2006-276: INTEGRATING PROFESSIONAL AND TECHNICAL SKILLS DEVELOPMENT IN TOOL DESIGN COURSE FOR MANUFACTURING ENGINEERING TECHNOLOGY CURRICULUM

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Integrating Professional and Technical Skills Development in Tool Design Course for Manufacturing Engineering Technology Curriculum

1. Introduction

Engineering educators are challenged to develop engineering students' skills and knowledge on new technical areas and non-technical areas such as teamwork, communication and lifelong learning. One possible and feasible approach is to address those professional life skills via targeted content in engineering applications courses [1]. This approach was chosen in reforming the tooling design and measurement course for manufacturing engineering technology (MNET) students at the South Dakota State University (SDSU).

Subjects in the course include jigs, fixtures, molds, tools and dies in various production settings, material selection, precision machining, manufacturing inspection equipment and techniques, dimensional metrology and geometric conformance. WebCT courseware, an environment for developing web-based educational activities and materials [2], was used to supplement lecture material, lab projects, homework, and enhance communication between the instructor and students.

With the reform effort, students developed professional non-technical and technical skills simultaneously in an integrated mode. The concept for this approach was based on the notion that technical information and new knowledge acquisition can be achieved in both formal and informal modes [3]. Formal learning experiences occur in lectures delivered by the instructor while informal learning is obtained through the self-directed and team-based projects with appropriate instruction. Professional skills including communication skills, teamwork skills and lifelong learning skills were integrated with up-to-date technical skills development in laboratory-rich and hands-on projects.

The course exposed students to a team-based and project-oriented cooperative learning environment. Students were placed in teams of three or four for each project. Teamwork principles were introduced at the beginning of the semester. Team progress reports, final reports, oral presentations, and student written operations manuals for the lab equipment provided students opportunities to improve technical oral and written communications skills while carrying out challenging technical tasks. This paper describes projects where students practiced lifelong learning skills including locating, seeking and understanding new information with self-directed and team-based cooperative learning approaches. Promoting self-directed learning activities could lead to the successful assimilation and cultivation of lifelong learning skills. Self-directed learning activities also make students have an intrinsic belief that one is responsible for one's own learning [4].

The current MNET curriculum produces manufacturing technology program graduates that are not as strong in understanding the overall methodology of design as expected. This has been a shortcoming identified in our outcomes assessment data as indicated by results on the Society of Manufacturing Engineers Certified Manufacturing Technologist (CMfgT) exam and other program assessments. It is important for MNET students to be able to develop and design tools and processes and to function as a liaison between design engineers and the production floor. Our goal in this course was to address the MNET students' knowledge gap in applied manufacturing design.

With much importance being given in the manufacturing environment to concurrent engineering, design for manufacturability (DFM) was introduced in this course to prepare students for industry careers [5]. An understanding of DFM principles and methods can help students understand the importance of an integrated approach to design and manufacturing. It would enable them to contribute to or lead in implementing DFM in industrial practice. computer-aided engineering (CAE) tools, such as finite element analysis (FEA) and simulation, play an important role in the integration of product/tool design and manufacturing to which manufacturing engineering technology students are not commonly exposed[6][7]. Basic FEA concepts and machining process modeling with FEA were added into this upper level manufacturing course and enabled students to make the connection among physics, static/dynamics, and material courses in the curriculum in an integrated learning environment.

Knowledge on new technologies including FEA and DFM were covered in this course. Projects utilizing emerging technologies such as cutting process modeling with FEA, CNC (computer numerical control) verification with VeriCut® software helped students "recognize their need for an ability to engage in lifelong learning", which is emphasized in Accreditation Board for Engineering and Technology (ABET) criteria [8].

This paper will describe how new lecture material and projects were used in the course in detail. The course outcomes from student surveys and students' final project reports are also provided in this paper.

2. Team-based projects integrating technical and professional skills development

The three credit Production Tooling Methods and Measurement senior-level course includes two one-hour lectures and two one-and-half-hour laboratories per week during one semester. The syllabus covering course objectives, projects, and grading methods presented at the beginning of the semester included the following competencies:

- Demonstrate the theoretical and practical knowledge required to develop, design, select, and justify tooling that will produce high quality manufactured products economically, reliably, and quickly.
- Demonstrate the theoretical and practical knowledge required to measure precision part parameters and propose appropriate corrective action.
- Demonstrate communication skills with respect to the ability to define a project, support choices made in the decision stage, and clearly communicate the parameters of a design to the professor and, in the future, to workplace peers.
- Identify appropriate information sources, assess validity, and integrate information sources in the design of tooling.
- Demonstrate the ability of self-directed learning for life-long learning.

- Form a team, create goals, effectively measure attainment of those goals, and learn from others in a cooperative learning environment.
- Understand basics of GD&T (geometric dimensioning and tolerancing), FEA and DFM.

Basic teamwork skills introduced during the first lab included:

- Everyone contributes and helps each other.
- Everyone listens to others with care.
- Encourage everyone in the team to participate.
- Praise helpful actions or good ideas.
- Ask teammates for help if you need it.
- Check to make sure everyone understands the project goal and problems existing in the project.
- Stay on task with your team and follow the time table.
- Divide work fairly and do not be unfair, such as changing team meeting recorder, reporter, or even team leader over the project.
- Criticize ideas without criticizing people.
- Differentiate where there is a disagreement within the group.
- Integrate a number of different ideas into a single position.
- Ask for justification for a member's conclusion or answer.

Those teamwork skills shown in team progress reports, final reports and presentations were reflected in teams' and team members' grades. Learning attitudes reflecting life-long learning skills such as hard-work and desire for learning were emphasized in the course, which was graded at 10% of the total grade and graded at 15% for projects. Some achievements listed in the syllabus included technical skills such as better usage of Computer Aided Design/Computer Aided Engineering/Computer Aided Manufacturing (CAD/CAE/CAM) software, CNC machines operation, and DFM/FEA knowledge and application, and professional life skills including teamwork, life-long learning and communication skills. The total points in the course were 600 points and points for projects were 250, about 40% of total points.

During the first week, students organized into three projects at their will and interest and one process report was submitted at the end of week to describe their project objectives, plans and work distribution among team-members. Those first-round projects shown in Figure 1 were completed in about 8 weeks. One team elected to operate the HAAS CNC machine and produce 3 coasters, and then create an easy-to-follow operation manual for using the HAAS to machine the coasters based on their machining practices and a pre-existing operation manual prepared by the instructor. The second team built tool path models for the HAAS VF-1 machining center using VeriCut CNC verification software and virtually machined the coaster. The third team investigated the effect of cutting speed, depth of cut, feed-rate, and various tool/work-piece material combination on cutting forces and temperature by using AdvantEdge® commercial machining modeling software. The three teams were individually named as HAAS team, VeriCut team, and AdvantEdge team. The processes of self-directed inquiry, which are important for developing life-learning skills, were required for students to complete those challenging tasks. Students worked hard during lab time in order to finish projects on time. Teams also arranged time outside of assigned labs to meet and work on projects.

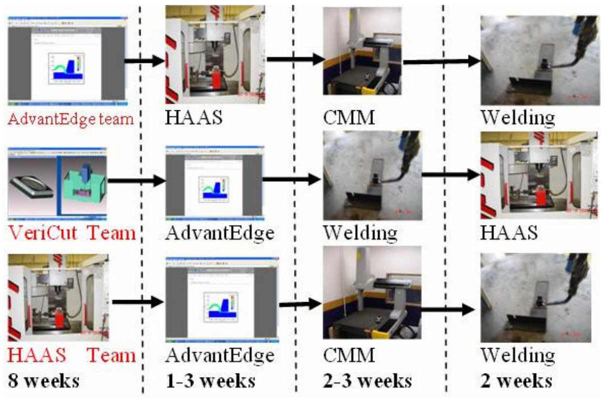


Figure 1. Projects and teams' schedules

Weekly process reports for every project were required to make sure that each team could follow the planned schedule and practice time management skills and written communication skills. Each team reported their work distribution among team members: what had been done in the previous week, and what would be done in the coming week. The instructor discussed outcomes with each team based on the progress report and gave advice if necessary.

In the final report for the first half-semester and in 15 minute presentations, each team was asked to describe the project objectives, methods and activities to achieve these objectives, project results, knowledge and skills obtained or improved, and work distribution. In the reports and presentations, all teams believed these projects improved their technical and professional skills and, as such, would help them in their future career related to manufacturing. "This project forces you to work with group members and get things accomplished on time…" as stated in one team's final report.

After midterm, the student teams moved to short-term second round projects. To make sure every student had opportunities to attain similar technical skills practices in the course, teams swapped projects every two or three weeks, as shown in Figure 1. These projects included: investigating the process to turn AISI 4340 hardened steel with process modeling software, operating welding robots; reverse engineering via coordinate measurement machine (CMM); and CNC verification and machining with the HAAS VF-1 machine. When one project was completed, the team moved to the next project. One final report was also required to describe project activities and results, team work, the skills and knowledge obtained from the project.

Students worked in one cooperative learning environment for all projects in which they were forced to learn by themselves, and also learn from all other classmates. Each team was supposed to learn through operation manuals for the HAAS, CMM and welding robot that had been written/modified by other teams and then subsequently update the manual with their newly developed practices. Students received extra points for helping others as observed by the instructor. For instance, the team working on machining process modeling during the first-round project helped other teams to use the AdvantEdge software; the team working on HAAS modeling in Vericut helped other teams to verify CNC codes for machining coasters; and the team who had first machined coasters helped other teams on their respective CNC machining projects.

The following sections provides descriptions of the student projects to illustrate how the course was used to improve students' technical and non-technical professional skills simultaneously in a team-based cooperative learning environment.

Machining process modeling via commercial FEA software

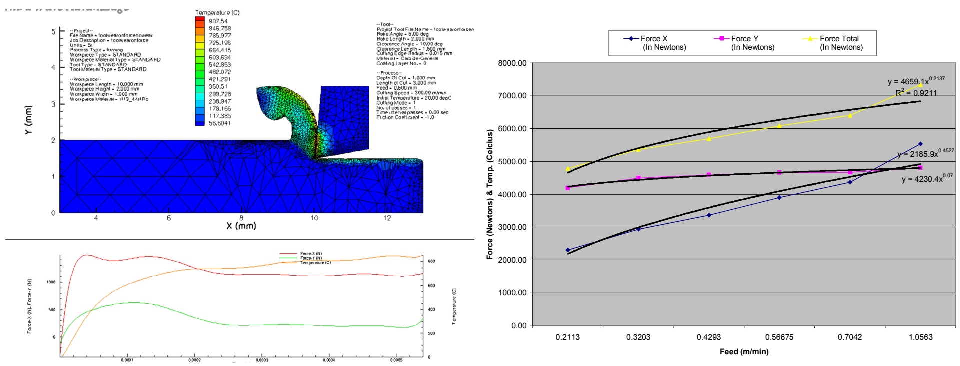
The first team was asked to investigate the effect of cutting parameters and cutting tool material on cutting force and temperature as covered in lecture and in the textbook[9]. AdvantEdge software was developed to determine machining parameters and tooling configurations that could reduce cutting forces, temperature, and part distortion - all offline. The instructor demonstrated how to use the software at the beginning of the project. The team was given the software manual and students were expected to solve problems in this challenging project by themselves with limited guidance from the instructor.

Students were able to figure out how to shorten simulation time such as submitting batch jobs instead submitting jobs one by one. Students learned how to design numerical experiments to determine relationships between forces and feed-rate, cutting speed, and depth of cut. The team sought information from the instructor and technical reference literature on appropriate cutting parameters. They also learned through failures and mistakes. At first, they submitted hundreds of simulations for each tool/work-piece material combination instead of more appropriate numbers of experiments based on rules in Design of Experiments (DOE)[10] to determine expected power equations[9] between cutting forces and cutting parameters. They wasted much time and, in response, the instructor revised some project requirements. Initial meaning-less file names for simulations also caused the team much difficulty in figuring out what cutting parameter combinations had been implemented and what cutting parameter combinations should be run next.

The results from this guided trial and error approach was noteworthy and the team was encouraged to write a paper for publication in the SDSU Journal of Undergraduate Research and present their research at the Undergraduate Research, Scholarship, and Creative Activities Day on campus. In preparation for their first 'publication' the students located information related to process modeling and material properties from the Internet, library, local companies, and the instructor. They were able to assemble, process and communicate this new information for the paper, a successful outcome for the course and program assessment[11].

These projects on machining process modeling with FEA improved undergraduates' research experience and, thereby, the learning outcomes of the curriculum. Education through applied research is an increasingly popular and effective learning method for undergraduates.[12] It is important for faculty to help undergraduates grow as researchers and make the connection via inquiry based learning for the life-long learning skill development.

During second-round projects, the other two teams had opportunities to use the AdvantEdge software in studying hard turning AISI 4340 (560 Bhn) with cubic boron nitride (CBN) tools at various cutting speeds and feeds. They were also required to submit final reports including narrative, results in spreadsheet format, and simulation files. Figure 2 shows some turning process modeling results with the software AdvantEdge.



a) Process modeling results b) Relationship between forces and feed

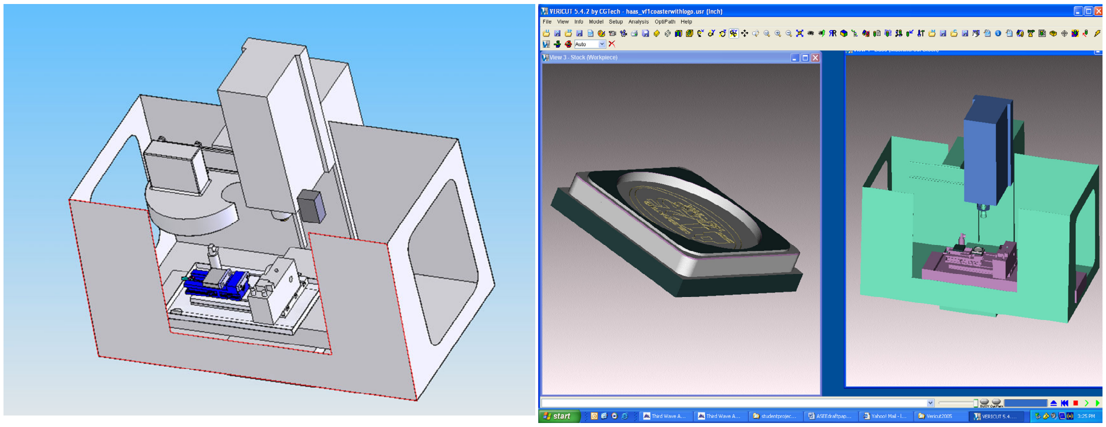
Figure 2. Turning process modeling with FEA

3-axis CNC verification with VeriCut

VeriCut is powerful CNC verification software, which detects errors and inefficient motions in CNC programs. It is a very desirable teaching and learning tool for the manufacturing engineering technology program [13]. In another course named CAM/CNC programming, students in the VeriCut team had already received basic VeriCut training.

In this project, the team were asked to build a HAAS VF-1 tool path model for CNC verification. They checked existing models, built the model of the coolant output on the z-axis, built the model for the tool change carousel, built models for tool holders, completed the whole machine model in VeriCut with STL or IGES files transferred from 3D software, and implemented the verification and simulation with input from the HAAS team.

The team had difficulty in transferring SolidWorks models to VeriCut at the right position. The problem was solved by using IBM/CATIA V5 to make machine home the same as coordinate zero in software. Figure 3 shows models and the part used in VeriCut.



(a) SolidWorks model (b) the virtual part(c) the Vericut model

Figure 3. HAAS VF-1 machine model completed by the VeriCut team

The team for the project stated in their final report that "…*We compiled a workable file collection and successful code run. Our final setup [filled] most of the deliverables. We learned how to better operate the given software more efficiently. We discovered new ways to work effectively within a time frame, make the most of our mistakes and organize task as a project group*".

3-axis CNC machining

This project required students to machine coasters with an SDSU 125th Celebration logo on it. Students in the course had not used the HAAS machining center before. Several short instructions on the machine were given during lab time. The materials used for machining were 4.2 long, 4.2 inch wide and 1 inch thick aluminum blanks and oak wood blanks. The team prepared all documentation including tools, fixture, and programs to enable a new operator set up everything quickly (30-60 minutes) by following their instructions. One easy-to-follow operation manual for the machining center was modified by the team based on the experiences from the project. Figure 4 shows coasters machined by the team.

a) Maple wood b) Aluminum

Figure 4. Coasters with SDSU logo machined by the HAAS team

In the final report, the HAAS team stated: "…*The knowledge we [gained] on this project will help us in the manufacturing industry no doubt. [We] would assume that the HAAS machine, …, is widely used in manufacturing items of all sorts. [We] have even seen a HAAS machine on "American Chopper" a TV program on the Discovery Channel. We also learned how to determine the offsets and zeros of the part that we were running*."

During the second-round projects, the other two teams were asked to follow the operation manual modified by the HAAS team, and further modify the manual based on their experiences. One team was required to use a flat end mill to engrave the logo instead of a spot drill. Another team was required to use thinner polymeric material to machine the coaster with a new clamping method.

Reverse engineering via CMM

This project was a new project in the second–round projects. This project required the students to use a non-automated coordinate measurement machine (CMM) to gather data points to create a reverse engineered model from any object of their choice. As shown in previously in Figure 1, the first team for this project moved from the HAAS application to the CMM application. In two weeks, the team had figured out how to set up the CMM probe, inspected a coaster they had machined from the earlier project and built a model from measurement data. They also wrote a simple operation manual for the CMM. Another team modeled the computer mouse shown in Figure 5 with the CMM scanning function. The third team had planned to reverse engineer a ball end mill, but they encounted problems in the earlier assignment when they had difficulty machining coasters from the polymeric material.

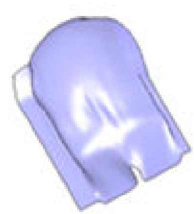


Figure 5. Computer mouse model built with CMM data

Welding via welding robots

This project was another new project for the second–round projects. The first team moved to robotic welding from the VeriCut assignment. In two weeks, they learned how to do a simple program to have the welding robot weld one straight line shown in Figure 6. a). They also wrote an easy-to-follow operation manual for other teams. As shown in Figure 6. b), another team welded two steel plates together at right angles after building a simple fixture. The third team welded one square tube on one piece of steel shown in Figure 6c.). Every team was required to write and/or modify the robotic welding operation manual.

a) Straight line b) two plates with right angle 3) square tube

Figure 6. Welding examples finished by three teams

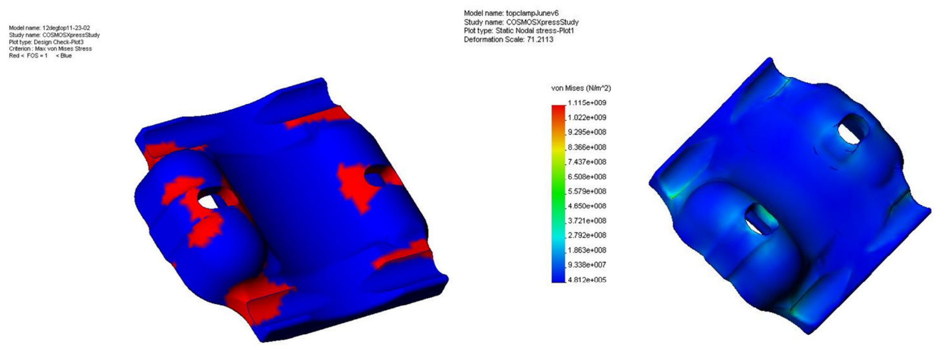
3. New material including FEA and DFM to address students' knowledge gap in design

Engineering design and manufacturing technology traditionally have been two discrete areas of learning. The existing curriculum in manufacturing engineering technology had identified weaknesses in understanding the broad concepts of the methodology of design. This had been a shortcoming in outcomes assessment as indicated by results on the Certified Manufacturing Technologist exam. The knowledge gap was critical to successful functioning of concurrent design teams where manufacturing engineers must contribute to design efforts and mechanical engineers collaborate with them on their designs [14]. To address the knowledge gap in design, new curricular material related to design including DFM and FEA were added to this course.

To introduce the topics, videos on DFM from SME and lectures on economics of design, manufacturing process capability, and design to machining were used to address this program learning objective. Students performed manufacturability analysis at the early tooling design stage. They made appropriate manufacturing process plans based on design specifications by performing manufacturability evaluations. Students extended their design knowledge and skills in fixture and inspection gage design and projects with solid modeling CAD software.

The basics of finite element analysis (FEA) were also covered in the course. During lecture time, the following contents related to FEA: basics of FEA, steps in FEA, the mathematical model for FEA, and analysis of results. Students become aware of FEA capabilities for analysis in tooling design and were encouraged to continue exploring applications for this subject. As described in the previous section, a commercial FEA manufacturing process modeling software, AdvantEdge, was used for demonstration and project assignments. This also addressed the ABET outcomes criteria a) familiarity with modern engineering tools [7].

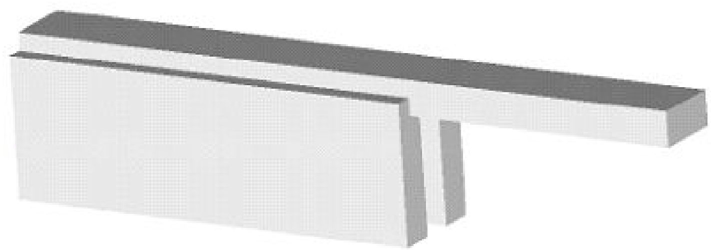
One actual industry application project was covered using the commercial FEA software Solidworks/COSMOSWorks in the class. To redesign lighter and stronger top clamps used in mountain bikes, finite element analysis was used, shown in Figure 7. The new part is about 30% stronger and 10% lighter than the original part design.



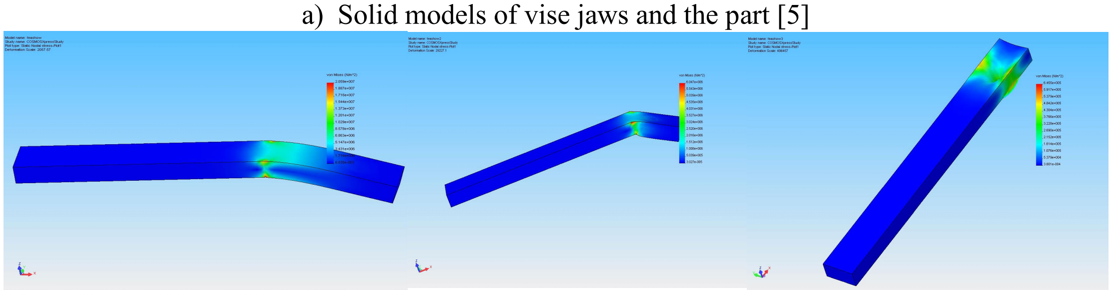
a) Part before redesign b) Part after redesign

Figure 7. Use FEA to design stronger and lighter mountain bikes

Another simple example was modified form Prof. Waldrof's CAE computer exercises used in his tool design course [5]. A hole was drilled at the right side of a piece 9" long steel stock, which is clamped by jaws in Figure 8.a). FEA results were shown in Figure 8.b), c) and d) for clamping the part at different position with 6" standard vise jaws.



a) Solid models of vise jaws and the part [5]



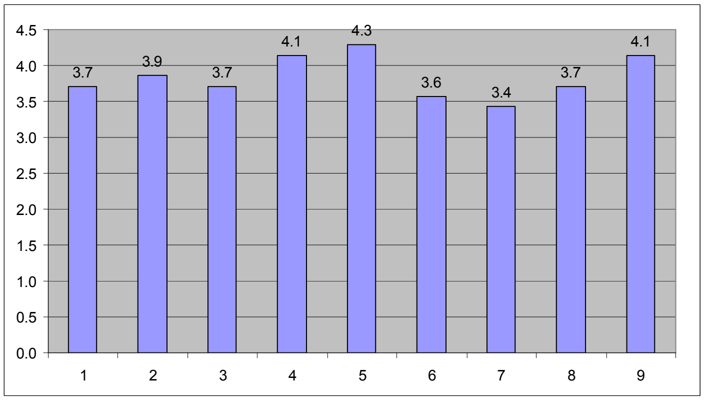
b) clamp part at left side c) clamp in the middle d) clamp at right side

Figure 8. FEA results for clamping a part at different positions

3. Assessment and Conclusions

Two reform efforts were implemented in the senior tooling design course for manufacturing engineering technology students. New design and analysis tools including FEA and DFM were added to address manufacturing students' knowledge gap in design applications. Team-based and self-directed projects integrated technical and professional life skills development.

Through projects, students understood their learning continues beyond the classroom or lab. They also have practiced self-learning and learning from others including team members and colleagues in a cooperative learning environment. Most students were motivated to solve problems in projects actively and by themselves. In observation by the instructor, there was a shift from their previous mindset which was to wait for instructions or assistance when they had difficulty in lab exercises or projects. In a separate assessment of student perceptions of the course and what they had learned, the instructor was able to gather feedback on the course. As shown in the Figure 9, most surveyed students believed they improved their professional skills and technical skills through the course. They would like to continue learning design and new technologies in manufacturing.



1-5 scale, 5 stands for highly agree with the survey question:

1 improve teamwork skills in projects
2 communication skills developed for my career
3 Divide work fairly in team
4 General rate about your team
5 DFM useful for my career.
6 FEA useful for manufacturing career
7 Like to Add new stuff into course
8 Improving our communication skills
9 Like to continue learning out class and lab

Figure 9. Survey results about skills development

There were several challenging issues that need to be addressed in the next revision of the curriculum. These included:

1. Using a 'real-world' time sensitive, results oriented pressured approach may bring resistance or even cheating by some students. This approach is tempered by the fact that most students are employed more than 20 hours per week in addition to their academic work.
2. Some students tended to criticize software, hardware and even instructional approaches instead of being proactive and solving it when they had problems in learning and using new software or technology.
3. Some students just want good grades without much work and they do not care about skills improvement and knowledge obtained from the course except the grade. Finding the best personal motivator is a challenge educators and employers alike. [15].
4. The need to improve life-long learning skills including self-directed study should be emphasized more through the whole program and throughout university education.

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