Interdisciplinary Integration of Courses – Automation and Design of Experiments

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Abstract *– Industries need engineers who are versed in streamlining processes from design to planning to manufacturing. Engineer with working knowledge of interdisciplinary concepts are very much in demand. A new initiative at Kettering has been established to cross-train students from different disciplines and different departments to work as interdisciplinary teams. A process for conducting a common project among two (or more) different courses had been established and an integration template was developed. This template was successfully implemented between Machine Components Design course (ME) and Robotics course (manufacturing). In this paper, the implementation of the template between Automation with Robotic/CNC course and Design of Experiments (DOE) course will be discussed. This marriage is an important step towards streamlining proper design and planning of the efficient production process that is an essential ingredient for manufacturing industry. The interdisciplinary teams had weekly common -hour class meetings as well as out-of-class meetings. A common lab project combining CNC and DOE was designed for the students to experience real world problem solving. The project investigated the surface finish of a machined part made under different parameters (in manufacturing engineering terms)/factors (in industrial engineering terms) including spindle speeds, feedrates, cutting depths, tool wear, and stock lengths. Using DOE, experiments were conducted, data collected and analyzed. The students drew conclusions from the data to determine the factors/parameters and/or combination of the factors/parameters that might significantly affect the part surface finish.*

The results of this integration showed that these students truly have a better understanding of other engineers' points of view, their languages, and technical terms. They are more well-rounded in knowledge, and they have improved people skills. This paper describes the results and implementation of the integration template. Student surveys and assessments are summarized. Students' reactions were very positive for such an integrative attempt.

Index Terms *–Interdisciplinary, Integration, Automation, Design of Experiments*

INTRODUCTION

Global manufacturing competitiveness demands production of any product to have the lowest cost, highest quality in the least amount of time. This spawns the necessity for streamlined processes from design to planning to manufacturing. Engineers with working knowledge of multi-disciplinary topics, who are strongly team-oriented, who have leadership qualities, are in demand. Most graduates are not prepared for such an environment. Current college engineering education systems deliver courses as disjoint units. Engineering students learn the course topics, but they seldom see how it is related to other fields. An approach to integrating engineering students' learning and knowledge and skills retained is presented. The authors and Mechanical Engineering professors at Kettering have established an ***integration template*** in integrating courses from different disciplines where students from two different classes conduct a common team project [1-3].

Only a few universities have created common classes involving general engineering courses combined with math, physics, communication or graphic arts [4-6]. Other approaches entail consecutive classes where one class of students utilize the reports of a previous class' work or team taught labs with instructors from different disciplines [7]. Integrating hard-core engineering courses are rare.

The procedure outlined in this paper involves two concurrent courses from different programs, forming teams with joint labs to complete a full spectrum DOE and manufacturing project. Students learned to work and communicate effectively with each other, understand other discipline's terminology and jargons. This type of design actualization gives students comprehensive perception of engineering reality in real life settings [8,9]. Through interaction and practical application in this experience, the students learn lessons in design for manufacturability and working in multidisciplinary teams that they would not have without the course integration.

GOAL

Our goal is to provide an integrated environment for interaction among students in different disciplines. This is termed horizontal integration.

OBJECTIVE

In order for engineers to interact intelligently with engineers of other disciplines, the best training is to assign them to work with the other engineers for a common project. Since we are focusing on Automation and DOE, our OBJECTIVE is to provide an environment for students to grasp basic concepts in automation with robotics and CNC, learn DOE principles and concepts, and use DOE to determine the significant factors (parameters) for the CNC process to produce the best quality parts. In the common project manufacturing students elect a process that they feel comfortable working on and team up with the IE students from the DOE class to design a statistical experiment to investigate a CNC process.

DESCRIPTION OF THE COMMON PROJECT

At Kettering, Robotics and CNC machining are covered in the **Automation** course in manufacturing engineering. Students design and manufacture work-part, they also design the process for making the parts. Though quality control is discussed in class, traditionally, quality metrics are not physically measured and analyzed in this course. In the **Design of Experiments** (DOE), an IE course, students learn how to design experiments to identify significant factors that impact a product and process and in turn to reduce product and process variation. DOE is a powerful tool that needs to be understood by all engineers.

The requirement for the integration is that the two courses have at least one common hour per week to initiate, design, develop, and implement a common project. Automation students first learn about CNC and the parameters that affect work-part surface finish quality. DOE students first learn about how to design and analyze the experiments for multiple factors (parameters). During the first two common lectures, they formally present and share with the other students their acquired respective knowledge. Students were charged with the responsibility to hold outside-the-lab meetings to develop their project. Each student team has to write and present a proposal, an interim progress report and a final report. Each team member has to be responsible for at least one section of the reports and speak at the presentations. Figure 1 shows the modified template for the current Automation-DOE application.

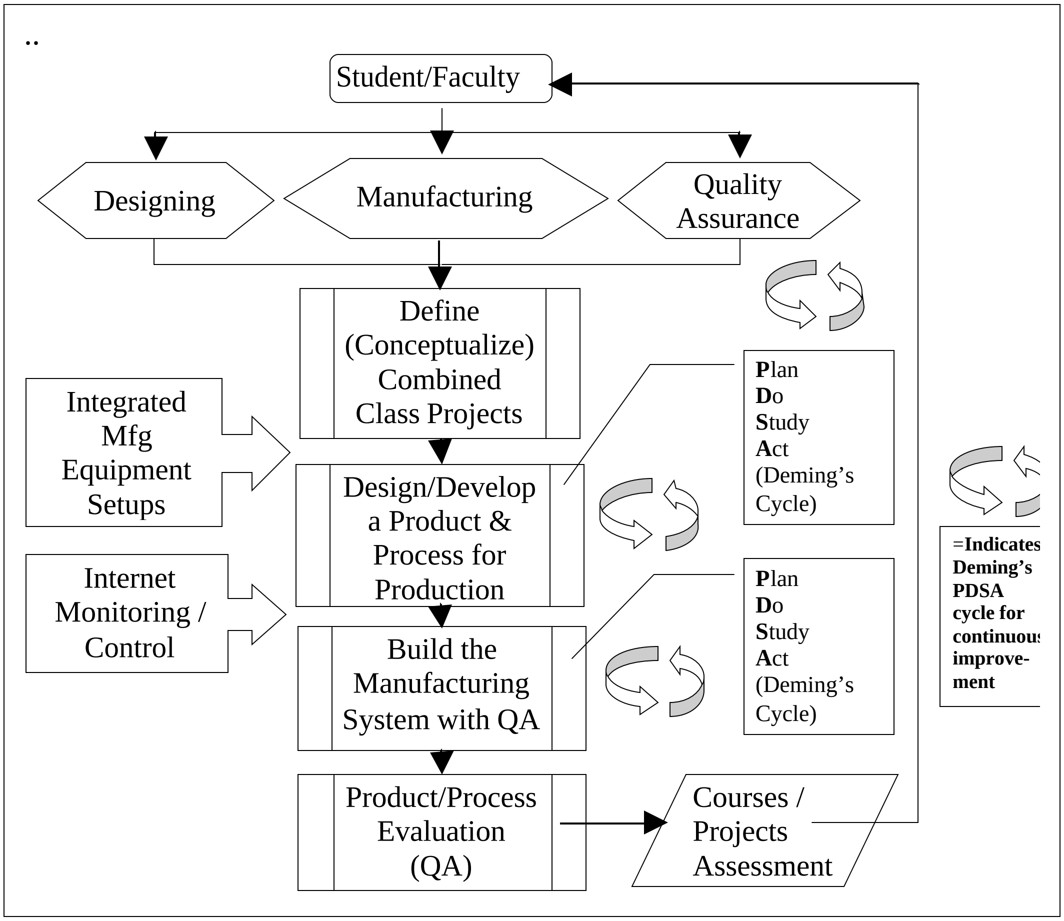

FIGURE 1
MODIFIED TEMPLATE FOR THE COMMON PROJECT

In the ensuing common hours, they form interdisciplinary teams to design a product and its manufacturing process(es) (in this case using the CNC), determine possible factors (parameters) that will affect a quality characteristic (surface finish) of a part, and possible experimental designs. During common hours and outside the classroom, students manage the project, brainstorm, design, agree / disagree, manage conflicts, procure material, fabricate working parts, collect and analyze the experimental data, and draw practical conclusions. They also write and present a (1) Project proposal, (2) Project interim report, and (3) Project final report.

NUTS AND BOLTS OF THE INTEGRATED STUDENT PROJECT

Three inter-disciplinary student teams were formed with the objective for each team to design the best CNC process for turning 1100 steel bars of 1 inch diameter with carbide cutter inserts. The students interacted and communicated both during common lab times and outside of the classroom. Manufacturing students designed their turning tool paths. They decided on the factors (parameters) that could have impact on the part surface finish. These factors are: (1) spindle speed, (2) feed rate, (3) depth of cut, (4) tool wear, (5) stock bar length. Each group selected their own combination of at least four factors. A 2^4 (or 2^5) experimental design with single replication is selected. Each team provided the high and low level for each factor based on what they learned from CNC machine during the previous week. Table 1 shows the given selection high and low levels of each factor.

Parameter	Description	Low value	High value	T1	T2	T3
1	Spindle speed (rpm)	800	1700	✓	✓	✓
2	Feedrate (inch/rev)	0.01	0.02	✓	✓	✓
3	Depth of cut (inch)	0.01	0.05	✓	✓	✓
4	Tool wear	New	moderately worn	✓		✓
5	Stock bar length	4 inches	8 inches		✓	✓

TABLE 1
UPPER AND LOWER LIMITS AND TEAMS 1-3 PARAMETER SELECTION

Students selected their own limits to produce very rough cuts and finer finish cuts (refer to Table 2). The DOE students took the information and used Minitab to generate a randomized sequence of experiments shown in Table 3. Their design of the part was simply to turn the outer diameter once by the specified depth of cut with the selected speed and feed. The quality of the surface finish namely the "roughness" was measured with a meter in terms of deviation from average (R_a) surface finish or Root Means Square (R_q) (refer to Figure 2).

	Spindle Speed	**Feedrate**	**Depth of Cut**	Tool wear
High +	1200 rev/min	0.014 in/rev	0.05 inch	**New**
Low -	**700 rev/min**	**0.0085 in/rev**	**0.005 inch**	**used**

TABLE 2
STUDENT SELECTED VALUES FOR THE EXPERIMENT

Manufacturing students mentored the IE students in the machining process by ensuring every student had a chance to mount and machine at least two workparts, including editing the CNC program to reflect the necessary changes in the speeds, feeds, depth of cuts. Together, they measured the surface finish and collected the data. Figure 3 shows some students machining and some performing Minitab data analysis.

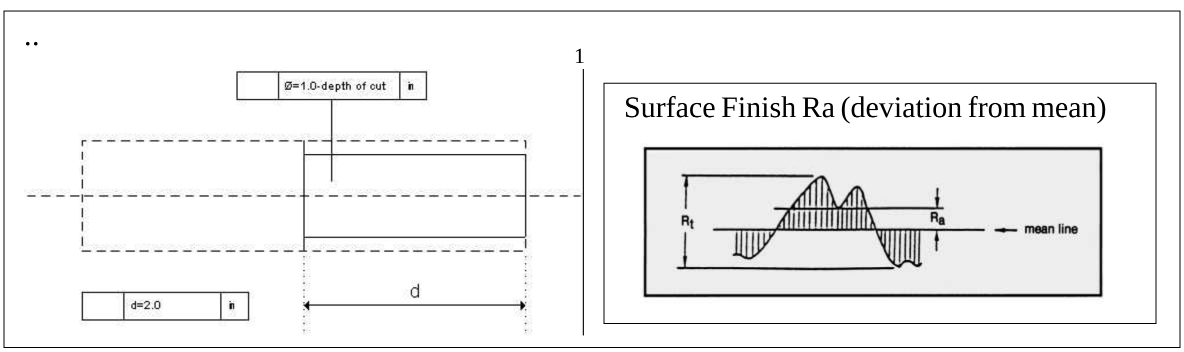

FIGURE 2
WORKPART AND SURFACE FINISH

Table 3: Sample Minitab randomized experiments

Std Order	Run Order	Spindle Speed	Feed Rate	Depth of cut	Tool Condition	Ra	Rq
13	1	low (-)	low (-)	high (+)	worn (-)	180.9	220.8
8	2	high (+)	high (+)	high (+)	sharp (+)	296.7	345.9
7	3	low (-)	high (+)	high (+)	sharp (+)	344.8	419.4
11	4	low (-)	high (+)	low (-)	worn (-)	262	299.1
16	5	high (+)	high (+)	high (+)	worn (-)	291	337.7
12	6	high (+)	high (+)	low (-)	worn (-)	224.5	262.3
5	7	low (-)	low (-)	high (+)	sharp (+)	192	219.3
10	8	high (+)	low (-)	low (-)	worn (-)	147.2	177.2
14	9	high (+)	low (-)	high (+)	worn (-)	177.8	213.6
15	10	low (-)	high (+)	high (+)	worn (-)	319	370.9
4	11	high (+)	high (+)	low (-)	sharp (+)	257	303.8
9	12	low (-)	low (-)	low (-)	worn (-)	143.3	175.7
2	13	high (+)	low (-)	low (-)	sharp (+)	205.9	234.4
3	14	low (-)	high (+)	low (-)	sharp (+)	314.3	361.1
1	15	low (-)	low (-)	low (-)	sharp (+)	215	247.3
6	16	high (+)	low (-)	high (+)	sharp (+)	207.9	241.2

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TABLE 3
SAMPLE MINITAB RANDOMIZED EXPERIMENTS

Figure 3 shows the measurement of surface finish. The IE students used MINITAB to analyze the data and explained to the Manufacturing students how the MINITAB analyses were done and what practical conclusions can be drawn. Manufacturing students lead the discussions in the feasibility of the results and used their knowledge to explain expected or unusual phenomena.

RESULTS

MINITAB analyses produced Probability Plots, Main Effects Plot and Interaction Plot as shown in Figures 4-6. A regression model of the data produced an interaction curve.

FIGURE 3
SURFACE FINISH

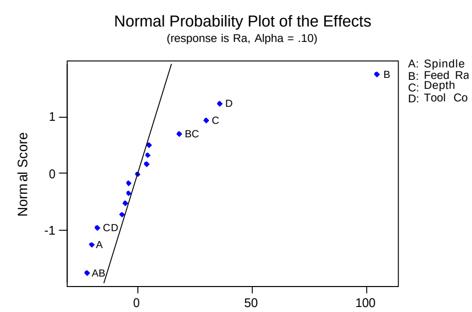

FIGURE 4
SAMPLE PROBABILITY PLOT

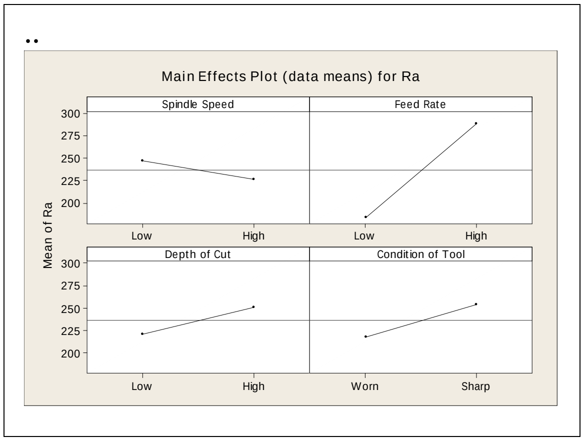

FIGURE 5
SAMPLE MAIN EFFECTS PLOT

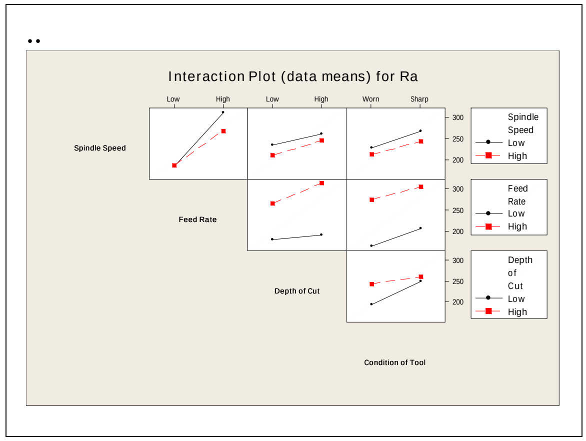

FIGURE 6
SAMPLE INTERACTION PLOT

Analysis of the plots showed that (a) the best results were found when the feed rate was low (0.0085 in/rev.), the tool was worn, and the depth of cut was low (0.005 in.). The spindle speed can be high (1200 rev/min.) or low (720 rev/min.), as long as the feed rate is low, (b) the surface finish depends on chip size and geometry. A chip is described as the piece of material that is being removed. As feed rate and depth of cut are increased, chip thickness and width increase. Wider, thicker chips will give a rougher finish, where as a narrower and thinner chip will give a smoother finish. The nose radius is a factor that promotes a good surface finish. A larger tool nose radius will give a better finish than a smaller sharper radius. "This may explain why our worn tool gave a better finish. The sharp tool may have had too small of a nose radius and as it becomes moderately worn, it produces a better finish." explained the students.

In all, the students gained mutual respect, despite their differences in background. They even noticed that they spoke in different "languages" even though everything is in English. The terminologies were different. A simple example is Parameters (manufacturing engineering) v.s. Factors (industrial engineering).

The three groups came to slightly different conclusions from their analyses results. Given the variation in their parameters, they were all feasible based on the explanations they provided. The students had diverse opinions, but came to consensus about their findings. This is a mild case of conflict resolution that is an absolutely necessary skill in industry.

ASSESSMENT AND RESULTS WITH STUDENTS COMMENTS

students presented their findings at the final presentation of the project. Professors and invited guests rate their presentations for *knowledge gained, content, preparedness, visual displays and coordination*. A grade sheet was given to each student with the project assignment sheet. The students knew what they would be graded on. On the whole, majority of the student knew exactly what to write or talk about. As a result, there were no surprises and the grades were high (average 92%). Each person is also rated for his/her participation during the term. In addition, peer grading was taken into account although the students were very generous with each other. Three team surveys were used to evaluate (a) peer team evaluation worksheet where students in the team evaluated each other, (b) teamwork self-assessment worksheet where each team member evaluated his/her contribution to the team, and (c) team evaluation where team members evaluated the performance of the team as a whole and assigned a % contribution by each team member including himself/herself. These surveys are adapted from Bodary [12]. Table 4 shows the survey questions and Table 5 summarizes the results of the 3 surveys and the peer grading scores.

	Peer Evaluation of Members	**Team Evaluation by Members**	Self Assessment towards Contribution to Team
1	Attends meetings	Effective Use of Time	Comfortable
2	Initiates/maintains dialogue	Development of Ideas	Active participant
3	Works/conflict resolution	Ability to Decide Issues	I listened
4	Strive/consensus	Overall Productivity	I encouraged
5	Supports		I explained/helped
6	Initiates/participates		I asked
7	Define problem		I felt encouraged
8	Collected/provided data		Comfortable in role
9	Generated solutions		Worthwhile
10	Documented solutions		Skills improved
11	Effectiveness/performing role		
12	Listening/speaking skills		

TABLE 4
EVALUATION SURVEY QUESTIONS

survey	Type of survey	Team average	Low	High
1	Peer team evaluation			
	Team1	2.50	2.18	3.00
	Team2	1.90	1.42	2.80
	Team3	3.00	3.00	3.00
2	Teamwork self-assessment			
	Team1	27	25	29
	Team2	21.25	19.5	23
	Team3	29	26	30
3	Team evaluation by members			
	Team1	24	23	25
	Team2	21.5	19	24
	Team3	27	25	28
grading	Oral presentation score			
	Team1	48.17	45	50
	Team2	47.17	44	50
	Team3	46.67	44	50

TABLE 5
SURVEY SUMMARIES

The surveys showed the reflections of the teams. Consistently, the scores showed that the team that worked very well together (Team 3) had consistently high scores. Team comments include “best team ever. I looked forward to our group meetings – they were both fun and productive”. All comments from this team were positive, appreciative and supportive of each other. The members praised the team leader. The team affinity was simply great. Team 2 had problems with personalities, conflicts, and is evidenced by consistent low scores. The problems surfaced as comments in each survey. There was one person that was not receptive to other people’s ideas. Teammates felt that this person always thought that he/she himself/herself was always right. Therefore, no compromise on his/her part was necessary. Conversely, this was consistent from this person’s point of view that the other members were inflexible.

The assessment surveys and discussions showed true team dynamics, and that students were enthusiastic about the project. The “worthwhile” factor was 2.17/3.0 with one low 1.5 score from the “difficult” student. Students felt that having to work under time constraints, communicating and working with engineers from different disciplines would “greatly benefit their engineering careers.” They felt that their skills improved (2.67/3.0).

The two most common complaints were (a) not having enough time in the 11-week term, and (b) pre-defined goals were not clearly defined. This is one improvement that the authors of this paper need to make to improve the general flow of the project for future attempts. The professors were satisfied with the level of engineering synthesis each group incorporated into their designs of workparts, design of experiments, data collection process, data analysis and conclusions drawn by the students about the optimal machining conditions.

CONCLUSION

With this interactive, hands-on learning experience, students were motivated to learn better and enhance their retention and ability to synthesize. The experience also enhanced project management and teamwork skills. Students were able to adopt multidisciplinary practice in a real project. Through this integrated learning experience, students gained interdisciplinary, manufacturing and DOE experience to better their proficiency of the real world, multi-disciplinary design synthesis process. The professors were ensuring that the objective was satisfied. They had good success considering the structure was implemented for the first time. With this experience, students are now more job-ready in industry than ever before. They are able to not only design products and make them, but also reduce the lead time in designing and making high quality products.

FUTURE

Encouraged by the students' positive reactions, their excitement and enthusiasm, the authors will continue to improve the collaborative effort and design a good assessment system. Many improvements are in order. One of them is to include a dictionary of equivalent but different words. The experience gained will allow the authors to draft a better common lab schedule, be more realistic about the rate of development of the project, provide network environment for communication of manufacturing and DOE information.

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