AC 2011-649: ASSESSING THE EFFECT OF CO-OP SEQUENCE ON CAPSTONE DESIGN PERFORMANCE

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In the Mechanical and Industrial Engineering department at Northeastern University, Capstone Design is a two semester course offered in one of two sequences. In one sequence, the two semesters follow each other directly, with students taking the first semester in late summer, followed immediately by the second semester in the Fall. In the other sequence, the students take the first semester in early summer, and then spend 6 months on co-op before returning in the Spring to complete the second semester of Capstone. Although these two sequences were developed simply to accommodate student schedules, this fact provides an opportunity to determine whether the lag between semesters hinders, aids, or has no effect on whether students generate quality designs and use good project management techniques. Students who take the consecutive sequence have the advantage of working continually on their design problem for 2 terms, allowing them to keep momentum going. However, it is possible that the students who interrupt their sequence with co-op are able to use that time to continue independent learning, even if they are not actively working on the problem. Both cohorts spend the same total amount of time on co-op. However, the group with the interrupted sequence can apply the valuable skills in project management and other real-world work skills that they learn in Capstone I to their co-op, reinforcing their skills in a timely manner. This could provide the groups in the interrupted sequence with an organizational advantage upon their return. The purpose of this study is to determine whether there is a distinct difference between the two cohorts in the quality of the final projects produced.. Several measures of project quality will be used to study the two groups. Final course grades for each group will be an initial indicator of any distinction. Another measure is whether or not the groups have reached the prototyping stage at a point two weeks from the end of the course. This can be determined from the executive summaries the groups submit at that point. The number of patent disclosures and provisional patents awarded per term will indicate both the quality of the project and the performance of the groups, as groups that file patents typically are further along in their project. Finally, the two cohorts will be compared based on feedback from the alumni jury members who judge the final projects. Results indicate that the nonconsecutive groups have slightly better grades, more projects which reach the prototyping stage 2 weeks prior to the end of term, and more projects rated successful by the alumni jury. Patent applications did not prove to be conclusively indicative of any difference between cohorts.

Introduction

Many studies on the benefits of co-op experience have centered on whether or not students who participate in co-op programs show improved academic performance as compared to students who do not have these experiences. Several studies have indicated a measurable increase in GPA among students who participate in co-op programs[1,2,3,4]. These reported increases in cumulative

GPA scores range from 0.02-0.25 for various studies. Schuurman et. al. showed that these increases, while small, were independent of prior GPA.[4] Moreover, the number of co-op experiences seemed to correlate positively with increased GPA. For students at the lower end of the grade scale, the benefits of co-op have been shown to have a proportionally greater influence[2]. This research indicates that after three co-op experiences, many students have learned skills that translate into improved academic performance.

One weakness of some of the established studies is that the indicators of academic performance focus on cumulative GPA, which is based on all courses combined. Capstone design courses, by their nature, have a different focus and require different assessment tools. Academic skills in computation, engineering topics, and computer modeling are all necessary for successful completion of a design project. However, successful design students must also master professional skills such as oral and written communication, project management, teamwork skills, problem solving, and professional ethics. These skills can be difficult to teach in a traditional lecture format, but can be very naturally integrated into capstone design[5]. Since capstone design courses offer many opportunities for situated learning, they allow students to learn these professional skills in a realistic context[6].

Given that these professional skills are necessary for a successful capstone design experience, one can expect a benefit to accrue from experiences which improve these skills. Several recent studies have attempted to quantify these benefits. Yin found that students see themselves as better problem solvers after co-op experience, but the measurable effects were small[7]. Students who had this work experience were also more likely to understand the need to examine wider implications of a given problem. The co-op experience seemed to give students an awareness of the importance of deadlines, documentation, and the importance of a step by step approach to a complex problem[8]. Another study found that students with co-op experience showed increased maturity compared to students with no co-op experience, which could translate to a better work ethic and an improvement in teamwork skills[9].

One limitation of these studies is that these professional skills can be very difficult to quantify. Unlike measures of post-graduation salary, which have been shown by several researchers to be higher in co-op students[1,3] it is only relatively recently that the professional skills have been studied in a systematic way[5]. The capstone design experience provides a unique opportunity to focus on these professional skills in a somewhat controlled environment. Although the projects vary widely in topic, scope, and difficulty, one would expect that a team composed of individuals with good teamwork and project management skills should be able to produce a final design that shows good technical skills, a logical thought process, and an effective solution. Effective teams should also be organized enough to produce this design solution in sufficient time to test and document the results of their design.

Assessing the effectiveness of capstone design projects is a complex undertaking. Many schools have turned to the use of design journals or notebooks to require students to document the progress of their design and to reflect on the design process[10,11]. Other schools, including Northeastern, have used a combination of faculty, industrial sponsors, and professional peer evaluations to provide a number of views of the quality of the projects[12]. Student self-assessment has also been used, often in combination with industry and faculty evaluation[13]. Student self evaluations often reveal what students feel they learned from the course, but may or may not reveal how they felt about the quality or effectiveness of the design itself. The current study seeks to assess the quality of the final designs developed during the capstone design course, and to determine what, if any, effect the timing of co-op experience has on the designs.

Mechanical Engineering Capstone Design at Northeastern University

Northeastern university has a longstanding co-operative education program. During the typical 5 year course of study, the students have the opportunity for 3 co-op experiences, each lasting 6 months. In addition to the co-op program, the Mechanical and Industrial Engineering (MIE) department has a long established 2 semester Capstone Design sequence, in which the students work on group design projects for industrial or faculty sponsors. The goal of this study is to determine what effect, if any, the sequence of co-op semesters has on the outcomes of the Capstone Design course.

The Capstone Design course is for senior students in the MIE department. This course satisfies the ABET requirement for senior level design experience.[14] The students work in self selected teams of 3-5 students. The first term is spent primarily on research and problem definition tasks. The second term is spent on developing, building, and testing their design. The final oral presentation and executive summary are evaluated by a jury consisting of alumni and individuals from related industry. Projects are evaluated based on their technical aspects as well as the ability of the group to communicate their findings. The final grade is determined by a committee made up of faculty advisors. In a typical semester in the second course approximately 1-5 projects have provisional patents filed to protect significant intellectual property. Students are expected to demonstrate both technical design skills and soft skills including project management, professional interactions with sponsors, technical writing and oral communication, and team management.

Students in the MIE department are organized into cohorts with common schedules. One ME group (referred to as the 'consecutive' schedule) goes on co-op during the Spring and first Summer terms prior to their senior year. Capstone I is then taken in the second Summer term followed by Capstone II immediately in the Fall of their senior year. The other ME group (referred to as the 'nonconsecutive' schedule) takes Capstone I in the first Summer term. This group then goes on co-op for 6 months before returning in Spring to take Capstone II. The IE groups have similar patterns, where the consecutive group takes Capstone I in the Fall followed by Capstone II in the Spring, and the nonconsecutive group takes Capstone I in the first Summer term followed by co-op, then Capstone II in the Spring. This pattern has been followed for the ME and IE students since Fall 2008.

Methodology

Four measures of project quality were used to determine differences between the two cohorts: final course grade, examination of the executive summaries, patent disclosures and provisional patents, and alumni jury surveys. Final course grades are determined by the team of faculty advisors according to the guidelines in Table 1 below. The grades in the first term include a number of assignments designed to guide students in their problem definition. This includes planning tasks, reverse engineering tasks, developing specifications, and developing standard operating procedures. The second term focuses heavily on communicating their design to others, keeping the project on target and dealing with setbacks, and producing a well tested and credible solution to the problem. Individual students may receive grades lower than the rest of their group for repeated absences from group meetings, poor teamwork, late assignments, or failing to contribute constructively to the design process.

Table 1: Grading scheme for Capstone I and II

Item	% Capstone I	% Capstone II
Project Management Plan	10	
Presentations		20
Reports		10
Final Report		15
Design quality	40	35
Design project management		10
Weekly progress reports		5
Homework assignments and attendance	40	5
Active Class Involvement	10	
Total	100	100

The executive summary assignment is due 2 weeks prior to the end of the term. It is understood that this summary reflects a snapshot of the project at that point in time, rather than the final finished project. As such these summaries show a range in the completeness of the projects. Some projects are essentially complete at this point in the term. Other projects have been prototyped and are awaiting testing. Others have not yet finished building the prototype, and some clearly will not produce a prototype by the end of term. Many groups do go on to do an incredible amount of last minute work in the final two weeks of term. In addition, it is recognized that some projects may be more difficult than others. However, it was felt that a group that could manage to get to the point of testing the prototype 2 weeks before the end of term not only showed excellent planning and project management skills, but also had the opportunity to further develop and improve their design in response to their test results. The executive summaries for each of the ME groups was rated for prototype and testing information. Prototypes were scored on a 5 point scale where 5 = functional prototype, 4 = partially functional prototype, 3 = expected functionality by end of course, 2 = prototype in progress, but not expected to be functional, and 1 = no prototype, prototype unlikely by end of course. The testing was rated on a similar scale where 5 = testing completed, 4 = testing substantially completed, 3 = testing in progress, 2 = testing planned, and 1 = no testing planned/testing not discussed. Information on the prototypes and testing was gleaned by careful reading of the executive summaries for six past offerings of the Capstone II course.

Groups are required to submit regular updates to their project advisor and to the Intellectual Property office concerning any potentially patentable ideas developed over the course of the project. Although updates on intellectual property potential are required, the filing of patents is not a stated requirement. The decision on whether to file a patent or a provisional patent is left to the discretion of the advisor and the Technology Development Director of the university. The Technology Development Director's decision is based on the success and the commercialization potential of the solution and does not reflect a direct connection to the course. Some advisors are known to be more proactive in seeking patent protection than others. It is recognized that designs can be successful without being patentable. However, the number of designs considered worthy of this action would give an indication of the quality of designs in a given term. Since the assignment of a patent or provisional patent is done by a party not associated with the course, it provides an external, objective measure of whether or not a design achieved its goals.

The final capstone oral presentations are evaluated by a jury consisting of alumni and industrial sponsors. The alumni are asked to evaluate experimental ability, design ability, engineering problem solving, communication skills, and engineering practice skills. In addition, they were asked to name groups that were particularly successful or particularly unsuccessful, or that had produced innovative design features. The assessment surveys were used to determine the number of groups considered particularly successful or unsuccessful. It was thought that a term that had a large number of groups considered successful by the jury would indicate a cohort that produced a larger number of quality designs. The jurors were asked to rate the groups' abilities on a 5 point scale, where 5 = excellent. For purposes of this study, the authors focused particular attention on the questions that related to the interpretation of problem statements and the effectiveness of the components or systems designed to solve the stated problem.

In an effort to compare the quality of projects in as quantitative a way as possible, the decision was made to evaluate only the ME projects. The ME and IE groups, due to the nature of their respective disciplines, work on rather different projects. ME groups tend to build physical prototypes, while the IE groups often test their solutions using simulation tools, the results of which can be more difficult to interpret and compare. Because ME projects tend to develop tangible, physical prototypes it is much easier to determine whether or not a project has reached this measurable stage at a given time.

Specific Research Questions

This investigation aims to answer two key questions. The first question investigates measures by which a project can be considered successful. For the purposes of this investigation a project will be considered successful if:

- Students involved in the project earn high grades in the course.
- The student group is sufficiently good at project management and organization to produce a prototype two weeks prior to the end of the course
- The alumni jury is convinced of the successfulness of the project

In addition, the number of projects considered of sufficient value to warrant intellectual property protection will be considered as a secondary measure of success.

The second question investigates whether there is a measurable difference in the number of successful project between the two cohorts. The goal is to determine whether interrupting the Capstone sequence with co-op is beneficial, detrimental, or has no effect on the quality of the projects produced by that cohort.

Results - Grades

Table 2 below gives the average grade achieved by students in each Capstone II course during the terms in question. The grading scale is such that A = 4, B+ = 3.667, B = 3.333, B- = 3, etc. Although the grades tend to be generally high, the grades were slightly higher in the Spring terms (nonconsecutive cohort) than the Fall terms (consecutive cohort). With the exception of two terms (Fall 2008 and Spring 2009) all terms were taught by the same lead instructor.

Table 2: Average class grades for Capstone II

Term	Class average	# projects
Fall 2008	3.73	10
Fall 2009	3.77	12
Fall 2010	3.77	14
Spring 2008	3.84	11
Spring 2009	3.97	15
Spring 2010	3.81	14

Results - Executive Summaries

Executive summaries were evaluated for a total of 76 projects. Of these 36 projects were from the consecutive cohort and 40 projects were from the nonconsecutive cohort. This data is compared in Table 3 below while Figure 1 shows a summary of the range of scores for both cohorts. The nonconsecutive cohort had more groups with a score of 10, which indicated that the projects were prototyped and tested at a point two weeks prior to the end of term. A total of 32.5% of the nonconsecutive groups had a score of 9 or greater, and 65% had a score of greater than 5, indicating that the project was at least half completed. The consecutive cohort had 16.7% of the groups score 9 or greater. There was no statistically significant difference between the two groups. However, there seemed to be a larger number of poor performing groups in the consecutive cohort. A total of 47.2% of the consecutive groups had a score of less than 5, compared to 35% of the nonconsecutive groups.

Table 3: Summary of Executive Summary Scores

Total Projects	**76**	**%>9**	**%>5**	**%<5**
Nonconsecutive Projects	40	32.5	65	35
Consecutive Projects	36	16.7	52.8	47.2

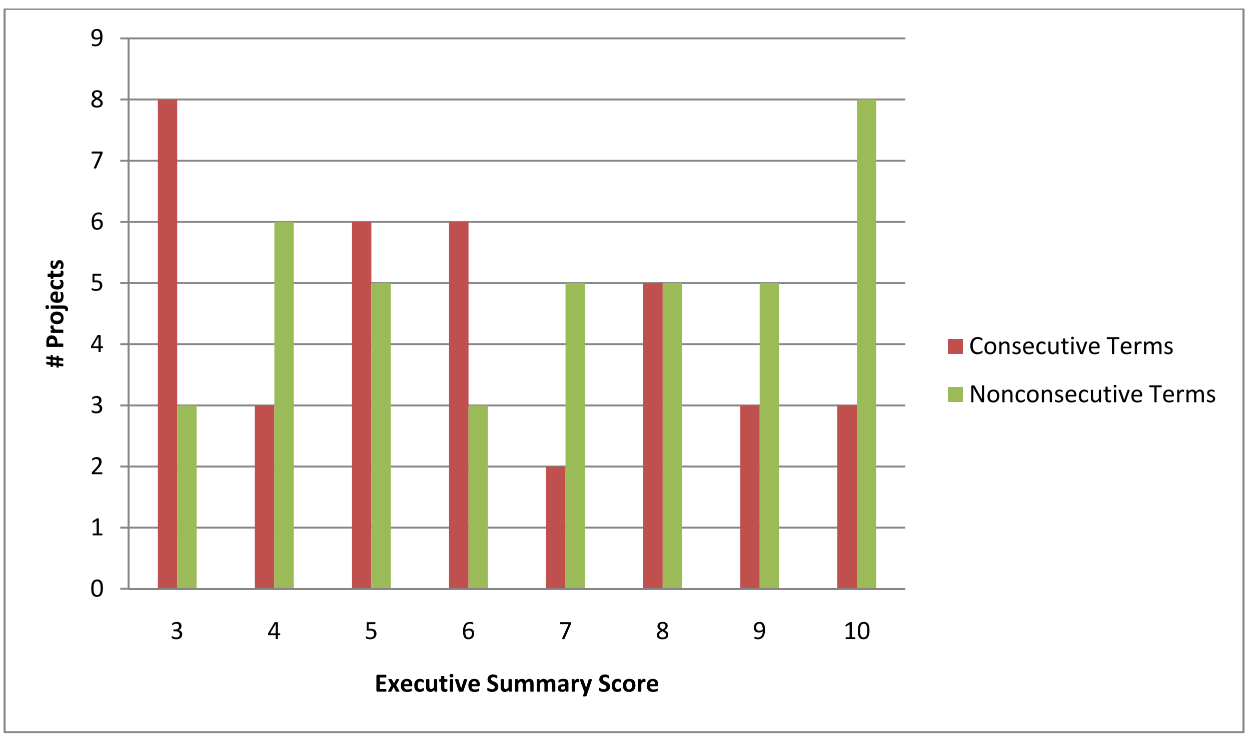

Figure 1: Comparison of Executive Summary Scores

Results – Patents

Data was gathered on the number of provisional patents filed as well as the number of provisional patents granted or likely to be granted during the various terms. During the consecutive terms, a total of 5 provisional patents were granted – 1 during Fall 2009 and 4 during Fall 2010. During Spring 2010, a nonconsecutive term, 3 provisional patents were granted or expected. Table 4 below provides data on each of the groups which applied for provisional patent protection, including their prototype score and whether or not the alumni jury judged their project to be successful. It is interesting to see that at least one project that applied for patent protection was considered unsuccessful by the jury, had a slightly lower grade, and also had a low prototype score. Patentable ideas did not seem to be particularly linked to any other measure.

Table 4: Comparison of individual projects leading to provisional patents

Project #	Group Grade	Jury Survey Assessment	Prototype Score	Term	Cohort
1	3.2	No data	3	Fall 2009	Consecutive
2	4	Successful	5	Fall 2010	Consecutive
3	4	Successful	6	Fall 2010	Consecutive
4	4	Successful	7	Fall 2010	Consecutive
5	4	Successful	8	Fall 2010	Consecutive
6	3.7	Unsuccessful	4	Spring 2010	Nonconsecutive
7	4	No data	6	Spring 2010	Nonconsecutive
8	4	Successful	9	Spring 2010	Nonconsecutive

Results - Jury Surveys

Table 5 shows the results from the jury assessment of the final project presentations. Jury survey results were not available for all terms. Table 5 shows that there is very little difference between the various terms. One interesting result is that the highest score pertaining to the ability of the designs to satisfy technical constraints fell during Fall 2010, a consecutive cohort. In addition, the three instances of scores slightly below 4 on the scale fell during Spring 2009 and Spring 2008, both of which were nonconsecutive terms. The Spring 2009 jury gave lower scores for presentation skills, while the Spring 2008 jury gave lower scores for design and execution of experiments and use of appropriate tools/techniques. In general, there was very little difference in the opinion of the jury members from term to term, based on the numerical scores. The jury members change from term to term, with a mixture of new jury members and returning members. The similarity in the scores gives an indication that although the juries change year to year, the overall feedback is relatively consistent. Inter-rater reliability was estimated for the two questions shaded in Table 5 based on the percentage of respondents giving the same rating. This information is presented in Table 6. It is interesting to note that the highest agreement among the jury members tended to be during the consecutive semesters.

Table 5: Average scores from Jury Survey questions

Question	**Spring 2008**	**Spring 2009**	**Fall 2010**	**Spring 2010**
Design and execution of experiments	3.93	4.14	4.19	4.13
Analysis and interpretation of data	4.00	4.21	4.25	4.38
Interpretation of the problem statements	4.00	4.21	4.80	4.00
Effectiveness of the systems, components, or processes that were designed to solve the problem statements	4.23	4.14	4.19	4.00
Resulting design satisfies the technical constraints	4.00	4.07	4.31	4.00
Organization of presentation	4.29	4.00	4.44	4.25
Presentation skills	4.00	3.93	4.19	4.00
Appropriateness of visual aids	4.43	4.64	4.44	4.13
Used appropriate tools/techniques to approach problem	3.93	4.29	4.44	4.14
Level of skill demonstrated in utilizing techniques	4.07	4.23	4.31	4.29

Table 6: Jury inter-rater reliability for questions pertaining to design effectiveness

Inter-rater Reliability (% of Respondents with common rating)	**Spring 2008**	**Spring 2009**	**Fall 2010**	**Spring 2010**
Effectiveness of the systems, components, or processes that were designed to solve the problem statements	74%	67%	56%	71%
Resulting design satisfies the technical constraints	84%	92%	62%	86%

In addition to examining the numerical scores, an attempt was made to examine the written comments made by the jury. The jury members were asked to name groups they thought were particularly successful or unsuccessful. Some projects were rated successful by some members of the jury and unsuccessful by others. These projects were counted in both columns. These results are summarized in Table 7 below. Jury surveys were not available for Fall 2008, or Fall 2009.

Table 7: Summary of jury results: successful vs. unsuccessful projects

Term	# Groups rated 'successful'	# Groups rated 'unsuccessful'	Total # groups
Spring 2008	7	6	11
Spring 2009	13	8	15
Spring 2010*	4	2	8
Fall 2010	6	4	14

*Only half of the jury evaluations were available for this term. There were two sessions of presentations, each with their own jury. This data represents one session. Groups that were rated differently by different jury members were counted in both columns.

It is interesting to note that all of the Spring terms, which contain students in the nonconsecutive cohort, had at least half of the projects rated as successful. Spring 2009 was particularly successful, despite having the largest number of groups. Almost all of the groups in Spring 2009 had projects that were deemed successful by at least one member of the jury. In contrast, the third largest group in Fall 2010 had only 6 'successful' projects out of 14 based on jury observations. It is recognized that more data from the Fall sections would be necessary to draw concrete conclusions from the jury information. Table 8 below shows a summary of all of the measures of project quality.

Table 8: Summary of measures

							Executive summary scores			
Term	**Class avg**	**# projects**	**#successful (Jury Data)**	**%successful (Jury Data)**	**#unsuccessful (Jury Data)**	**%unsuccessful (Jury Data)**	**# >9**	**%>9**	**#<5**	**%<5**
Fall 2008	3.73	10	no data		no data		2	20	6	60
Fall 2009	3.77	12	no data		no data		2	17	7	58
Fall 2010	3.77	14	6	43	4	29	2	14	4	29
Spring 2008	3.84	11	7	64	6	55	5	45	2	18
Spring 2009	3.97	15	13	87	8	53	3	20	6	40
Spring 2010	3.81	14	4*	50	2	25	5	36	5	36

* Jury data was only available for 8 of the 14 projects for the Spring 2010 term

Discussion

The Fall terms had students in the consecutive cohort, meaning that the capstone I and II courses were taken one after the other, with no break for co-op. For these terms all had greater percentage of executive summary scores <5 as opposed to >9, meaning more groups were less than half done with their project by a point 2 weeks from the end of term. Overall class averages were slightly lower in the Fall terms than in the Spring terms. Although only 1 Fall term had jury data available, that term had the lowest percentage of successful projects of any of the terms. The only measure by which the Fall terms outperformed the Spring terms was the measure of provisional patent applications. A total of 5 provisional patent applications came out of the combined Fall terms.

The Spring terms had students in the nonconsecutive cohort. Grade data showed higher average grades in the Spring terms. One term had the same number of groups with executive summary scores <5 and >9, one term had equal numbers of groups in these two categories, and one term had more groups with scores >9. All the Spring terms had the same or greater percentage of scores >9 compared to the Fall terms. The Spring terms all had a higher percentage of successful projects than unsuccessful projects according to the alumni jury. There were 3 provisional patent applications that came from the Spring terms. Taking all the measures in aggregate, the Spring terms did slightly better in producing quality projects. This difference was not substantial, but it was noticeable.

The Spring 2009 term had a lot of unusual features. This group had the lowest number of executive summary scores >9 of all the Spring cohorts as well as the largest number of scores <5, and no patents arose from this term. However, it had the highest class average, and the largest percentage of successful projects of all the terms. It is unclear why this group was anomalous. This term does highlight some of the flaws in the measures. It is possible for groups to have a large surge of activity in the last two weeks, moving rapidly from a half finished prototype to one that is complete and tested enough to be considered successful. It is also difficult to control for the jury. It is possible that the jury that term was particularly lenient. This term also had the lowest score of any term on presentation skills. This would indicate that a last minute ‘sales pitch’ is not what swayed the jury, but rather something in the quality of the projects. Finally, this term had a different lead instructor, which may also have some effect.

Based on the measures of project quality, it appears that the nonconsecutive cohort, overall, produced higher quality projects, and in many cases had the projects substantially finished at a point two weeks prior to the end of term. Initially, it was thought that this group might be at a disadvantage. They must start their design projects, and then interrupt work for 6 months to go on co-op. The students in any given group may be doing their co-op work in any number of locations. For work to continue on the project, students must have the ability to coordinate work and communicate at a distance, while working full time at their co-op job. When they return from co-op, they need to reform their team and get back to work promptly to avoid falling behind. In contrast, the consecutive cohort gets an uninterrupted period of two terms to devote to their project. The students are all on campus, so there are no barriers to meeting, and 24 hour access to computer modeling laboratories is provided. The consecutive cohort in theory has more access to faculty advisors as well.

Despite the potential benefits of two consecutive terms on campus, it seems that there is some benefit to going on co-op after the first term of Capstone. Many groups do manage to continue working on their problems, despite the distance between group members. Groups have also been known to take advantage of subject matter experts at their co-op company to get information to help them solve their design problems. During co-op, students need to work to external deadlines, communicate with supervisors and team members, and communicate progress and results. These skills can be immediately reinforced upon returning to campus for Capstone II. Indeed, the most successful groups have used these skills to take advantage of the extra time available for the project. The nonconsecutive groups are also closer to graduation, and the immediacy of this fact may drive them to work more efficiently.

It would be possible to argue that the nonconsecutive groups are more successful simply because they have an extra 6 months to work on the problem. However, the students are not required to continue working on their problem during those 6 months. Students are encouraged to do so, and are given advice during their Capstone I lectures on tools and skills to coordinate work on the project at a distance. Not all groups seem to take this advice, but a surprising number do. This allows them to get much farther on problem definition, background research, and computer modeling before Capstone II starts. When they return to campus, these groups are better positioned to begin building prototypes and designing and executing testing schemes.

The consecutive cohort must work very hard during Capstone I in order to be in the same position at the start of Capstone II. Unfortunately, students often have difficulty with problem definition and gathering relevant background information. Because of this a large part of the Capstone I term may be wasted in trying to define the problem, causing these students to be at a disadvantage at the start of Capstone II. Some groups do manage to define their problem quickly and begin more detailed analysis, building and testing, but it is difficult to predict which groups will do this. In addition, the nonconsecutive groups know that they will be going away for 6 months, and thus they know that unless they clearly define their problem, they will not be able to continue working on it during the co-op period. The consecutive groups do not have this added pressure, which may lead them to put less effort into problem definition up front, since they can work on it at the start of the second term, 2 weeks after the end of Capstone I.

Conclusions

The Capstone Design students in the nonconsecutive cohort, who have a 6 month co-op between the first and second term of Capstone seem to produce higher quality designs than the consecutive cohort. This effect is small, but noticeable. Further study to develop improved metrics by which to measure project quality would be beneficial to further explore this observation. It may also be beneficial in future calendar revisions to consider some adjustment to scheduling in order to close the gap between the two cohorts.. These students would then have a 2 month break between Capstone I and II. This might allow them to get farther on problem definition and background analysis prior to the start of Capstone II, and could perhaps allow them to practice the necessary professional communication and project management skills necessary to produce higher quality designs.

If a university does not have a co-op program, then building skills typically learned on co-op into the curriculum in a timely manner could improve student performance during Capstone design courses. By allowing the students to practice these skills while still fresh, they can produce designs which are more advanced and professional. Schools that already have a co-op program could benefit from considering scheduling and allowing students to have time between when they receive their Capstone design challenge and when they must produce their design. Supplementing Capstone with professional skills instruction is beneficial in either case.

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