcomes
Specific manufacturing process	Task 1	• Questionnaire survey • Quality of the computer simulation software program
Business knowledge	Task 2	• Questionnaire survey • Quality of the business plan
Oral and written communication	Task 3 and student communication over the project period	• Questionnaire survey • Quality of the written report • Quality of oral presentation
Teamwork	Tasks 1 -3	• Questionnaire survey • Quality of the computer simulation software program • Quality of the business plan • Quality of the written report • Quality of oral presentation

Task 1 includes the following six sub-tasks:

1) Choose a specific learning topic to work on. Seven topics are provided to each student team for them to choose from. These topics include the predictions of the cutting forces, the cutting temperatures, the built-up edge, tool wear, tool life, the machined surface roughness, and the residual stress of the machined parts. These learning topics are also covered to various extents in regular classroom lectures by the instructor. Students can gain a more in-depth understanding of a specific topic by working on their project.

2) Search literature from multiple resources such as journal, magazine, and conference papers, books, patents, Internet websites, and consultation with industry professionals. Literature search also involves the use of common online databases, such as the Web of Science and the Engineering Index, which our university library subscribes.

3) Critically review the literature and select an appropriate machining model. Students are required to critically review their collected literature and then choose an appropriate machining model that is reported in the literature. The machining model can be analytical, numerical (such as finite element), or empirical (experimental).

4) Develop computer codes. Based on their chosen machining model, students develop the computer codes using one of the computer programming languages that they learned before in other classes, such as Matlab, Visual Basic, or C++.

5) Develop the computer graphical user interface. Students are also required to develop the graphical user interface associated with their computer simulation software program.

6) Test the developed software program to make sure it runs well. This sub-task also includes the modification and refinement of the computer program.

Task 2 includes three sub-tasks. It must be pointed out a complete business plan consists of many sub-tasks [19]. Considering that students must complete their project within the one-semester time frame, the instructor chooses the following three fundamental sub-tasks (that must be addressed in any business plan) for students to conduct:

1) Identify target markets to which the developed computer software product can be applied. Students are required to conduct comprehensive market surveys and determine if there are market demands and opportunities for their products.

2) Develop a marketing plan. This includes estimating market size, anticipating growth and competition in each of the most promising markets, and developing a feasible go-to-market strategy, that is, how to move the developed software product out of the current "lab" status into marketplaces.

3) Identify the major specific competitors of the developed software product in each target market, identify the competitive edge of the developed software product, and evaluate barriers to entry and potential future competition.

Task 3 consists of two sub-tasks as follows:

1) Write a final project report in a required format. The report is typewritten using Microsoft Word, single-spaced with 12 pt. font size on 8.5 by 11 inch papers. It contains the following required contents:

   - Cover page: List the project title and all team members.
   - Executive summary: Summarize major aspects in Sections 3-6 below.
   - Product description: Describe the functions and innovation of the developed software product, the machining model based on which it is developed, and how to use it.
   - Target market: Describe target markets to which the developed product can be applied and how target markets are found and selected.

- Marketing plan: Describe the estimated market size, anticipated growth and anticipated competition in each of the most promising markets, and the go-to-market strategy.
- The competition: Describe the major specific competitors of the developed software product in each target market, the competitive edge of the developed software product.
- References: Provide at least 15 references from multiple resources.
- Appendix: Students can attach any documents that they think are important.

2) Orally present their project results. At the end of the semester, each student team is given 20 minutes to present their project results. This also provides an additional experience for students to learn from each other.

A Representative Example of Student Projects

The above-described PB-ACL approach was implemented in an upper-division manufacturing engineering course – Machining Theory and Applications – which was taught by the author of this paper. A total of 22 students who enrolled in this course were grouped into six project teams with three or four students on each team.

A representative example of student projects is provided to demonstrate how the active and cooperative learning approach worked. In this example, the project team consisted of four senior mechanical engineering undergraduate students. The students on this team were interested in tool-life prediction in metal machining. The team elected its team leader and assigned each member various responsibilities as shown in Table 2.

After extensive literature review and consultations with the instructor, the team identified an empirical tool-life model [20] to develop their computer simulation program for turning with coated chip-groove tools. The mathematical expression of the identified tool-life equation is

$$T = T_g \cdot W_g \cdot \left(\frac{V_R}{V} \right)^{W_c \cdot \frac{1}{n}}$$

where T is tool life, V is the cutting speed, T_g is the reference tool life, V_R is the reference cutting speed, n is Taylor's tool life exponent, W_c is the coating effect factor, and W_g is the chip-groove effect factor.

The original literature [20], however, does not provide a mathematical expression of the chip-groove effect factor W_g., which is an essential input of the computer simulation program. Therefore, the student team derived four equations to calculate W_g for four different tool inserts. The derivation was done by using a software package TableCurve 3D (Version 4.0) to create a surface plot of the experimental data reported in the literature [20]. All of the four equations had an accuracy of 99.95 percent or higher.

The student team finally employed Visual Basic to write all computer codes and developed the associated computer graphical user interface as shown in Fig. 2.

Table 2. The responsibility of each student in a project team

Student	Role	Responsibility
A	Team leader	• Task 1: Computer Simulation Program o Design of User Interface and Programming o Program Layout o Timeline and Team Organization o Research Machining Model Equation • Task 2: Business Plan o Target Market o Executive Summary o Organize Layout of Business Plan o Timeline and Team Organization o Final Compilation and Editing of Business Plan • Task 3: Presentation and Report o PowerPoint Slide Layout o PowerPoint for and Presentation of Target Market o Presentation of Program Operation
B	Team member	• Task 1: Computer Simulation Program o Research Machining Model Equation • Task 2: Business Plan o Marketing o Cover Page o Executive Summary o Compile References o Organize Layout of Business Plan o Editing of Business Plan • Task 3: Presentation and Report o PowerPoint for and Presentation of Marketing
C	Team member	• Task 1: Computer Simulation Program o User Interface and Programming o Research Machining Model Equation o Compile Different Tool Insert Equations • Task 2: Business Plan o Product Description o Executive Summary • Task 3: Presentation and Report o PowerPoint Slide Face Design o PowerPoint for and Presentation of Product Description
D	Team member	• Task 1: Computer Simulation Program o User Interface and Programming o Research Machining Model Equation o Program Layout • Task 2: Business Plan o Competition o Executive Summary • Task 3: Presentation and Report o PowerPoint for and Presentation of Competition

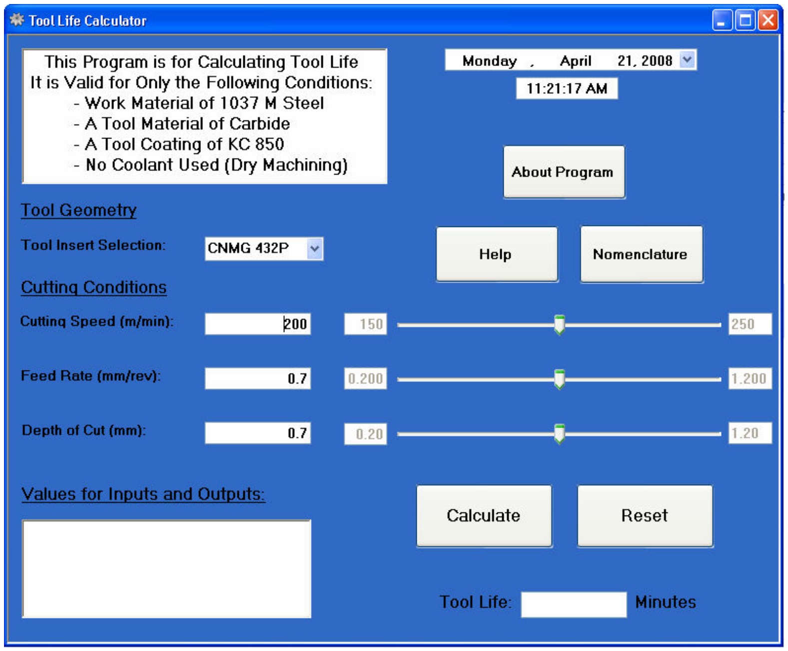

Figure 2. The computer graphical user interface developed by the student team

The major function of the developed computer simulation program is to predict tool life in turning operations with a given set of tool inserts (with a variety of chip-groove geometry) under a range of cutting conditions (the cutting speed, the feed rate, and the depth of cut). With this computer simulation program, the users can quickly determine how different tool inserts and cutting conditions affect tool-life.

Based on the written report submitted by the project team, Table 3 (next page) summarizes the student-designed business plan.

Assessment of Student Learning Outcomes

In addition to using a set of scoring rubrics to assess the quality of student projects, a Likert-type and open-ended questionnaire was developed to assess if the project-based active and cooperative learning approach was effective in addressing those four competency gaps. A total of 21 students in the class responded to the questionnaire survey. The following paragraphs provide a detailed description of assessment results.

The question to address the competency gap of "a specific manufacturing process" was: Please describe to what extent the team project helped improve your understanding of machining processes? Representative student responses were as follows:

- "It forced us to think critically about what was going on in machining."
- "This project helped me understand the complexity of machining and how much potential there is for learning."

Table 3. Summary of the student-designed business plan

Sub-task	Summary of research findings and plan

Target markets	• Manufacturing facilities that involve machining operations
	  ○ Large companies that require a tool life management system
	  ○ Small machine shops with limited resources
	• Cutting tool manufacturers

Marketing plan	• Market size
	  ○ 91.1% of machine shops use turning
	  ○ Carbide tools used 76% of the time
	• Growth
	  ○ Machine tool consumption increased 6.5%
	  ○ Machine tool use increased 15%
	  ○ More materials, coatings, and tools
	• Go-to-market strategy
	  ○ Partnership with major carbide-tool companies
	  ○ Create a company website
	  ○ Use additional strategies: take out advertisements in magazines for machinists and engineers and attend trade shows

The competition	• Competitors
	  ○ "Machine Calc" developed by a research engineer
	  ○ "Tool Life Durations and Tool Life Speed Adjustments" developed by Iscar Inc.
	• Competitive edge of the software
	  ○ Usefulness – targeting common steel materials
	  ○ Accuracy of prediction
	  ○ User friendliness and simplicity
	  ○ Affordable price
	• Barriers to entry potential future competition
	  ○ No established brand name – brand new
	  ○ Currently having limited abilities

- "Researching the different models gave me a better understanding of machining."
- "It gave us opportunity to research, build and run software. It made learning about machining meaningful."
- "It helped me gain a more in-depth understanding."

The questions to address the competency gap of "business knowledge" were: 1) Do you agree that your business knowledge was improved by developing a business plan? 2) What did you learn most from developing a business plan? Figure 3 shows that 81% student responses to the first question were positive. The typical student responses to the second question were as follows:

- "I learned how important it is to 'push' your design after it has been created."
- "Target market is very important and it is the basis for successful business plan."
- "I was responsible for the marketing sections of the business plan. I gained an understanding of some real life marketing techniques that companies use in industry."
- "I learned a few useful techniques for marketing a product."
- "I learned about different aspects of a business. Some I had not thought of."

The questions to address the competency gap of "oral and written communication" were: 1) Do you agree that Tasks 1 and 2 that you have done enhanced your communication skills? 2) Do you agree Task 3 (writing a final project report and then orally presenting it) enhanced your communication skills? Figure 4 shows that 81% student responses to the first question were positive. Figure 5 shows that 85.8% student responses to the second question were positive.

The questions to address the competency gap of "teamwork" were: 1) Do you agree that the team project that you have done enhanced your team-working skills? 2) What did you learn most from conducting your team project? Figure 6 shows that 85.8% student responses to the first question were positive. The common student responses to the second question were as follows:

- "I learned a lot about tool wear because we all shared our research."
- "Talking to each other made better understanding."
- "How to do effective research in a team working environment."
- "How to work as a team."
- "Parallel work between team members was very useful."

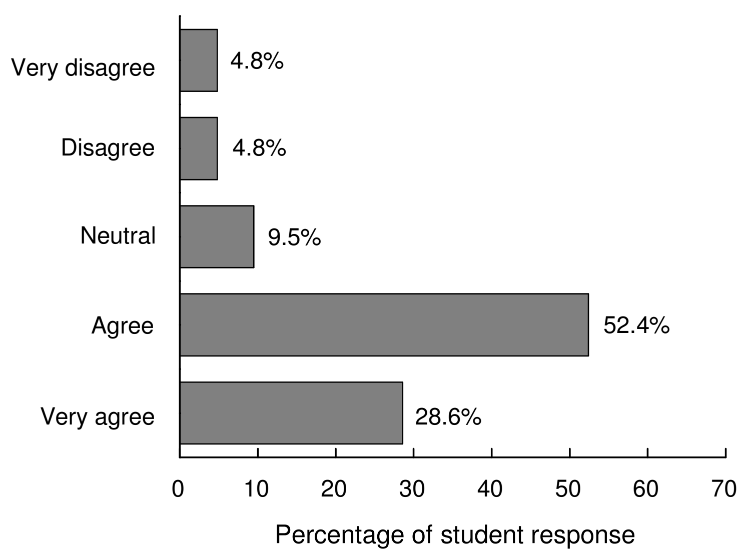

Figure 3. Student responses to the question of "Do you agree that your business knowledge was improved by developing a business plan in your project?"

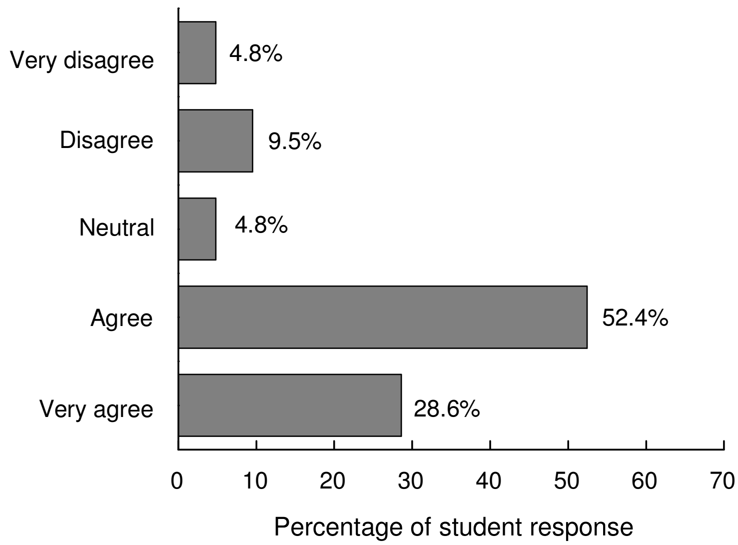

Figure 4. Student responses to the question of "Do you agree that Tasks 1 and 2 that you have done enhanced your communication skills?"

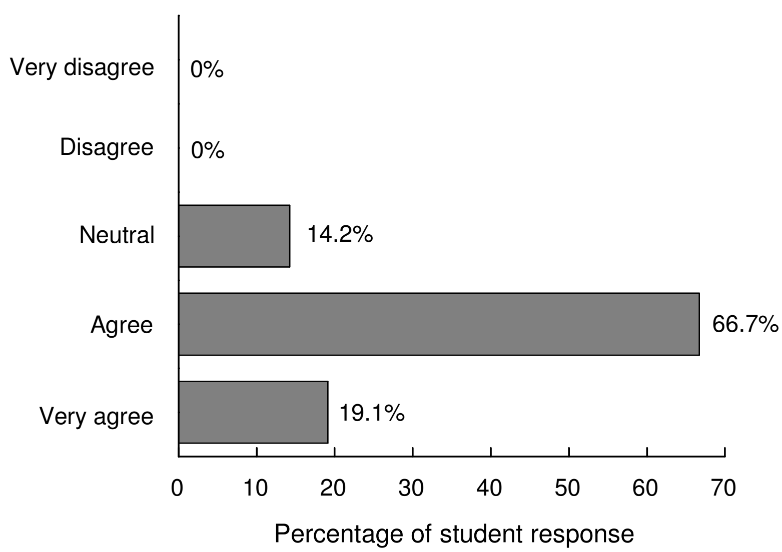

Figure 5. Student responses to the question of "Do you agree Task 3 (writing a final project report and then orally presenting it) enhanced your communication skills?"

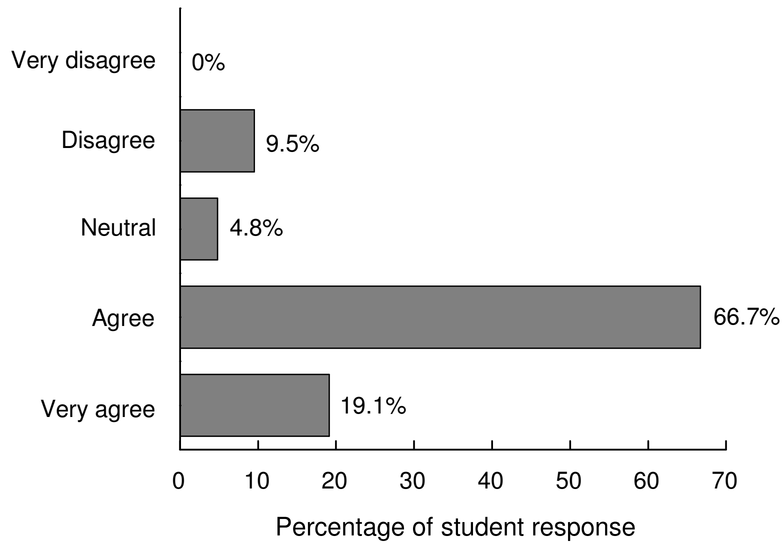

Figure 6. Student responses to the question of "Do you agree that the team project that you have done enhanced your team-working skills?"

Concluding Remarks

This paper has provided a detailed description of the project-based active and cooperative learning approach that was developed for simultaneously addressing four industry-identified competency gaps. The effectiveness of this approach was validated by a close examination of the quality of student projects (as demonstrated by the student project example described in this paper) and the questionnaire survey that included Likert-type and open-ended questions. The following paragraphs summarize major assessment results in each of the four competency gaps:

A specific manufacturing process: the students developed an in-depth understanding of a specific aspect of machining by working on their project through research and critical thinking. Many students reported that they began to understand how complex machining is.

Business knowledge: 81% of the surveyed students agreed or very agreed that their business knowledge was improved by developing a business plan. They began to realize how important it is to "push" their design to the marketplace after it has been created and learned some useful marketing techniques that they had not thought of.

Oral and written communication: 81% of the surveyed students agreed or very agreed that Tasks 1 and 2 enhanced their communication skills. 85.8% of the surveyed students agreed or very agreed that Task 3 enhanced their communication skills.

Teamwork: 85.8% of the surveyed students agreed or very agreed that the team project enhanced their team-working skills. They appreciated the benefits of working in a team environment such as sharing research ideas and performing parallel work among team members.

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