AC 2008-2172: TEACHING DESIGN AND MANUFACTURE OF MECHANICAL SYSTEMS - PART II

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Teaching design and manufacture of mechanical systems using multidisciplinary teams-Part II

Introduction

A lot of progress has been made in recent years in improving engineering education, e.g., emphasizing communication skills, working in teams, integration of computer-aided engineering (CAE), and capstone/senior design projects. Previous work by the authors has focused on improving the integration of CAE[1,2] into mechanical engineering programs. Noble[3] writes that there is "a need for a broad based individual that is capable of working in an integrated fashion in a team environment." According to King and Lin[4], "Industries need engineers who are versed in streamlining processes from design to planning to manufacturing." Tsang and Wilhelm[5] developed a one-credit laboratory to "integrate the disciplines of materials science and engineering, manufacturing and design." Noble[3] also notes that "little is done to provide any synthesis between the courses."

The goal of this paper is to document efforts to improve the experiences of students working in integrated design project teams and the synthesis of the designs and between the courses. Part I of this paper discussed the experiences of Machine Design II students during the Winter 2006 semester with non-integrated projects and also the early experiences of students with integrated projects in Winter 2007. The authors worked on a NSF sub-grant provided by faculty at Kettering University using their model for the horizontal and vertical integration of interdepartmental courses. Vertical integration involves students in the same discipline but different class years, e.g., juniors have the opportunity to learn from the seniors. With horizontal integration, project teams are created with students in the same class year, but different disciplines, e.g., Mechanical Engineering and Product Design and Manufacturing Engineering. This allows students to collaborate with people with other specialties and be introduced to integrated system design and manufacturing. It also helps them visualize the complete system and the big picture throughout the project. Integrated or multidisciplinary teams allow learning from faculty to faculty, faculty to students, and students to students. Comparisons can be made between integrated and non-integrated teams. There is also an opportunity for the administration to develop strategies for scheduling classes so that the students from each class are able to find common times to work together.

Another consideration was that machine design courses tend to be focused primarily on machine *component* design. A second goal was to increase the emphasis on the design of machine systems, e.g., an automotive engine instead of just the crankshaft. To accomplish this, a just-in-time approach was used for component design so that students could focus more on the topics that were needed for their projects. Students could also outsource work to other classes, e.g., finite-element analysis might be done by students in a graduate course.

There were a large variety of projects integrated with students from EGR 367 (Manufacturing Process), EGR 409 (Machine Design II), and EGR 480 (Advanced Product Design). The results were mostly good, but there were some teams that either had poor math models, prototypes, or their prototype satisfied the design requirements but did not require significant effort. One major difficulty was that many of the students were involved in three or more projects during the

Winter 2007 semester, including their Senior Design Project. This resulted in many absences from the classes involved in the projects and also classes that were not involved in the integrated projects. In hindsight, the workload would have been more reasonable if the students were only required to work on one project for both of their classes, e.g., EGR 367 and 409.

Actually most of the Winter 2007 projects were integrated because many of the students were enrolled in two or more of the three courses. This situation could be described as "seamless" integration because many team members had common skill sets and exchanged assignments as necessary to manage their project and course loads.

Two conclusions were that the organization of the projects should be improved and future integration projects should be coordinated so that the students share at least one class time with their partners from another class.

Phase I: EGR 409 Projects – Winter 2006

In Phase I during the 2006 Winter semester, two sections of EGR 409 (Machine Design II) developed solid models of mechanisms designed to raise the lower dishwasher rack to reduce pain and injury for people with physical disabilities. Teams of two students created a wide variety of designs that included motor-driven mechanisms and spring-driven designs. At the end of the semester, the Machine Design II students participated in a "Project Celebration" poster session with other project-based classes, and awards were provided for the best technical design and the most innovative design. The competitions provided additional motivation for the students to do their best work. Figure 1 shows a dishwasher design from the 2006 Winter semester.

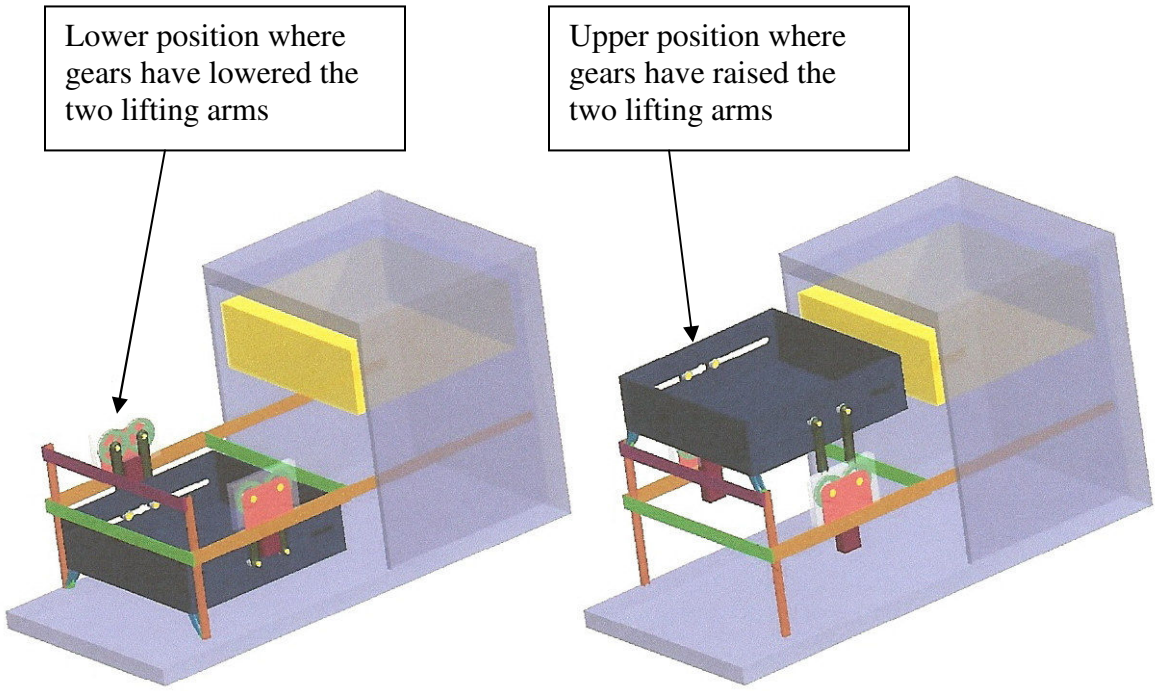

Figure 1: Lower dishwasher rack raised with four arms from Winter 2006.

Phase II: EGR 367/409/480 Projects – Winter 2007

Machine Design II, Manufacturing Processes, and Advanced Product Design faculty supervised Phase II during the 2007 Winter semester with a variety of projects and this time prototypes were built. The designs were put into two categories, i.e., those built by integrated and non-integrated project teams. The integrated teams included one or more students in EGR 409 (Machine Design II) and EGR 367 (Manufacturing Processes) or EGR 480 (Advanced Product Design). Since there were 42 senior Machine Design II students and only 11 senior Advanced Product Design and 12 junior Manufacturing Processes students, not every student could be placed on an integrated team.

Significant preparations were necessary including the development of projects for the teams, the integration structure, methods for monitoring the integrated and non-integrated teams, and plans to provide assessment. Figure 2 show the design process that was used for the projects.

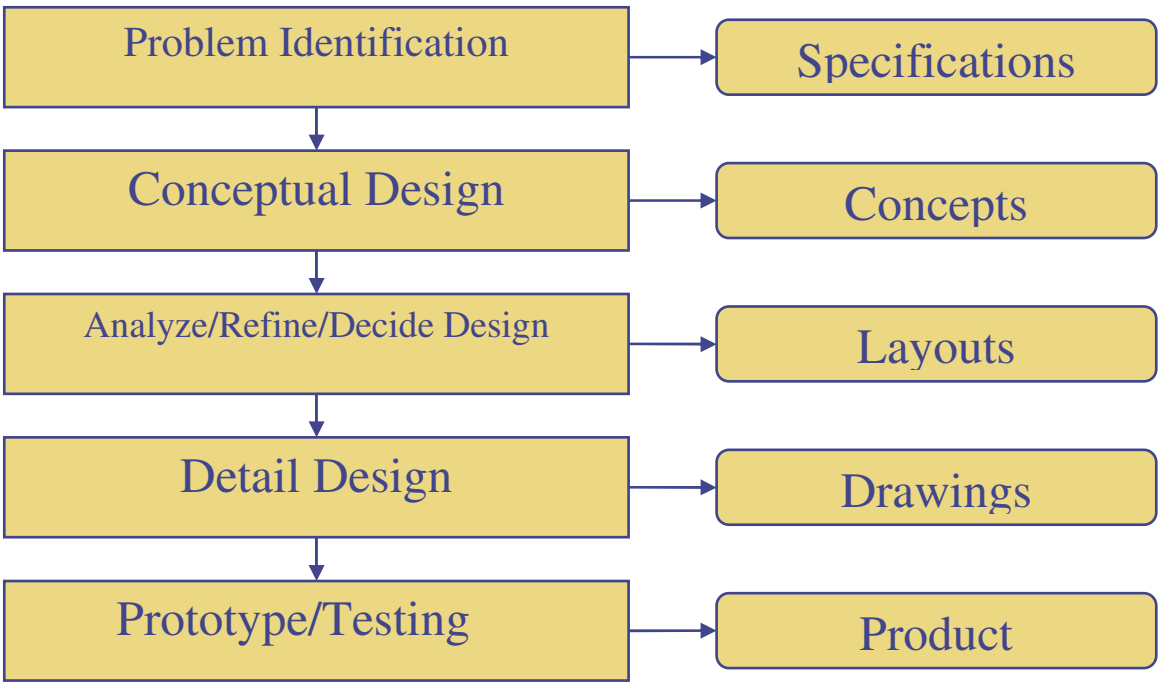

Figure 2: Design Process used for Integrated Projects.

Table 1 Vertical and horizontal integration of machine design, product design, and manufacturing project teams.

Project Description	Integrated Faculty	Number of Students		
		EGR 480 Product Design	EGR 409 Machine Design II	EGR 367 Manufacturing Processes
Roast, Grind, and Brew Project Second generation coffee machine prototype needed. Team must integrate control system from Electrical Engineering class and work done in EGR 380. Mechanism design, Heat transfer and packaging are all challenges for this team.	FARRIS	1	3	N/A
Winter Wrist Brace Project Previous work by Matt Anderson is proposing that the project continue with the construction of prototypes, and measurement against the current best practice.	FARRIS	2	2	N/A
Trap Thrower Automated trap thrower project sponsored by the Innovation committee at GVSU. Team must take initial prototype and refine into a product that can be sent to potential customers for review.	FARRIS	2	2	N/A
Pedal Pro prototype Bicycle torque measuring product project sponsored by GVSU's Innovation committee. Team must create a testable design from a paper design. Product enables the user to see the torque as a function of crank angle from each leg.	FARRIS	2	1	N/A
Prosthetic Hand Project Fluid powered prosthetic hand is under development by Elkins Innovation, a company housed in GVSU's smart zone. SOE helped company develop the foot control for the hand. Sponsor wants to develop actuators, pump, motors and valves suitable to application.	FARRIS (Lead) CHAPHALKAR	2	2	N/A
Dishwasher Rack Lift System Raises lower dishwasher rack to avoid muscle strain and injury.	WALDRON (Lead) CHOUDHURI	N/A	2	2
Chain-Drive Vacuum Improved durability for drive system to eliminate belt replacement	CHOUDHURI (Lead) CHAPHALKAR	N/A	2	2
Gear-Driven Wheel Chair Increased torque or speed wheel chairs	CHAPHALKAR	N/A	2	2

Table 1 shows the organization of the integrated teams. Integrated projects involve students from more than one course. An example of an integrated project is shown in Figures 3 and 4, where a traditional vacuum cleaner was modified by replacing the belt and AC motor with a direct-drive DC motor attached directly to the cleaning brush. Some of the projects were already in the prototype stage, e.g., the integrated Roast, Grind, and Brew project shown in Figure 5.

Table 2 lists the projects that were not integrated, i.e., the students in these teams were all in the same class. An example of a non-integrated project is shown in Figure 6, where a Machine Design II team developed a sine plate to rotate a workpiece about multiple axes for machining operations. This project was sponsored by a student's Co-op employer. Another non-integrated team designed and built new trailing arms for the 2007 Baja SAE competition (see Figure 7).

In order to fully benefit from this effort, assessment tools were developed, and the data was reviewed so that changes can be made to improve the experience for students and faculty. One of the assessment tools was a survey developed by a faculty member in the School of Education,

which included questions about student issues and issues for faculty and outside evaluators to help understand the students' positive and negative experiences in this project.

Table 2: Teams that were not integrated with other classes.

Project Description	**Faculty**	**Course**
Baby Formula Mixer A new mother in the Entrepreneurship Program has suggested that there is a need for a product that will correctly mix water and powdered baby formula when the operator has been impaired by sleep deprivation. Team will be responsible for taking user need through to a product prototype.	FARRIS	**EGR 480** **Product Design**
Dishwasher Rack Lift System Raises lower dishwasher rack to avoid muscle strain and injury.	WALDRON	**EGR 409** **Machine Design II**
Chain-Drive Vacuum Improved durability for drive system to eliminate belt replacement	CHAPHALKAR	**EGR 409** **Machine Design II**
Gear-Driven Wheel Chair Increased torque or speed wheel chairs	CHAPHALKAR	**EGR 409** **Machine Design II**
Sine Plate Rotate a workpiece about multiple axes for machining operations	WALDRON	**EGR 409** **Machine Design II**
SAE Baja Gear Case Increased torque and protection for gears including heat effects	WALDRON CHAPHALKAR	**EGR 409** **Machine Design II**

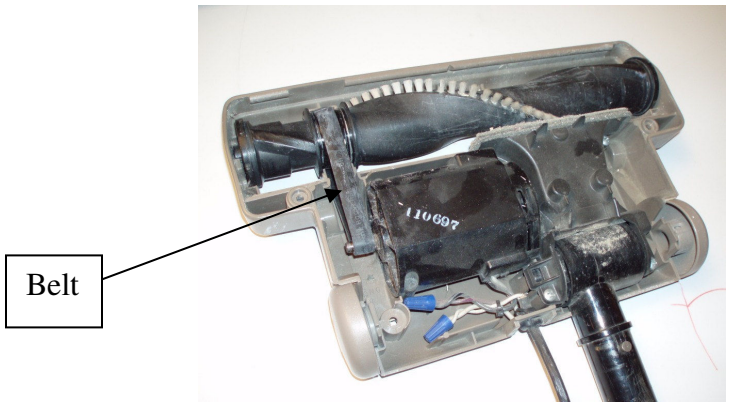

Figure 3: View of standard vacuum cleaner with belt.

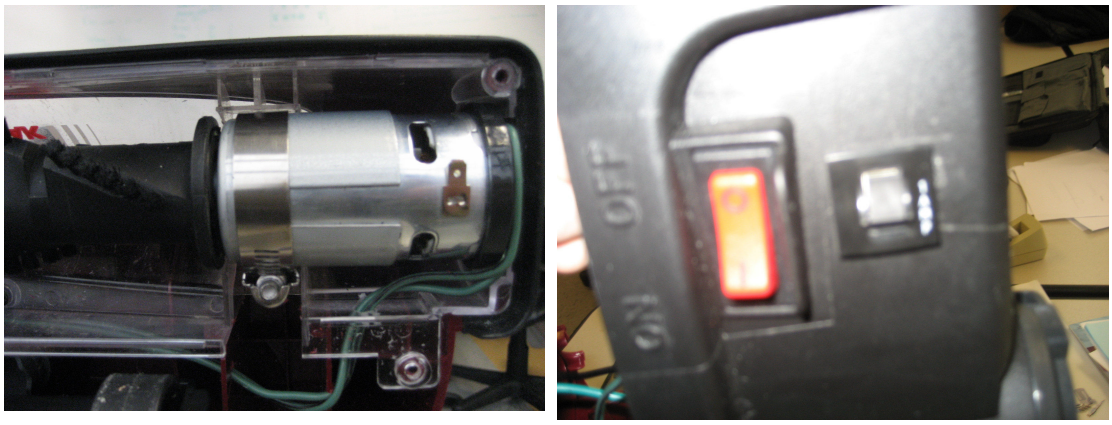

Figure 4: Vacuum cleaner with a direct drive motor and on/off switch with circuit protection.

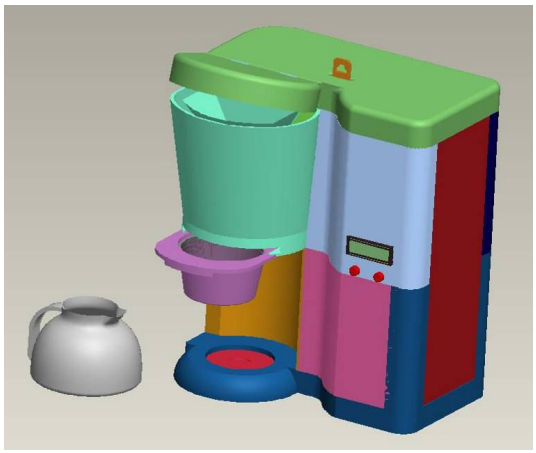

Figure 5: Solid model of Roast, Grind, and Brew project.

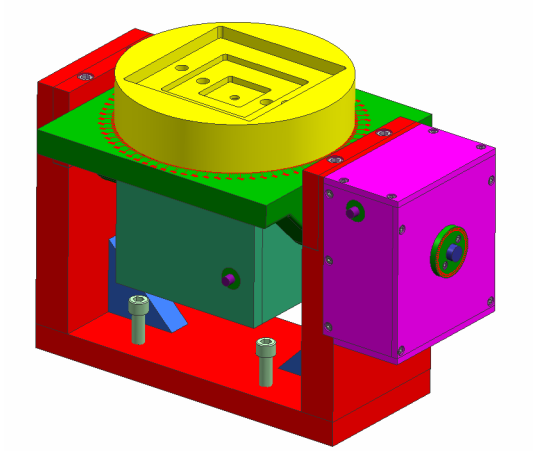

Figure 6: Solid model of the sine plate designed and built for a student's Co-op employer.

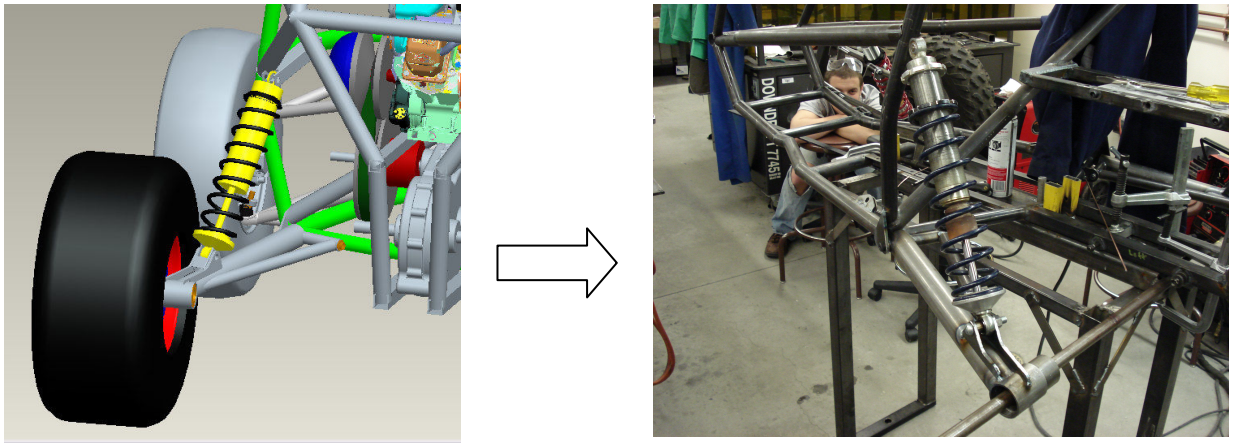

Figure 7: Solid model of trailing arms for 2007 Baja SAE vehicle and early stages of the build.

Overall the Phase II integrated projects were a success because most of the projects were well done and many students felt that they benefited from working with students from other

disciplines. As can be seen from the survey responses and comments in the Appendix (Student survey for Phase II), organization was a significant issue. However, the following percentages include students who strongly agreed or agreed. 60% learned a great deal from their teammates (Question #3). 83% said they used creativity (Question #7). 80% used knowledge and skills gained in classes to solve the design problem (Question #8). 63% said their project was difficult (Question #11). 53% increased their ability to learn new knowledge and skills outside of class (Question #14). 73% used technical models or equations to refine their design (Question #18).

One concern was that many of the students had two or more projects during the Winter semester so the work load resulted in an increase in absences from the three courses involved as well as other courses that were not involved in the integrated projects. Another challenge was balancing the goals of developing projects that involve topics that are covered in the associated courses with developing products with that are marketable on a cost and need basis.

Conclusion

Projects were completed by GVSU School of Engineering students during the Winter 2006, and Winter 2007 semesters. The Winter 2006 projects were not integrated and every student developed paper designs to lift the lower rack of a dishwasher to help people with handicaps avoid injury from back strain. Horizontal (senior ME and PDM students) and mixed integration were used (senior ME and junior PDM students) in the Winter 2007 semester to see if the students were able to take advantage of each other's strengths. The performances of non-integrated teams were also compared with the integrated teams. In general the integrated teams performed better, but this was partly because the stronger students were placed on integrated teams.

In varying degrees, it was a challenge for the instructors to coordinate so many projects when all the work was done outside of the class. Developing an efficient organization and becoming familiar with the problems is very important, and the instructors with more experience in managing courses with many projects tended to have more successful results.

The quality of work was good to excellent, but logistical challenges caused many problems for students and faculty, including faculty who were not involved in the projects but also experienced low attendance in their classes. The organization will be improved for future integrated projects and there will be some regularly scheduled class time with all the students present.

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References

1. J. Oliva and W.K. Waldron Jr., "Virtual Design Competitions in a Computer Aided Engineering Course," *Proceedings of 2004 ASEE/NCS Conference*, Western Michigan University, Kalamazoo, Michigan (2004).
2. W. Waldron, P. Chaphalkar, S. Choudhuri, J. Farris, "Teaching Design and Manufacture of Mechanical Systems," 2007 ASEE National Conference and Exposition, Honolulu, Hawaii, June 24-27, 2007.
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4. L.S-B King, T. Lin, "Interdisciplinary Integration of Courses – Automation and Quality Control, *International Conference on Engineering Education*, Gainesville, Florida, October 16-21, 2004.
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APPENDIX – Survey for Phase II (EGR 367/409/480) Integrated Projects - Winter 2007

Design Project Assessment

Course: EGR CTS 071

#1 My team cooperated to finish the project.

1	Strongly Agree	11	36.67%	
2	Agree	15	50.00%	
3	Neither agree nor disagree	3	10.00%	
4	Disagree	0	0.00%	
5	Strongly Disagree	0	0.00%	

Valid: 29 **Missing:** 1 **MEAN (Avg):** 1.724 **Std Dev:** 0.649

#2 My team experienced conflict during the project.

1	Strongly Agree	3	10.00%	
2	Agree	12	40.00%	
3	Neither agree nor disagree	4	13.33%	
4	<P>Disagree</P>	9	30.00%	
5	Strongly disagree	2	6.67%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.833 **Std Dev:** 1.177

#3 I learned a great deal from my team mates.

1	Strongly agree	4	13.33%	
2	Agree	14	46.67%	
3	<P>Niether agree nor disagree</P>	10	33.33%	
4	Disagree	2	6.67%	
5	Strongly disagree	0	0.00%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.333 **Std Dev:** 0.802

#4 The project work was distributed evenly among the team members.

1	Strongly agree	0	0.00%	
2	Agree	14	46.67%	
3	Niether agree nor disagree	8	26.67%	
4	Disagree	8	26.67%	
5	Strongly disagree	0	0.00%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.800 **Std Dev:** 0.847

#5 My team planned ahead to avoid a last minute rush.

1	Strongly agree	2	6.67%	
2	Agree	16	53.33%	
3	Niether agree nor disagree	4	13.33%	
4	Disagree	8	26.67%	
5	Strongly disagree	0	0.00%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.600 **Std Dev:** 0.968

#6 My team was creative.

1	Strongly agree	7	23.33%	
2	Agree	18	60.00%	
3	Niether agree nor disagree	5	16.67%	
4	<P>Disagree</P>	0	0.00%	
5	Strongly disagree	0	0.00%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 1.933 **Std Dev:** 0.640

EGR CTS 071 - # Respondents: **30**

Design Project Assessment
Course: EGR CTS 071

#7 I used creativity to solve the design problem.

1	Strongly agree	5	16.67%	
2	Agree	19	63.33%	
3	Niether agree nor disagree	5	16.67%	
4	<P>Disagree</P>	1	3.33%	
5	Strongly disagree	0	0.00%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.067 **Std Dev:** 0.691

#8 My team used knowledge and skills gained in classes this semester to solve the design problem.

1	Strongly agree	4	13.33%	
2	Agree	20	66.67%	
3	Niether agree nor disagree	2	6.67%	
4	Disagree	1	3.33%	
5	Strongly disagree	3	10.00%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.300 **Std Dev:** 1.088

#9 My team relied on knowledge and skills not covered in classes to solve the design problem.

1	Strongly agree	5	16.67%	
2	Agree	22	73.33%	
3	Niether agree nor disagree	3	10.00%	
4	Disagree	0	0.00%	
5	Strongly disagree	0	0.00%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 1.933 **Std Dev:** 0.521

#10 I am satisfied with my project experience.

1	Strongly agree	4	13.33%	
2	Agree	13	43.33%	
3	Niether agree nor disagree	5	16.67%	
4	<P>Disagree</P>	6	20.00%	
5	Strongly disagree	2	6.67%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.633 **Std Dev:** 1.159

#11 The design problem my team solved was difficult.

1	Strongly agree	6	20.00%	
2	Agree	13	43.33%	
3	Niether agree nor disagree	8	26.67%	
4	Disagree	2	6.67%	
5	Strongly disagree	1	3.33%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.300 **Std Dev:** 0.988

#12 My design team solved the design problem successfully.

1	Strongly agree	4	13.33%	
2	Agree	19	63.33%	
3	Niether agree nor disagree	5	16.67%	
4	<P>Disagree</P>	1	3.33%	
5	Strongly disagree	1	3.33%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.200 **Std Dev:** 0.847

EGR CTS 071 - # Respondents: **30**

Design Project Assessment
Course: EGR CTS 071

#13 The design project increased my ability to tackle poorly defined problems.

1	<P>Strongly Agree</P>	2	6.67%	
2	Agree	13	43.33%	
3	Niether agree nor disagree	11	36.67%	
4	Disagree	4	13.33%	
5	Strongly disagree	0	0.00%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.567 **Std Dev:** 0.817

#14 The design project increased my ability to learn new knowledge and skills outside of class.

1	Strongly agree	4	13.33%	
2	Agree	15	50.00%	
3	Niether agree nor disagree	9	30.00%	
4	Disagree	2	6.67%	
5	Strongly disagree	0	0.00%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.300 **Std Dev:** 0.794

#15 My design team followed a structured design process.

1	Strongly agree	3	10.00%	
2	Agree	16	53.33%	
3	Niether agree nor disagree	9	30.00%	
4	Disagree	1	3.33%	
5	Strongly disagree	1	3.33%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.367 **Std Dev:** 0.850

#16 My design team made trade-offs during the design process.

1	Strongly agree	5	16.67%	
2	Agree	23	76.67%	
3	Neither agree nor disagree	2	6.67%	
4	Disagree	0	0.00%	
5	Strongly disagree	0	0.00%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 1.900 **Std Dev:** 0.481

#17 My design team seriously considered alternative design solutions.

1	Strongly Agree	8	26.67%	
2	Agree	16	53.33%	
3	Niether agree nor disagree	5	16.67%	
4	Disagree	1	3.33%	
5	Strongly disagree	0	0.00%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 1.967 **Std Dev:** 0.765

#18 My design team used technical models or equations to refine our design.

1	<P>Strongly agree</P>	2	6.67%	
2	Agree	20	66.67%	
3	Niether agree nor disagree	5	16.67%	
4	Disagree	3	10.00%	
5	Strongly disagree	0	0.00%	

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.300 **Std Dev:** 0.750

EGR CTS 071 - # Respondents: **30**

Design Project Assessment
Course: EGR CTS 071

#19 Our prototype met the design specifications.

1	Strongly agree	5	16.67%
2	Agree	20	66.67%
3	Niether agree nor disagree	4	13.33%
4	Disagree	0	0.00%
5	Strongly disagree	1	3.33%

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.067 **Std Dev:** 0.785

#20 Our solution to the design problem was innovative.

1	Strongly agree	3	10.00%
2	Agree	17	56.67%
3	Neither agree nor disagree	8	26.67%
4	Disagree	2	6.67%
5	Strongly disagree	0	0.00%

Valid: 30 **Missing:** 0 **MEAN (Avg):** 2.300 **Std Dev:** 0.750

#21 Our prototype is well built.

1	Strongly agree	7	23.33%
2	Agree	17	56.67%
3	Niether agree nor disagree	4	13.33%
4	Disagree	0	0.00%
5	Strongly disagree	1	3.33%

Valid: 29 **Missing:** 1 **MEAN (Avg):** 2.000 **Std Dev:** 0.845

#22 Was your project sponsored by an outside group of company?

1	Yes	11	36.67%
2	No	19	63.33%

Valid: 30 **Missing:** 0 **MEAN (Avg):** 1.633 **Std Dev:** 0.490

#23 Which EGR classes are you taking this semester? Check all that apply.

1	EGR 367 - Manufacturing Processes	11	36.67%
2	EGR 409 - Machine Design II	27	90.00%
3	EGR 480 - Advanced Product Design	6	20.00%

#24 What is your Emphasis Area?

1	Mechanical Engineering (ME)	23	76.67%
2	Product Design and Manufacturing Engineering (PDM)	2	6.67%
3	Both ME and PDM	4	13.33%
4	Other	1	3.33%

Valid: 30 **Missing:** 0 **MEAN (Avg):** 1.433 **Std Dev:** 0.858

#25 Did you work on a team with students from other emphasis areas?

1	Yes	20	66.67%
2	No	10	33.33%

Valid: 30 **Missing:** 0 **MEAN (Avg):** 1.333 **Std Dev:** 0.479

EGR CTS 071 - # Respondents: **30**