Job Readiness through Multidisciplinary Integrated Systems Capstone Courses

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Abstract

Industry wants job-ready engineers from day one. A panel of industry partners pointed out six qualities expected of recent graduates. These engineers need to adopt an enterprise-wide ***integrated systems approach*** from product conceptualization to realization. They need to work closely with engineers from different disciplines while maintaining their own technical expertise. ***Leadership***, ***conflict resolution*** and ***inter-departmental collaborative*** skills are consequently very crucial in an integrative environment. No company can sit on its laurels. Change must happen and change is good even though there is constant resistance to change. These young engineers need to ***think out-of-the-box to be innovative***, and become ***effective change agents***. To address these needs, Kettering University is initiating an effort to establish an interdisciplinary, enterprise-type integrated capstone course that encapsulates students from all available engineering degrees – mechanical, electrical, computer, and industrial with or without a manufacturing option, plus business students. As in industry, students concentrate on tasks corresponding to their own disciplines while multitasking with a number of cross-functional activities. Effective and efficient communication skills and team dynamics are essential. They will work on one product, separating the engineering challenge into modules of various tasks in design, manufacturing, facilities planning and business functions, each task managed by a sub-team. A case study will be presented. As a result, students not only synthesize what they have learned but also apply what they have gained: teamwork experience, collaborative finesse, ability to comprehend the global picture of engineering, the urgency to be innovative, and the drive to become effective leaders. The university gains a better reputation and strengthened bonds among departments.

Introduction

Today's work environment demands that engineers be trained in multidisciplinary areas and team-oriented leadership. Industry and Academia must collaborate to expand students' experience otherwise companies will have to assume the costs of on-the-job training. Many universities provide engineering students with adequate skills and qualifications through their interdisciplinary capstone courses. For example, the capstone design course in the Cullen

College of Engineering at the University of Houston taught students to function in multidisciplinary teamwork by involving the Electrical and Computer Engineering (ECE), Industrial Engineering (IE), and Mechanical Engineering (ME) departments.[1] Similarly, the Kate Gleason College of Engineering at the Rochester Institute of Technology offers a multidisciplinary design in the senior capstone course taught by the Electrical, Industrial, and Mechanical Engineering departments and plans in the future to involve the College's other academic disciplines -- Computer Engineering and Microelectronics Engineering. Their mission is to develop engineers who have an end-to-end life cycle perspective of product realization. Their main components of this multidisciplinary capstone course are problem solving, teamwork, market-oriented product development, and technical communication.[2]

A group of universities including Georgia Tech and PTC of Needham, MA, founded the Product Lifecycle Management Center of Excellence at Georgia Tech to develop a paradigm of fostering multidisciplinary product development in an academic curriculum.[3] Their 2002 experiment involved students from multiple schools and many disciplines collaborating virtually over a two-year period to deliver a product design. Dennis and Fulton reported a pilot program conducted by students and faculty at Georgia Tech and the University of Maryland College Park during the spring semester of 2003. This pilot program introduced a 2-year capstone - Distributed Collaborative Product Development – a project with Mechanical Engineering students from Georgia Tech, University of Maryland and University of Illinois Urbana-Champaign collaborating to design an amphibious utility vehicle for the John Deere Corporation. They plan to involve students from Industrial Design, Manufacturing, Business and other disciplines in the future.

There are many other universities that educate their engineering students in multidisciplinary areas by introducing new courses. However, literature is lacking that shows the work of universities in multidisciplinary areas using their existing courses. Integrating existing courses offered by different departments to provide students a multidisciplinary experience is a new step that Kettering University faculty have recently taken. Traditionally, at Kettering University, each department conducts its own capstone experience within the confines of the discipline. In the last few years, a few engineering faculty members from ME and Manufacturing programs at Kettering University have been cross-training engineering students from Manufacturing and Mechanical engineering programs to work as interdisciplinary teams. For example, (1) Robotics and Machine Components Design (MCD) courses had a common project in designing, fabricating and implementing a robotic gripper in the assembly of flashlights;[4] (2) Automation and Design of Experiments had a common project in designing the experiments to produce machining parameter values for the best quality of a turned workpart. (3) An automotive capstone was integrated with the Computer Integrated Manufacturing course and the students worked on the design and production of a wheel hub used in the SAE Formula Race Car. A third course was integrated with this project when the components were "farmed out" to the Finite Element Course for analysis[5].

This paper describes a structured management approach that a group of faculty developed for a 4-way integrated project for IE/Mfg Senior Design Project, ME Automotive/Machine Components Design, Computer Integrated Manufacturing (CIM) and a junior level Machine Components Design (MCD) Course. This project involved two (ME and IE/Mfg) programs.

Integrated Capstone Design Educational Process Flow

In order to have some commonality among seemingly disjointed courses, the integration process requires a set integrated capstone process. It should provide a structured approach to project management and integrated product design while allowing students to find creative solutions to the design problems in their own discipline. The primary process is described below. Each course has its adaptation to the technical topics. However, the managerial and social aspects remain common.

Kettering University has a unique schedule of alternating academic and co-operative work terms. Due to this schedule, the courses are eleven weeks in length. The courses included in this integration were offered two days per week with 120 minutes each session. Starting with week one, lectures on team dynamics, team formations criteria, and industrial work-environment skills are conducted. Students select their teams based on the given criteria, with the following two main objectives:

1. Ability to work together
2. Technical complements for each other

To be technically complementary, the teams were formed across disciplines with team members representing all the different participating specialties. After team formation, students received lectures on brain storming skills and creativity as a right brain activity, on both an individual and team level. The key for successful brain storming sessions is to suspend judgment and allow creative ideas to flow. After brain storming the students prepare a list of potential projects. From the list of projects one is selected based on the following criteria:

1. Originality and creativity
2. Enough work for all the team members
3. The ability to deliver desired results within class time frame.

In the second and third weeks lectures included the topics: the design process, project selection and planning, bill of product, product attributes, project management, proposal writing and presentation. Additional lectures relating the product attributes to the design criteria and engineering targets were given next. Finally, at the end of the third week, the topics of the proposal development and delivery of class were covered.

The proposal developed by each team and the project management chart become the road map for the team for the rest of the term. The concepts of design construction, design development and simulation methodology, analytical simulation, design synthesis and optimization, safety, ethics, and social and political implications to design decisions were covered in the week four to week seven timeframe. The design construction, analysis and simulation of work are also taught during these four weeks. The Bill of Materials is populated during these four weeks for the progress report due at the end of week seven.

From weeks seven to eleven the students learn about manufacturability, bill of process development, variation, quality, reliability and product life cycle, and design validation. During this period the Bill of Process is developed, populated and the design project is finalized. These activities culminate into the final report and presentation during the eleventh week. The educational design process flow diagram is presented in Figure 1.

As shown by the educational design process flow diagram, the process is tailored around an industrial based design process. The educational process starts by covering an important but absent aspect of engineering education: the relationship between engineering requirements or targets and the desired final product and its attributes. The flow down of attributes defined in the end user domain to design criteria defined in the engineering domain from which a set of targets are derived for analysis and simulation is the key for any successful product design and educational effort.

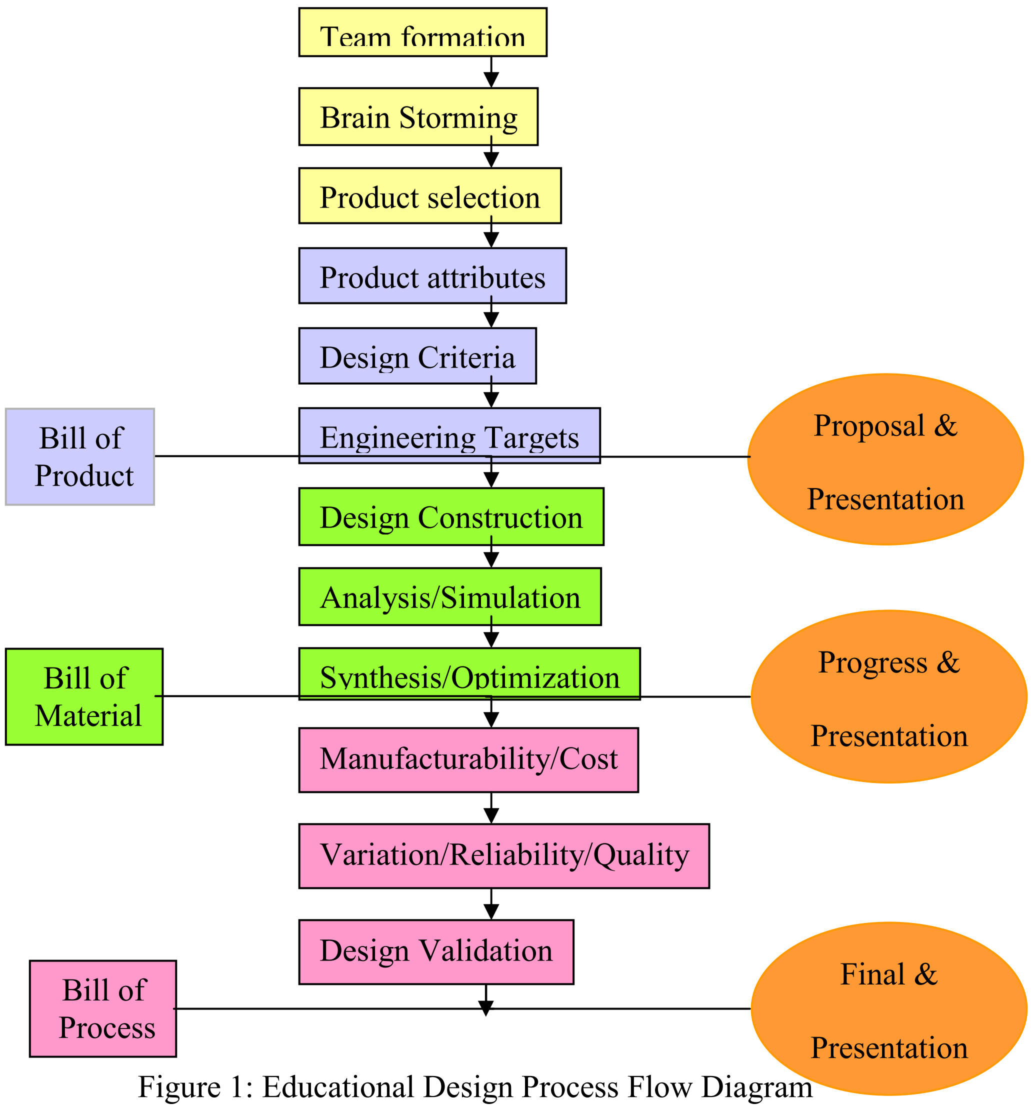


Figure 1: Educational Design Process Flow Diagram

After identifying the target for each attribute and ranking these targets according to a preset priority for each attribute the design construction, simulation, synthesis and optimization can be performed. The success in this stage hinges on the ability to perform representative virtual or physical simulations and choose the proper design alternative to achieve the desired attributes within the priority structure.

Prototyping the Integration Process with a Four-way Integration

The above integrated capstone process was prototyped successfully involving Machine Design capstone, automotive design capstone, industrial engineering and manufacturing capstone along with previously integrated CIM and junior level Machine Components Design classes at Kettering University. This is shown in Figure 2.

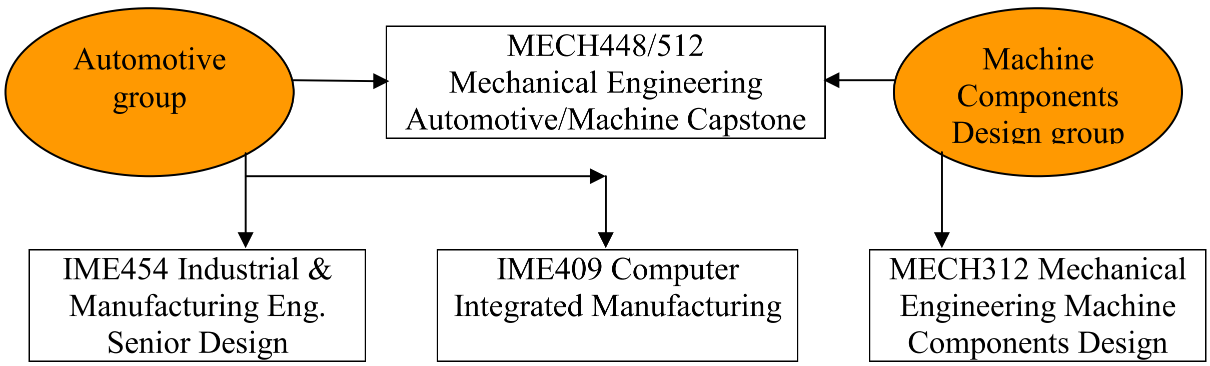


Figure2. 4-way Multidisciplinary Integration of Courses

The students had a structured approach to managing the project and integrated the steps in a product cycle while not being constrained in generating creative solutions to the design problems in their own discipline. It allowed students to use off the shelf technologies to focus their efforts on the needed components and simulations to achieve the desired product attributes. In the following, selected deliverables are presented to demonstrate the application of the integrated design capstone process.

Instead of offering one multidisciplinary projects course, which is administratively complex at Kettering University, a unique integration method was developed[4] to integrate students from different disciplines without major structural curricula changes. The secret is prior scheduling for common hours, collaboration among faculty, and planning.

The process for integration is to adapt the integrated capstone process to each course and follow these guidelines: (a) prior scheduling of a common class time (at least one hour per week) and planning for a multi-disciplinary project, (b) lecturing on team building and dynamics, organizational dynamics, brainstorming technique, and the six industry-desired young engineers' qualities, (c) students meeting as a team once a week in the first three weeks and as needed for the rest of the term, (d) sub-teams performing different disciplinary functions, (e) each sub-team working on their project reports (a proposal, an interim and a final). Each point will be addressed separately.

(a) Prior scheduling: arrangements are made two terms ahead of time to work with administration on class scheduling. The common class time is of utmost importance since it gives the team members time to meet. Large group meetings outside of the classroom are very difficult to arrange due to the students' busy schedules. Professors from each discipline are involved in creating and helping plan generic modules of a multidisciplinary project that start from product concept, continues through design, analysis, manufacture, workplace design, and operations planning (refer to Figure 1).

(b) Common lecture topics help students conduct effective multi-disciplinary teamwork. Topics on teamwork include team building skills and dynamics, organizational dynamics, creativity, and brainstorming techniques as described in the Integrated Capstone Process section. Lectures include the six qualities of job-ready, young engineers. They are inter-multidisciplinary integration systems, leadership, conflict resolution, inter-departmental collaborative skills, innovation, and effective change agents.[6]

(c) Students meet during the common hour to organize the project, define tasks, and modularize sub-projects, each with a specific disciplinary function. They share their knowledge and expertise in their subject matter during this planning phase.

(d) Sub-teams are formed to cover the defined modules, usually by discipline. They treat each module as a mini project defining its own mini-goals, objectives, and planned procedures with sequence of operations, bill of materials (BOM), material procurement, budget, and timeframe (Gantt chart).

(e) Report (proposal, interim and final) generation covers the events in (d), including what has been achieved to-date, what were the roadblocks, what are the expected problems and how they will be solved. All sketches, drawings, equipment layout, machine / robot programs, and purchase orders, should be included.

Student Project Description

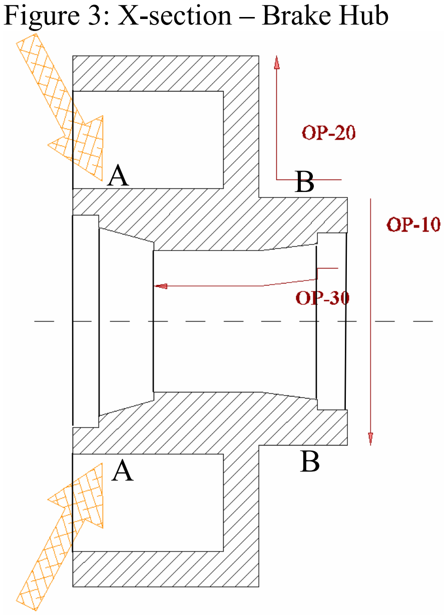
An example of cross-disciplinary integration is presented here. The primary purpose of this project is to enable all students involved to work on a multidisciplinary team with the goal of planning the manufacture of a part from concept to completion. Seven students from the IE/Mfg Senior Design course, five from ME automotive design capstone, seven from CIM, and five from MCD classes formed an engineering team for the multidisciplinary project. There were three students who were in more than one of the aforementioned classes. The students' co-op experience ranged from 1.5 to five years in various industries with the majority in the automotive industry.

CIM and ME capstone had two common hours on Mondays. Unfortunately, the IE's and MCD's did not enjoy the same benefits. The students from the IE capstone rotated their time to come to the project meeting on Mondays. They received some release time from their usual class time. The project is defined in form, but the content and product is open-ended. Since the ME capstone is automotive, the students have to design a vehicle. They chose to redesign a "Dream SUV". With limited time, students could make a small component that can be produced in the CIM Lab. They chose the brake hub.

After the initial lectures and team brainstorming, a brake hub was selected for production. The major modules for the project were: 1) engineering design for the brake system, concentrating on the production of the hub (ME), 2) automated manufacturing processes for the hub (IE/Mfg CIM), and 3) design of the workplace and workflow (IE). Sub-teams were thus formed by discipline. They met to discern what each module entailed, what the common elements were, and how information should flow from one sub-team to another. The design and manufacturing sub-teams used Design for Manufacturing techniques to finalize the hub design shown in Figure 3. Figure 3 also shows the machining operations OP-10 to OP-30. The next meeting was an interesting and critical information exchange since the manufacturing sub-team recommended a change in the design to streamline production by simplifying the fixturing on the lathe from two to one set of jaws. The design team then modified the diameter of the inner shaft (A in Figure 3) to match closely that of other end B, and analyzed that the reduced thickness was sufficient to sustain the forces. This type of Concurrent Engineering is exactly what needs to happen in industry. The ME sub-team interfaced with both the CIM and IE sub-teams to help IE layout the production shop floor and flow plans needed to assemble the brake system, and address the quality and ergonomic issues. The students cooperated fairly well with each other.

Within the sub-teams, each group was subdivided into sub-modules. ME students were divided into several groups. Two of those groups worked with this project. One of the groups worked with IME454 Senior Design Project and IME409 Computer Integrated Manufacturing students to design the hub. The other group worked with MECH312 Mechanical Engineering Machine Components Design students to study the transmission for the SUV.

Figure 3: X-section – Brake Hub



CIM students were divided into (a) a machining process group to ensure the integrity of the design and produce the process plan for turning the hub from a blank, (b) a robotic automation group for material handling from an input station with hub blank into and out of the lathe and back to the output tray (includes robotic fingers design), and (c) a fixturing design and fabrication group for designing a fixture for transporting raw material, the finished product and designing the chuck jaws on the lathe.

The IE/Mfg Senior Design Project course was the pin that joined the project together. Students in this class were provided with the challenge of integrating and synthesizing general engineering knowledge and creatively solving real world, open-ended problems in a team setting. Students started with doing theoretical research and communicated with other team members in order to learn what a disc brake system is and how it works. Students identified required processes for producing the part and evaluation of the current layout. They found several areas of potential improvement in the layout and then suggested updates. All safety issues and multiple ergonomic factors were studied. Since the current manufacturing process is automated, most of the safety concerns focused not on the production process, but on processes involved with periodic and emergency maintenance. Students dealt with Machine/Work Cell, Plant Environment, and Operator safeties. Furthermore, they performed a comparison analysis between returnable and disposable packaging of disc brakes. Finally, this group studied the quality assurance of the product and provided suggestions for tolerance, surface finish, and concentricity for manufacturing this hub.

The Machine Component Design (MCD) course involves application of theory and techniques learned in the mechanics courses to the concepts of mechanical component design. This methodology requires learning to develop and set-up a mechanical component design problem, properly understanding and solving the problem based upon the given data and design constraints, making and verifying assumptions. The main assignment of the MCD students was to analyze the transmission of the "Dream SUV." The assignment was challenging, because transmissions are complicated entities and slightly too advanced for the MCD students, and because of the severe lack of information on the transmission chosen. MCD students did not receive a print nor dimensions from the ME capstone students. After researching on the Internet, dealerships, mechanic shops, and even Chrysler, they had to reverse engineer one of the lab's rear wheel drive transmissions that was the correct size. Students also used the hp ratios to determine if they had overcome the built-in safety factor of the transmission.

The project was brought to fruition on paper during the last week. The SUV was designed, analyzed and simulated. Only one component, the brake hub, was used to design all manufacturing plans and processes (lathe programs and robot programs). Additionally, the workpart flow was designed, simulated and confirmed. Due to the shortness of the term, the special set of chuck jaws ordered did not arrive in time for the students to use it to produce the actual hub. The CIM students used their prior knowledge of lost foam casting to make aluminum hub blanks. The blank was pre-machined to a shape ready to be used as the raw part for the hub (see Figure 4). Robot gripper fingers were machined waiting to be drilled and mounted. AGV (automated guided vehicle) tray fixture was also built for transportation of the hubs (Figure 5).

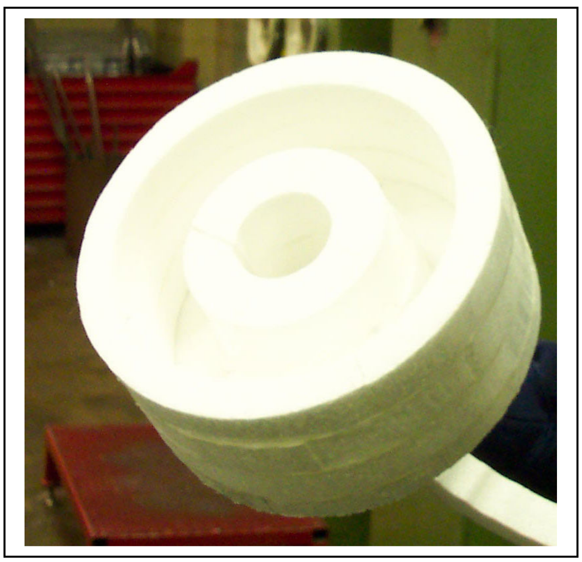


Figure 4: Roughed Aluminum Lost Foam Casting

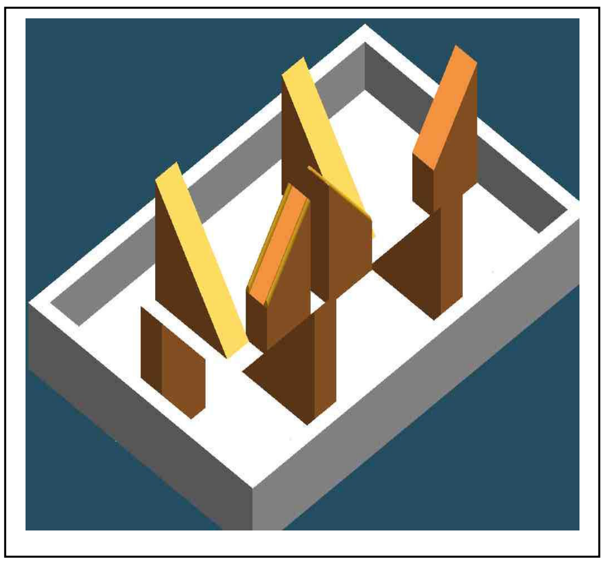


Figure 5: AGV Tray Fixturing

Evaluation Surveys and Results

To improve the project, data on observations and suggestions as well as identification of problems are collected. The effectiveness of the project is measured by evaluations and students' comments. At the end of the term, students were asked to respond to four sets of questionnaires. Namely, the End-of-Term Peer Teamwork Evaluation, Teamwork Self-Assessment, Team Evaluation, and a set of questions with comments. Each student was asked to respond to each of the questions in terms of whether they completely agree (C.A.), somewhat agree (S.A.), somewhat disagree (S.D.), or completely disagree (C.D.). The statements and students' responses are summarized in tables 1 through 4.

Team Participation -- Assignment Completion	**% Completely agree**
• Attends group meetings on regular basis	88%
• Initiates and maintains task-oriented dialogue	87%
• Works for constructive conflict resolution	81%
• Works to negotiate group consensus on important project issues	85%
• Supports other team members	89%
• Initiates and participates in group maintenance	86%
• Communicates with the group members effectively	87%
• Worked to define problem	88%
• Collected/provided data relevant to problem	86%
• Worked to generate solutions	88%
• Worked to document solutions	90%
• Performed assigned role effectively	90%

Table 1. Peer evaluation.

Overall, a high percentage of students completely agreed with respect to the questions related to their peers' team participation and assignment completion as shown in Table 1. Table 2 shows a similar conclusion can be drawn with respect to statements/perceptions when students evaluated themselves.

Statements/Perceptions	**% Completely agree**
I felt comfortable working with this team	94 %
I was an active participant in my team	94 %
I listened to everyone on my team	100 %
I encouraged and praised others on my team	100 %
I explained/helped someone who didn't understand	88 %
I asked for an explanation or help when I didn't understand	88 %
I felt encouraged by people on my team	88 %
I felt comfortable in my role as	94 %
I found the team activities to be a worthwhile experience	82 %
I believe that my team-working skills improved	82 %

Table 2. Self-evaluation.

With respect to the interdisciplinary team project special qualities required in industry, students varied in the type of skill. Table 3 shows the percentage of students that rated learning ratio equal or above 8/10. The results indicate that these qualities are quite foreign to the students. More work needs to be done to introduce the students to these aspects earlier in their student career.

Special Qualities Required in Industry	**% Scoring ≥8/10**
Leadership Skills	88%
Conflict Resolution	80%
Ability to act as a change agent	57%
Out-of-the-box thinking / Innovation	80%
Inter-Departmental Collaboration Skills	50%
Knowledge and Experience in System Integration	47%

Table 3. Students' responses/opinions

Most students had a good experience with their team members and teamwork (see Table 4).

Team Participation -- Assignment Completion	**% Completely agree**
• I felt encouraged by the people on my team	92%
• I was comfortable working with my team	92%
• I felt free for to do out-of-the-box thinking	100%
• I felt free to initiate & maintain task-oriented dialogue	100%
• I felt comfortable negotiating a group consensus	92%
• I felt the people on my team were supportive	92%
• I think the team defined the problem effectively	71%
• I think the team collected/provided relevant data	78%
• I think the team generated solutions effectively	85%
• I think the team documented solutions properly	85%
• I found the team activities to be worthwhile	57%
• I found no communication problem with the team	71%

Table 4. Team-Evaluation.

Some of students' comments with respect to the questions in Table 3 are as follows:

Leadership Skills:

- "I felt I had a leadership role in my group by giving ideas of how to proceed."
- "We definitely had to learn to take initiative to do the project."
- "Had to take initiative with projects and lead groups."
- "I believe just about everyone had the chance to perform a leadership role at some point in the project…., we became leaders for the day."
- "It gave us the responsibility to make sure everything was accomplished on time."

Conflict Resolution:

- **"**There were many problems with the project which caused conflicts that I learned how to solve."
- **"**We had to work out differences between ME needs and CIM capabilities."

- "We did not have a lot of conflicts, it was mostly combating apathy & ambivalence about the project."
- "Had to compromise on meeting times and distribute work evenly."

Ability to act as a change agent:
- "We were able to change print tolerances and diversions to accommodate mfg parameters."
- "Inherent in the project."
- "Matt & I worked together to re-design the part & CNC program as problems occurred."
- "We were able to change quickly if any issues came up."

Out-of-the-box thinking / Innovation:
- "We were forced to consider areas that we weren't familiar with and to look at new ways to produce it since most of the current methods were pretty antiquated."
- "Had to come up with ideas for improvements on previous group's ideas."

Inter-Departmental Collaboration Skills:
- "I communicated w/ both the IE & ME groups."
- "We worked together with IE capstone, CIM & ME capstone to overcome problems which arose such as casting quality, dimensions we changed and allowable tolerance…"
- "This project gave me my first chance to work with the other groups in the Department which was helpful."

Knowledge and Experience in System Integration:
- "Learned about brake systems & worked with other groups."
- "The group integrated the concepts of productions, quality, ergonomics, packaging and raw materials in a concise manufacturing plan."
- "It was difficult because there wasn't a general time to meet since all the classes had different meeting times."
- "We were able see and have knowledge of how the whole system (from ME to IE) works."
- "I have already done a few Robotic work cells this gave me another chance to apply the knowledge."

All four faculty members teaching the courses discussed their assessment of the efficiency of the students' learning experience. The multidisciplinary integrated System Capstone course is important and can be very productive if more detailed planning took place before students are ready for their projects. Having a dedicated part of the day at the University level for the Capstone course will help students' time conflict. Having examples of previous projects distributed and explained in the class on the first day will assist students in expediting their selection of project. Having information available, for example, Blackboard with access for all Capstone students will increase the level of communication and consequently increase the quality of their work. However since this was the first attempt at integration of two capstones and two other courses, there was no prior example to present. In the next attempt, the faculty will have more ammunition. The template developed previously for common interdisciplinary courses was not exactly applicable since in Capstone courses, project development is more intense and fast paced. Instructors discovered that the template needs to be modified.

Conclusion

The feedback from students indicates that the project works relatively well and has been tremendously successful, both in terms of student satisfaction and goal achievement. Goal achievement is evidenced by students' oral and written reports. The project has team members excited about working together. It helped students to understand that engineers from different backgrounds can work together and they can work together successfully and enjoyably. Every single individual of the group was such a diverse member of the team, which in turn, was very beneficial to their understanding of concurrent engineering. Students had a synergy among all of them. They all empowered and motivated each other and consequently they had an effective team. Their group was able to pull from each others strengths and in that essence, they were all willingly able to provide more to the group for the satisfaction that they got from their interactions. This is the exact thing Industry needs from interdisciplinary groups.

This project shows the students how important multidisciplinary teamwork is to the workplace. The application of Concurrent Engineering in design and manufacturing is an excellent example of the reason for avoiding late design changes or a design to reduce manufacturing lead time. The use of tolerance was another example that helped the students to realize how critical it is to assign reasonable tolerances based on the capabilities of the machines available.

We must train the next generation of engineers and scientists in multidisciplinary and team work environments if the United States is to keep its global competitive edge. The training can be initiated by offering projects similar to the ones the authors stated in this paper. This enables engineering students to do out-of-the-box thinking and increases both their leadership and inter-departmental collaboration skills. Students can then be more job-ready which in turn implies Industry will not have to assume the costs of re-training the fresh engineers in the field. Lessons learned from this prototype include (a) the necessity to have prior help from administration to schedule one common hour per week for the classes involved, (b) the need to have technical information transferred properly and in a timely fashion, (c) better established communication channels with instructors playing an intricate role in facilitation of opportunities, and (d) the need of special qualities required by industry to be addressed more in depth early in the course, or even earlier in the student's education. Kettering University is prepared to improve this process.

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Biographies

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