International Journal of Engineering Education Vol. 28, No. 1, pp. 26–36, 2012
Printed in Great Britain

0949-149X/91 $3.00+0.00

Improving Engineering Students' Technical and Professional Skills Through Project-Based Active and Collaborative Learning*

NING FANG
Department of Engineering Education, College of Engineering, Utah State University, Logan, UT 84322, USA.
E-mail: ning.fang@usu.edu

This paper presents a project-based active and collaborative learning approach to improving the technical and professional skills of engineering students. The approach includes three integrated tasks that students develop and design, rather than simply use them. Task 1 focuses on developing a computer simulation program for machining; Task 2 on developing the associated business plan; and Task 3 on the written and oral presentation of the project. Two examples of student projects are provided to demonstrate what and how students learned from their projects. The students' attitudes and experiences with their projects were assessed with a Likert-scaled survey questionnaire. The assessment showed that more than 80% of students responded that the overall experience with their projects was 'positive' or very 'positive', and they 'agreed' or 'very agreed' that their projects enhanced their teamwork and communication skills, business knowledge, and entrepreneurship skills.

Keywords: technical skills; professional skills; project-based learning; active learning; collaborative learning

1. Introduction

1.1 Technical and professional skills required for engineering graduates

Owing to market competition and tight resources in today's world, industries have set high requirements for engineering graduates. These requirements involve not only technical skills, such as proficiencies and a broad knowledge in a specific academic discipline, but also professional skills, such as effective communication, teamwork, leadership, business knowledge, entrepreneurship, and project management [1–4]. Some of these requirements are also documented in the well-known ABET engineering criteria a–k [5].

In spite of continuous effort by the engineering education community, a large competency gap still exists between industry's engineering workforce and current educational programs. For example, a recent study of the ABET engineering criteria [6] revealed that three out of four employers assessed graduates' teamwork and communication skills as "adequate." In another research study, which was conducted in collaboration with numerous industrial partners and universities and colleges in North America, the Society of Manufacturing Engineers Education Foundation identified fifteen competency gaps. These competency gaps involved both the technical and professional skills of engineering graduates [7].

1.2 Project-based active and collaborative learning

To address the above problems and issues, a variety of instructional approaches, such as project-based learning, active learning, and collaborative learning have been developed and implemented in various educational settings. In project-based learning, students work on specific projects that are based on challenging questions or problems. Those projects often involve complex tasks that offer students an opportunity to work dependently or collaboratively over an extended period of time to culminate in realistic products or presentations [8–10]. In active learning, students are actively participating, instead of passively listening during the course of knowledge acquisition, and therefore students can recall information and remember course materials better [11–13]. In collaborative learning, small heterogeneous groups of students work together to achieve a common learning goal [14, 15]. Simultaneous interaction and equal participation among students are part of collaborative learning.

Depending on the context, the same instructional approach can be called project-based learning, active learning, or collaborative learning. An instructional approach that effectively integrates all three approaches is called project-based active and collaborative learning—which means that students are actively engaged in the learning process by forming student teams working on specific projects.

The project-based active and collaborative learning approaches have been implemented in various engineering classes. For example, Zhan and Porter

* Accepted 10 November 2011.

recently applied these approaches to teaching Six Sigma concepts and principles in a seven-week course that was offered to electronics engineering technology students [16]. The students were asked to develop effective methods to improve the performance of an existing product, which was a traffic control system that could adjust the time delay between the green traffic lights at intersections based on the weather and road conditions. The students formed several project teams. Each team identified its own methods for product improvement, such as cost reduction, optimization of the signal conditioning circuit, and fault detection. During the project, the students learned how to use Six Sigma tools and developed a better understanding of the five stages of a Six Sigma process (Define, Measure, Analyze, Improve, and Control) [16].

1.3 Innovation and uniqueness of the present study

In this study, the project-based active and collaborative learning approach was implemented in an upper-level undergraduate manufacturing engineering course entitled Machining Theory and Applications. The author of this paper was the developer and instructor of the course. This study is innovative and unique in the two following aspects.

First, this study focuses on student learning in a metal machining course in which students developed their *own* computer program for machining simulations. The students were not simply just users but, more importantly, they were the developers and designers. The author of this article has conducted an extensive literature review using popular literature databases including those of the Education Resources Information Center, Science Citation Index, Social Science Citation Index, Engineering Citation Index, and Academic Search Premier. The results show that it is common for an instructor to develop a computer simulation program for students to learn, but it is unusual for students to develop their own simulation program to improve their own learning. For example, Marquez *et al.* [17] developed a computer simulation program for students to learn plastic injection molding processes. In an earlier work, Fang *et al.* [18] also developed a computer simulation program for students to learn metal machining processes. In both cases, students were users rather than developers and designers. It can be reasonably expected that a developer and designer would learn a subject matter better than just an end user.

Second, this study effectively integrates the training of both technical and professional skills (especially business knowledge and entrepreneurship) of the engineering students. The results of the literature review show that many relevant studies focused either on the training of just technical skills or just professional. The training of professional skills was limited to communication and teamwork. As emphasized in many reports [5–7], business knowledge and entrepreneurship are very important for engineering students. A few universities have programs that offer students an option of a minor in engineering entrepreneurship. However, from the perspective of the entire education system, which consists of thousands of institutions of higher learning nationwide and worldwide, the training for improving engineering students' business knowledge and entrepreneurship skills is still inadequate.

1.4 The overall objective of the present study and the contents of this paper

The aim of this study is to improve engineering students' technical and professional skills through a project-based active and collaborative learning approach. This paper first provides a brief introduction to the Machining Theory and Applications course, followed by a detailed description of how the project-based active and collaborative learning approach was implemented in the machining course. Then two samples of student projects are provided. The students' attitudes and experiences of their projects were surveyed with a Likert-scaled questionnaire at the end of the semester. The assessment results are reported and discussed.

2. A project-based active and collaborative learning approach

2.1 Course description and student learning styles

Machining Theory and Applications is an upper-level, three-credit, technical elective course offered to mechanical engineering students. The course covers a variety of topics ranging from fundamental principles of metal machining (such as chip formation mechanisms, tool geometry and tool materials, cutting forces and temperatures, tool wear and tool life, and machined surface quality) to the application of modern advanced machining technologies (such as dry machining and high-speed machining) [19, 20]. The course has the following six student learning objectives: objectives 1–5 focus on the training of students' technical skills, and objective 6 focuses on the training of students' professional skills:

1. Identify correct tool geometry and their effects
2. Calculate and experimentally measure the shear-plane angle
3. Perform fundamental analysis on the cutting forces and temperatures in machining
4. Understand different tool material properties

and tool wear mechanisms and apply Taylor's tool life equation to predict tool life
5. Analyze factors affecting the machined surface quality
6. Develop and improve professional skills (such as communication, teamwork, business knowledge, and entrepreneurship) to help enable machining innovation

A total of 22 engineering undergraduates were enrolled in the above course in a semester. Not only did the students attend regular classroom lectures and conduct a series of homework and laboratory assignments, but the students also formed six teams working on a variety of projects throughout the semester.

Student learning styles were first surveyed to facilitate effective teaching and learning. Up to now, educational researchers have developed a variety of models to categorize learning styles [21, 22]. In a widely-adopted model [23], student learning styles are divided into three basic types: auditory, kinesthetic, and visual. Auditory learners learn through hearing the spoken word; kinesthetic learners learn through doing and interacting with the material; and visual learners learn through looking at images, mind maps, demonstrations, and body language [23]. Because a learner may use a combination of all three styles, the students in the machining class were asked to rank the order of their learning styles—in terms of auditory (A), kinesthetic (K), and visual (V) learning—from the most frequently used to the least frequently used. Figure 1 shows the survey results: 57.1% of students ranked their learning styles as KVA, and 28.6% of students as VAK. Therefore, it can be concluded that most of the students in the machining class primarily relied on kinesthetic learning or visual learning. These survey results implied that project-based active and collaborative learning should be effective for most of the students in the class.

2.2 The project-based active and collaborative learning approach

Figure 2 shows the overall framework of the project-based active and collaborative learning approach that consists of three integrated tasks in which students are developers and designers. Task 1 focuses on developing a computer software program for machining simulations, which helps improve students' technical skills (i.e., course objectives 1–5). Task 2 focuses on developing the associated business plan, and Task 3 on the written and oral presentation of the project. Both Tasks 2 and 3 help improve students' professional skills (i.e., course objective 6). Each task includes a set of sub-tasks that are described in detail in the following paragraphs.

- Task 1

Sub-task 1.1 (labeled as T1.1 in Fig. 2): Select a specific project to work on. At the beginning of the semester, the instructor provided a list of seven project topics from which students can choose. These general projects included 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 project topics covered various extents in regular classroom lectures. Students gained an in-depth understanding of a specific topic by working on their corresponding project throughout the semester.

Sub-task 1.2: Search literature from multiple resources, such as journals, magazines, conference proceedings, books, patents, Internet, and consultation with industry professionals. Literature search also involved the use of common literature databases, such as the *Web of Science* and the *Engineering Index* that are available at the university library.

Sub-task 1.3: Critically review the literature and select an appropriate machining model. Students were required to critically review their collected literature and choose an appropriate machining model that was found from the literature. The machining model can be analytical, numerical

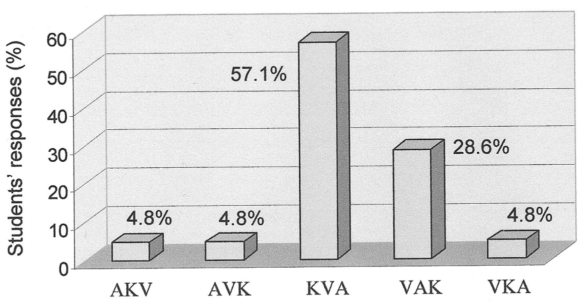

Fig. 1. Student learning order of styles: auditory (A), kinesthetic (K), and visual (V) learning.

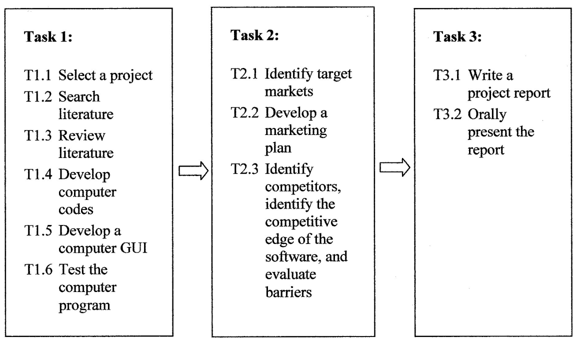

Fig. 2. Overall framework of the project-based active and collaborative learning approach.

(such as finite element), or empirical (experimental).

Sub-task 1.4: Develop computer codes to translate the machining model that the students chose in sub-task 1.3 into a computer program. The students were allowed to develop the computer codes using any one of the programming languages (such as MatLab, Visual Basic, or C++) that they had learned in other classes.

Sub-task 1.5: Develop the computer graphical user interface (GUI). The students were required to develop the GUI associated with their computer simulation program.

Sub-task 1.6: Test the computer simulation program to make sure it runs well. This sub-task also includes the modification and refinement of the computer simulation program.

- Task 2

A complete business plan includes many components such as the target market, marketing plan, the competition, strategic position and risk analysis, operations, management and organization, profit and loss statement, and case flow projection [24, 25]. Typically, these components are addressed in a stand-alone course offered by the business college. Considering that students in our machining class must complete their projects within the semester time frame, the instructor chose the following three fundamental sub-tasks (which must be addressed in any business plan) for students to conduct.

Sub-task 2.1: Identify target markets where the developed computer simulation program (product) can be applied. The students were required to conduct comprehensive market surveys and determine if there were market demands and opportunities for their products.

Sub-task 2.2: 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 on how to move the developed software product out of the current "lab" status into marketplaces.

Sub-task 2.3: 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

Sub-task 3.1: Write a final project report in a required format. The students were required to present their reports in Microsoft Word with 12 pt. font size on 8.5 × 11 inch paper. The report contains the 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 fifteen references from multiple resources.
- Appendix: Students can attach any documents that they think are important.

Sub-task 3.2: Orally present their project results. At the end of the semester, each student team was given 20 minutes to present their project results. This also provided an additional opportunity for students to learn from each other.

2.3 Formation of project teams and the selection of projects

Of the 22 students who were enrolled in the class, nine students had experienced working part time in a machine shop or a manufacturing company that involved machining. Therefore, efforts were made to ensure that each project team had at least one student with practical machining experience. A total of six project teams were formed with three or four students on each team. Each team selected its team leader either by voting or by volunteering.

Table 1 shows a list of six projects selected by student teams. In a subsequent survey, the students were asked the reasons why they selected their particular projects. Representative student responses were:

- "We searched the literature and chose the one that was most interesting to everyone in the group."
- "We thought it looked interesting and could be useful in industry."
- "We felt that there was a lot of opportunity for research, competition, etc."
- "We thought it would be useful in real world."
- "[We selected it] because it sounded like a useful tool to have in a machining setting to optimize cutting processes."

- "We thought we would learn the most with this project and it would be the most useful."
- "It sounds a little more challenging."

It is clear that the students chose their project topics for two primary considerations: Is the project useful in the real world? Can the project provide a valuable opportunity to learn? This demonstrated that the students did care about their learning.

3. Representative examples of student projects

Two representative examples of student projects are provided to illustrate what and how the students learned via the above-described project-based learning approach. These two examples include project 5 ("machining model to predict tool wear") and project 6 ("drilling forces for composite materials"). Each project team has four students. Table 2 summarizes key components in these two projects: the machining model (Task 1), the computer simulation program (Task 1) and the business plan (Task 2). The following paragraphs provide a more detailed description of these key components.

3.1 Machining model

The students on project 5 chose tool wear as their project topic because they thought it would be

Table 1. List of student projects

Team	Project title	Project objectives
1	Predicting tool flank wear in machining composite materials	• Develop a computer simulation program to predict tool flank wear based on the fiber orientation angle and the cutting conditions • Develop and write the associated business plan
2	Cutting force calculators	• Develop a computer simulation program to calculate the cutting forces in turning operations • Develop and write the associated business plan
3	Tool life calculator	• Develop a computer simulation program to predict tool life for the given tool geometry and cutting conditions in turning operations • Develop and write the associated business plan
4	Cutting force predictions	• Develop a computer simulation program to predict the cutting forces based on work materials, tool geometry, and the cutting conditions • Develop and write the associated business plan
5	Tool wear predications	• Develop a computer simulation program to predict tool flank wear based on the cutting conditions and a force ratio • Develop and write the associated business plan
6	Drilling forces for composite materials	• Develop a computer simulation program to predict the drilling forces based on composite materials and their thickness, drill bit diameter, and the cutting conditions • Develop and write the associated business plan

Table 2. Summary of key components in two projects

Key components	Project 5	Project 6
Machining model	• The tool wear model by Choudhury and Kishore [26] • The tool life model by Oraby and Hayhurst [27] • The surface roughness model by Özel and Karpat [28]	• The cutting force model (without a pilot hole) by Won and Dharan [29] • The cutting force model (with a pilot hole) by Tsao [30]
Functions of the computer software program	• Given: force ratio, machine tool spindle speed, feed rate, depth of cut, and workpiece diameter • Predict: tool flank wear length, tool life, and machined surface roughness	• Given: composite material, drill bit diameter, feed rate, and material thickness • Predict: cutting force, thrust force, whether or not delamination will occur
Target market	• Small machine shops	• Construction, transportation, and aerospace industries • Institutions of higher learning
Marketing plan	• Product demonstration at technical expositions and trade shows, in journals and other high visibility areas • Product demonstration and evaluation at potential customers' physical locations	• Test and evaluation at universities and colleges • Company website • Advertising campaign such as trade shows, press release, and seminars
The competition	• A major competitor that has a finite-element-based computer program for machining simulations	• A CD and book combination entitled Advanced Metalcutting Calculators & Engineering Formulas for Metalcutting

useful in the real world. Based on extensive literature review and discussions with the course instructor, the students identified the tool wear model suggested by Choudhury and Kishore [26] as the machining model on which their computer simulation program would be built. The mathematical form of Choudhury and Kishore's model is [26]:

$$W = 0.324(F_f/F_c)^{0.601} + 0.00003 \times N^{1.628} \times f^{0.912} \times d^{1.162} \times D^{1.01}, \quad (1)$$

where W is the tool flank wear length (in mm), F_f is the feed force (in N), F_c is the cutting force (in N), N is the machine tool spindle speed (in rpm), f is the feed rate (in mm/rev), d is the depth of cut (in mm), and D is the workpiece diameter (in mm).

During the learning process, the students realized that it was equally important to determine tool life because [quote from the students] "it allows a machinist to estimate the time to the given wear and make tool changes as needed so that downtime and loss of product can be minimized." The students further identified the following model suggested by Oraby and Hayhurst [27] as the machining model to predict tool life:

$$T = 78573.35 \times V^{-1.712} \times f^{-0.714} \times d^{-1.107} + 249.49 \times e^{-78.571(R_f - R_o)}, \quad (2)$$

where T is tool life (in seconds), V is the cutting speed (in m/min), f is the feed rate (in mm/rev), d is the depth of cut (in mm), and both R_f and R_o are force ratios.

The students on project 5 also identified a machining model to predict the machined surface roughness based on the research conducted by Özel and Karpat [28]. For reasons of brevity, Özel and Karpat's model, which involved extensive data analysis, is not described in this paper. Interested readers can refer to their original work [28] for details.

The students on project 6 focused their efforts on composite machining partially because [quote from the students] "everyone in the team has taken the composite class and we thought this would be different from what the other groups were doing." The students conducted an extensive literature review and also discussed their project idea with the course instructor. The students identified the following model suggested by Won and Dharan [29] to predict the cutting forces in drilling two types of composite materials.

For drilling carbon/epoxy laminates:

$$F_t = 40.77(f\,d)^{0.66} - 0.36d^2 \quad (3)$$

$$Fc = 14.12(f\,d)^{0.66} \quad (4)$$

For drilling aramid/epoxy laminates:

$$F_t = 35.84(f\,d)^{0.50} - 0.09d^2 \quad (5)$$

$$F_c = 30.81(f\,d)^{0.50}, \quad (6)$$

where F_t is the thrust force (in N), F_c is the cutting force (in N), f is the feed rate (in mm/rev), and d is the drill diameter (in mm).

Based on their research, the students learned that the above model [29] only applied to drilling without a pilot hole. If a pilot hole is made on the work material before drilling, a different model is needed to predict the drilling force. The students did further research and identified Tsao's model [30] to predict the cutting forces in drilling with a pilot hole. The students also studied how to determine the critical force at which delamination begins to occur at the exit side of a drilled hole.

3.2 Computer simulation program

The students employed MatLab in developing computer codes for their simulation programs include the graphical user interfaces (GUIs). Figures 3 and 4 show the GUI developed by the students on project 5 and 6, respectively. The GUI in Fig. 3 allows a user to set up initial conditions (including the force ratio, machine tool spindle speed, feed rate, depth of cut, and the workpiece diameter) in a turning operation. Once the "Analyze" button (see Fig. 3) is pushed, the user can immediately see the results of predictions regarding the tool flank wear length, tool life, and the machined surface roughness. The GUI in Fig. 4 allows the user to select a composite material and change the drill bit diameter, feed rate, and material thickness. Once the "Calculate" button (see Fig. 4) is pushed, the user can immediately see the results of predictions including the cutting force, the thrust force, and whether or not delamination will occur in drilling with or without a pilot hole.

3.3 Business plan

Based on extensive market surveys and consultation

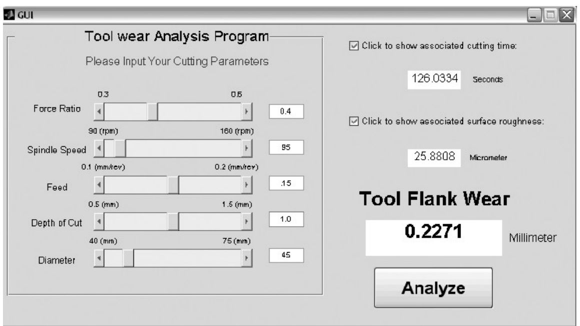

Fig. 3. Graphical user interface of the computer simulation program developed by the students on project 5.

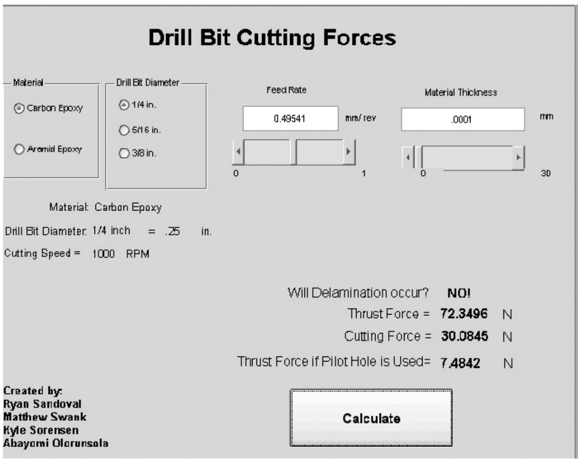

Fig. 4. Graphical user interface of the computer simulation program developed by the students on project 6.

with local manufacturers and machine shops, the students identified the target market of their products (i.e., their computer simulation programs). In their written project reports, the students included data, figures, and tables generated from their market surveys to justify the reasons that they selected their particular target market.

The students on project 5 identified small machine shops as the target market for their low-cost, affordable computer simulation program. The students reported that "there are 23 000–34 000 machine shops in the United States, and that the 50 largest shops control only 15% of the market in machining." The students concluded that "85% of all machine shops are small with less than 100 employees." The students also discussed their project idea with the supervisor of a machining department at a local company that manufactures sports and fitness equipment. The students were informed that tool wear had long been a significant issue in the machining department (which had seven employees and three CNC turning centers), and that in a case of tube cutting, a 10% increase in machining productivity could reduce the overall machining costs by 9–10%.

The students on project 5 developed their marketing plan. First, they would compile statistics on the accuracy of the outputs of their computer simulation program and would demonstrate the usefulness of their product at technical expositions and trade shows, in journals and other high visibility areas. Then, the students would contact specific machine shops to schedule a product presentation. A demo version of their computer simulation program would be provided to potential customers for evaluation before the customers make a purchase decision.

The students on project 5 identified a major competitor to their product. That competitor had a finite-element-based computer program for machining simulations. However, the competitor's computer program could not directly predict tool wear. It could only predict the cutting forces and the cutting temperatures, then use the predicted forces and temperatures to indirectly estimate tool wear. Therefore, the users of the finite-element-based simulation program must have a solid understanding of the inter-relationship among the cutting forces, the cutting temperatures, and tool wear. The students emphasized that their computer simulation program could directly predict tool wear and was very easy to use.

The students on project 6 identified two target markets: 1) construction, transportation, and aerospace industries, and 2) institutions of higher learning. Based on extensive market surveys and a literature review, the students reported that "the current U.S. composites industry generates 69.45 billion dollars of economic activity per year in manufacturing, and trends are on the rise." They reported that of the 4.01 billion pounds of composite shipments in 2006, construction (45%) and transportation (12%) constituted the two largest portions. The students also identified universities and colleges as another target market because [quote from the students] "when students get to use particular software and they master it, they will encourage other students, colleagues and the companies they work for to use the same software they have used when they were in school."

The students on project 6 developed a set of marketing strategies. These strategies include: 1) distribute the computer simulation program to universities for evaluation, 2) build a website with a very detailed company profile, and 3) have a broad advertising campaign to introduce their product to the market. The advertising campaign would include trade shows with demonstrations and case studies, press releases, and seminars with training and testimonials from other companies who have already successfully integrated the computer simulation program into their machining processes.

The students on project 6 stated that the major competitor to their product would be a CD and book combination entitled *Advanced Metalcutting Calculators & Engineering Formulas for Metalcutting* [31]. The students acknowledged that the CD [31] is a very sophisticated metal cutting predictor and has a broad range of capabilities including the prediction of the cutting forces. However, it does not have the capability to predict delamination, nor does it provide an option for a pilot hole, which could drastically affect the production process.

4. Assessment of student outcomes

4.1 Assessment instruments

Student learning outcomes were assessed using the two types of instruments listed in Table 3. The first instrument was a set of scoring rubrics for assessing student learning in a specific aspect of their projects. For example, a rubric that included five scoring levels (excellent, very good, good, fair, and poor) was employed to assess students' understanding of the specific machining topic that their projects addressed. Each scored level was associated with a set of assessment criteria. The first assessment instrument is highly related to the technical content of machining (such as tool wear, tool life, the cutting forces and temperatures, machined surface quality) in which the general readers may not be interested. Therefore, this paper does not intend to describe the details of the first assessment instrument. Instead, it focuses on the description of the second assessment instrument in which the readers may have more interest.

The second assessment instrument was a questionnaire survey on students' attitudes toward and experiences with various aspects of their projects. Of the 22 mechanical engineering students who were enrolled in the machining course, 21 students responded to the questionnaire survey. The survey included a set of Likert-scaled and open-ended questions that asked for detailed information regarding students' projects, for example, how students communicated and worked as a team and what they had learned from their projects. Table 4 summarizes the results of students' responses (in percentages) to seven Likert-scaled questions regarding students' attitudes toward and experiences with their projects. These seven questions include:

- Question 1: What is the overall experience with your team project? Choose one from: very positive, positive, neutral, negative, very negative
- Question 2: Do you agree that the team project that you have done enhanced your teamwork skills? Choose one from: very agree, agree, neutral, disagree, or very disagree
- Question 3: Do you agree that Tasks 1 and 2 that you have done enhanced your communication skills? Choose one from: very agree, agree, neutral, disagree, or very disagree
- Question 4: Do you agree Task 3 (writing a final project report and then orally presenting it) enhanced your communication skills? Choose one from: very agree, agree, neutral, disagree, or very disagree
- Question 5: Do you agree that your business knowledge was improved by developing a business plan in your project? Choose one from: very agree, agree, neutral, disagree, or very disagree
- Question 6: Do you agree that it is necessary and important to integrate entrepreneurship into manufacturing engineering education? Choose one from: very agree, agree, neutral, disagree, or very disagree
- Question 7: Do you agree that a team project with entrepreneurial activities is a good addition to classroom lectures because it makes learning more meaningful? Choose one from: very agree, agree, neutral, disagree, or very disagree

In Table 4, each rating was assigned a numerical value: very agree (4), agree (3), neutral (2), disagree (1), and very disagree (0). These numerical values were used to calculate the mean value and the standard deviation of students' responses to each question. A mean value of 3.0 means that, on average, the students provided an "agree" rating to a question.

Table 3. Assessment instruments

Skills categories	Specific skills	Major assessment instruments
Technical skills	In-depth understanding of the specific machining topic that the project addresses	• Scoring rubrics that assesses the quality of the computer simulation program • Questionnaire survey
Professional skills	Teamwork	• Questionnaire survey • Scoring rubrics that assesses the quality of the computer simulation program • Scoring rubrics that assesses each student's role and responsibility in the project
Professional skills	Communication skills	• Questionnaire survey • Scoring rubrics that assesses the quality of the written report • Scoring rubrics that assesses the quality of the oral presentation
Professional skills	Entrepreneurship and business knowledge	• Questionnaire survey • Scoring rubrics that assesses the quality of the business plan

Table 4. Assessment of students' attitudes and experiences

Category	Survey question number	Very agree (4)	Agree (3)	Neutral (2)	Disagree (1)	Very disagree (0)	Mean	Standard deviation
Overall experience	1*	19.1%	66.7%	4.8%	9.5%	0%	2.95	0.80
Teamwork	2	19.1%	66.7%	4.8%	9.5%	0%	2.95	0.80
Communication	3	28.6%	52.4%	4.8%	9.5%	4.8%	2.90	1.09
Communication	4	19.1%	66.7%	14.2%	0%	0%	3.05	0.59
Business knowledge	5	28.6%	52.4%	9.5%	4.8%	4.8%	2.95	1.02
Entrepreneurship	6	42.8%	47.6%	4.8%	0%	4.8%	3.24	0.94
Entrepreneurship	7	28.6%	52.4%	9.5%	4.8%	4.8%	2.95	1.02

* For question 1, choose from: very positive (4), positive (3), neutral (2), negative (1), very negative (0).

4.2 Assessment of students' overall project experience

Students' responses to Question 1 in Table 4 indicate that 85.8% of students rated the overall experience with their projects positive or very positive. Students were asked to describe to what extent the team project helped to improve their understanding of machining processes. Representative responses of the students were as follows:

- "This project helped me understand the complexity of machining and how much potential there is for learning."
- "It forced us to think critically about what was going on in machining."
- "It gave us opportunity to research, build and run software. It made learning about machining meaningful."
- "Researching the different models gave me a better understanding of machining."
- "It helped me gain a more in-depth understanding."
- "Doing research actually made me think."
- "Talking to each other makes better understanding."

4.3 Assessment of students' teamwork and communication skills

Students' responses to Question 2 in Table 4 indicate that 85.8% of students 'agreed' or 'very agreed' that the team projects that they have done enhanced their teamwork skills. The students were asked what they had learned most from conducting the team projects. They responded:

- "[I learned] how to do effective research in a team working environment."
- "[I learned] how to work as a team."
- "I learned a lot about tool wear because we all share our research."
- "Parallel work between team members was very useful."
- "[I learned] time management is very important."
- "[I learned] we must set deadlines and milestones in order to complete our project."

Students' responses to Questions 3 and 4 in Table 4 indicate that 81.0% of students 'agreed' or 'very agreed' that Tasks 1 and 2 enhanced their communication skills, and that 85.8% of students 'agreed' or 'very agreed' that Task 3 enhanced their communication skills. The students were asked to describe the most frequent way in which they used to communicate among team members. 52.4% of students indicated that they primarily used emails. 42.6% of students primarily used face-to-face meetings. 4.8% of students primarily relied on telephones. Students were also asked how many times they had met with at least one other team member for at least half an hour to discuss the project results and progress. 19% of students indicated that it was less than four times; 47.6% of students four to six times; 9.5% of students seven to nine times; and 23.8% of students more than ten times.

4.4 Assessment of students' business knowledge and entrepreneurship

Students' responses to Question 5 in Table 4 indicate that 81.0% of students 'agreed' or 'very agreed' that their business knowledge was improved by developing a business plan in their projects. The students were asked to describe what they had learned most from developing a business plan. Representative student responses are as follows:

- "I learned how to approach the average investor, business owner, and customer with the idea."
- "[I learned] how to compete against other companies and be competitive in industry."
- "[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."
- "[I learned] how to write a business plan and I have used this learning in my own personal business plan."

Students' responses to Questions 6 and 7 in Table 4 indicate that 90.4% of students agreed or very agreed that it is necessary and important to integrate entrepreneurship into manufacturing engineering education, and that 81.0% of students agreed or very agreed that a team project with entrepreneurial activities is a good addition to classroom lectures. Therefore, it can be concluded that most students had a positive attitude toward entrepreneurship. In fact, 60% of students reported that they consulted with at least one industrial professional about how to bring their computer simulation program to the marketplace.

5. Discussions

This paper has presented a project-based active and collaborative learning approach to improving both the technical and professional skills of engineering students. The approach includes three integrated tasks where the students are developers and designers and not just simply users. 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. Each task has a set of sub-tasks that have been described in detail in this paper. Two representative examples of student projects have been provided to demonstrate what and how the students learned from their projects. How one can better prepare students for their projects is discussed below.

First, engineering students typically do not have essential knowledge on how to develop an effective business plan if they have never taken any business courses. Prior to this study, the author of this paper (i.e., the instructor) worked closely with an experienced business professional to bring one of the instructor's patents to the marketplace via extensive market analysis and customer interviews. This provided the instructor with a valuable experience in this aspect. Therefore, the instructor gave two lectures to the students on business plans and entrepreneurship, along with supplemental reading materials, to ensure the students have fundamental knowledge to complete the task related to business planning and entrepreneurship.

Second, "Machining Theory and Applications" is an upper-level undergraduate course. Prior to this course, the only relevant course that students took was a sophomore-year "Manufacturing Processes" course at the author's institution. The machining content covered in the "Manufacturing Processes" course was limited. Therefore, the instructor provided students with much instruction in the beginning of the semester to help students to identify a particular machining project on which to work. The instructor's quick response to students' questions is also very important to ensure that students can complete all the tasks by the end of the semester.

The present study has one limitation in assessing student learning outcomes. The present study involved only a single group of students and did not include a quantitative comparison between a control group and an experimental group. Therefore, it is unclear to what extent the project-based active and collaborative learning approach helps improve the technical and professional skills of engineering students. This limitation can be addressed in future work by randomly dividing students in the class into a control group and an experimental group. Both groups will learn the same machining topic but with different learning approaches. A comparison of learning outcomes between the two groups will reveal the effectiveness of the project-based active and collaborative learning approach.

6. Conclusions

The project-based active and collaborative learning approach has been successfully implemented in an upper-level undergraduate course "Machining Theory and Applications." Students' attitudes toward and experiences with their projects have been assessed using a set of Likert-scaled and open-ended questions. The assessment results show that 85.8% of students rated the overall experience with their projects positive or very positive; 85.8% of students 'agreed' or 'very agreed' that the team projects that they have done enhanced their teamwork skills; 81.0% of students 'agreed' or 'very agreed' that Tasks 1 and 2 enhanced their communication skills; 85.8% of students 'agreed' or 'very agreed' that Task 3 enhanced their communication skills; 81.0% of students 'agreed' or 'very agreed' that their business knowledge was improved by developing a business plan in their projects; 90.4% of students 'agreed' or 'very agreed' that it is necessary and important to integrate entrepreneurship into manufacturing engineering education; and 81.0% of students 'agreed' or 'very agreed' that a team project with entrepreneurial activities is a good addition to classroom lectures because it makes learning more meaningful.

References

1. F. J. Sanchez, F. Aparicio, M. A. Alvarez, and F. Jimenez, SAE formula project for developing personal and professional skills in automotive engineers, *International Journal of Engineering Education*, **25**, 2009, pp. 585–594.
2. Y. B. Moon, T. S. Chaparro, and A. D. Heras, Teaching professional skills to engineering students with enterprise resource planning (ERP): an international project, *International Journal of Engineering Education*, **23**, 2007, pp. 759–771.
3. S. H. Pulko and S. Parikh, Teaching "soft" skills to engineers, *International Journal of Electrical Engineering Education*, **40**, 2003, pp. 243–254.
4. E. H. W. Chan, M. W. Chan, D. Scott, and A. T. S. Chan, Educating the 21st century construction professionals, *Journal of Professional Issues in Engineering Education and Practice*, **128**, 2002, pp. 44–51.
5. Accreditation Board for Engineering and Technology, *Engineering Criteria 2000*, ABET, Inc., Baltimore, MD (2000), http://www.abet.org, Accessed 20 August, 2010.
6. J. F. Volkwein, L. R. Lattuca, P. T. Terenzini, L. C. Strauss, and J. Sukhbaatar, Engineering change: a study of the impact of EC2000, *International Journal of Engineering Education*, **20**, 2004, pp. 318–328.
7. SME Education Foundation, *Manufacturing Education Plan Phase III: 2001–2002 Critical Competency Gaps*, Society of Manufacturing Engineers, Dearborn, MI, 2003.
8. J. W. Thomas, *A Review of Research on Project-Based Learning*, The Autodesk Foundation, San Rafael, CA, 2000.
9. W. Pan and J. Allison, Exploring project-based and problem based learning in environmental building education by integrating critical thinking, *International Journal of Engineering Education*, **26**, 2010, pp. 547–553.
10. E. Iscioglu and I. Kale, An assessment of project-based learning (PBL) environment based on the perceptions of students: a short course case study on circuit design for VLSI, *International Journal of Engineering Education*, **26**, 2010, pp. 564–572.
11. M. Prince, Does active learning work? A review of the research. *Journal of Engineering Education*, **93**, 2004, pp. 223–231.
12. J. M. Acevedo, S. P. Lopez, J. S. Real, R. A. Santos, and M. S. Alvarez, Active learning approach for engineering in collaboration with the corporate world, *International Journal of Engineering Education*, **25**, 2009, pp. 777–787.
13. C. Bonwell, J. Eison, and C. C. Bonwell, *Active Learning: Creating Excitement in the Classroom*, *ASHE-ERIC High Education Report Series*, George Washington University, Washington, DC, 2000.
14. S. R. Turns, L. L. Pauley, and S. E. Zappe, Active and collaborative learning in a first course in fluid mechanics: implementation and transfer, *International Journal of Engineering Education*, **25**, 2009, pp. 979–997.
15. R. Salgado, N. Takeda, and N. Roffe, Interdisciplinary collaborative active learning: the "WOW"! factor for project oriented industrial design and electronic engineering courses, *International Journal of Engineering Education*, **25**, 2009, pp. 381–390.
16. W. Zhan and J. R. Porter, Using project-based learning to teach Six Sigma principles, *International Journal of Engineering Education*, **26**, 2010, pp. 655–666.
17. J. J. Marquez, M. L. Martinez, M. Rodriguez, and J. M. Perez, Simulator development for active learning of the fundamentals of plastic injection moulding, *International Journal of Engineering Education*, **25**, 2009, pp. 1176–1182.
18. N. Fang, G. A. Stewardson, and M. Lubke, Enhancing student learning of an undergraduate manufacturing course with computer simulations, *International Journal of Engineering Education*, **24**, 2008, pp. 558–566.
19. E. M. Trent and P. K. Wright, *Metal Cutting*, 4th edn, Butterworth–Heineman, Woburn, MA, (2000.
20. M. C. Shaw, *Metal Cutting Principles*, 2nd edn, Oxford University Press, London, UK, 2005.
21. T. A. Litzinger, S. H. Lee, J. C. Wise, and R. M. Felder, A psychometric study of the index of learning styles, *Journal of Engineering Education*, **96**, 2007, pp. 309–319.
22. R. M. Felder and R. Brent, Understanding student differences, *Journal of Engineering Education*, **94,** 2005, pp. 57–72.
23. N. Fleming and D. Baume, Learning styles again: VARKing up the right tree! *Educational Developments*, **7**, 2006, pp. 4–7.
24. Dethomas and S. Derammelaere, *Writing a Convincing Business Plan*, 3rd edn, Barron's Educational Series, Inc., Hauppauge,NY, 2008.
25. R. Abrams, *The Successful Business Plan*, 4th edn, Capstone Publishing Ltd., Chichester, UK, 2003.
26. S. K. Choudhury and K. K. Kishore, Tool wear measurements in turning using force ratio, *International Journal of Machine Tools and Manufacture*, **40**, 2000, pp. 899–909.
27. S. E. Oraby and D. R. Hayhurst, Tool life determination based on the measurements of wear and tool force ratio vibration, *International Journal of Machine Tools and Manufacture*, **44**, 2004, pp. 1261–1269.
28. T. Özel and Y. Karpat, Predictive modeling of surface roughness and tool wear in hard turning using regression and neural networks, *International Journal of Machine Tools and Manufacture*, **45**, 2004, pp. 467–479.
29. M. S. Won and C. K. H. Dharan, Drilling of aramid and carbon fiber polymer composites. *Journal of Manufacturing Science and Engineering*, **124**, 2002, pp. 778–783.
30. C. C. Tsao, The effect of pilot hole on delamination when core drill drilling composite materials, *International Journal of Machine Tools and Manufacture*, **46**, 2006, pp. 1653–1661.
31. E. Isakov, *Advanced Metalcutting Calculators & Engineering Formulas for Metalcutting*, Industrial Press, New York, NY, 2005.

Ning Fang is an Associate Professor in the College of Engineering at Utah State University, USA. He has taught a variety of engineering courses such as metal machining, design for manufacturing, and engineering dynamics. His areas of interest include computer-assisted instructional technology, curricular reform in engineering education, the modeling and optimization of manufacturing processes, and lean product design. He earned his PhD, MS, and BS degrees in mechanical engineering and is the author of more than 60 technical papers published in refereed international journals and conference proceedings. He is a Senior Member of the Society for Manufacturing Engineering and a member of the American Society of Mechanical Engineers. He is also a member of the American Society for Engineering Education and a member of the American Educational Research Association.