ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #40921

The Conversion of Capstone Senior Design to a Two-Semester Format

Dr. Chau M. Tran, Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, NC 27695-7910

Chau Tran is an associate teaching professor in the Mechanical and Aerospace Engineering department at North Carolina State University. He is currently the course coordinator for capstone senior design and previously was the course coordinator for vibration, the director for undergraduate advising and the director for undergraduate laboratory. He teaches senior design and vibration annually. He received his Ph.D. in Mechanical Engineering from North Carolina State University in 1998.

The Conversion of Capstone Senior Design to a Two-Semester Format

Abstract

This paper illustrates the conversion of capstone senior design from a one-semester format to a two-semester format and reveals the benefits of such conversion. In the past, a senior design project was completed in either a fall semester or a spring semester course. Since fall 2019, a senior design project was completed in a sequence of two courses, Mechanical Engineering Design I in the fall and Mechanical Engineering Design II in the spring. The one-semester format enables the students to adjust their graduation path when unforeseen events occur, for example, a failure to satisfy pre-requisite classes for senior design, or a last-minute decision to join the Cooperative Education Program in their senior year. The two-semester format loses this flexibility and also takes away the available credit hours for a technical elective course; however, it provides the students with an opportunity to solve a more complicated project and produce a product of proven quality. With the two-semester format, the conceptual design phase increases from three to five weeks; the embodiment design phase increases from four to eight weeks and the prototype construction phase increases from five to eleven weeks. Besides additional design concepts, the two-semester format provides three new experiences – consultation with real-world engineers during the feasibility study review, construction of a mock-up model prior to building the prototype and substantiation of robustness.

Keywords

Capstone senior design, two-semester design project, mechanical engineering senior, conversion of courses.

1. Introduction

The improvement of capstone senior design course has been a persistent process. Robert H. Todd, et al. [1] found that disciplines involving design and manufacture of products such as mechanical, industrial, manufacturing, and electrical engineering have placed high emphasis in design courses. The survey identified the importance of industry-sponsored projects, teamwork, course duration, course logistics, and requirements for project completion. These aspects were confirmed through literature [2] and online survey [3]. Non-technical aspects of the course that make students better engineers were also discovered [4], [5]. To assess senior design courses across engineering disciplines, Larry J. McKenzie pointed to Accreditation Board for Engineering and Technology (ABET) outcomes [6]. The outcomes with sufficient specificity enable straightforward assessment. With this framework, the course can be revised to accommodate the rise in enrollment [7] and the preparation of students for the course can be implemented [8], [9].

Depending on the available spatial and manpower resources, universities implement either one-semester or two-semester format for their senior design. Regardless of the format, a capstone

design course will be successful if the needs of all stakeholders – students, faculty, industry, academic administration – are considered [10]. In 2005 University of Alberta changed their senior design from a two- semester course to a one-semester course in response to a large increase in the number of students [11]. They found that the new senior design project workload has no impact on the performance of other classes. On the other hand, University of Florida added a second semester course to its existing one-semester course in 2020 to provide students with hands-on experience [12]. The Citadel went beyond a two-semester course by inserting an Introduction to Mechanical Engineering System Design course in the junior year as a pre-requisite for senior design [13].

Mechanical engineering capstone senior design at North Carolina State University had been a one-semester course credited four hours. At minimum, there are two fall and four spring classes in an academic year. There are occasions when an extra fall and/or spring class be added. A typical senior design class has six teams, each composed of five members, working on an industry sponsored project. In a team, manufacturing positions include one machinist, two shop fabricators and two welders; administrative positions include one captain, one company contact and one treasurer. The teams are graded on four presentations – Feasibility Study Review (FSR), Preliminary Design Review (PDR), Critical Design Review (CDR) and Detail Design Review (DDR), three cumulative reports, and the prototypes. In addition, each student is graded individually on feasible design and engineering notebook.

Starting fall 2019, senior design was converted into a sequence of two courses, each credited three hours. The design phase is covered in the fall. The teams are graded on three presentations – FSR, PDR and Mock-Model, and two cumulative reports. For individual grades, each student submits feasible design, engineering notebook, and a certificate in manufacturing. The prototype construction phase is covered in the spring. The teams are graded on four presentations – CDR, first test of the prototype, final test of the prototype and DDR, one cumulative report, and the prototypes. Individual grades are from engineering notebooks.

While the two-semester format provides a better design experience, it does create limitations for the students and the department.

a. The rising seniors who fail pre-requisite courses for senior design must pass these courses no later than the summer preceding the fall semester. If such courses are not offered at the university and their equivalent courses are not offered at other universities in the summer, the students will delay their graduation by one year.
b. Cooperative Education Program students with two or more work rotations are restricted to starting the first work rotation no later than the spring semester of their junior year.
c. One technical elective course is taken away.
d. More spatial resources are needed. A facility with the maximum capacity of four classes, once accommodating four classes in the spring and two classes in the fall, must now be expanded to accommodate six classes.

2. One-Semester Capstone Senior Design

Table 1 shows the abbreviated version of the syllabus for a one-semester capstone senior design. Note that a spring semester class is represented here. A fall semester class would have a similar syllabus due to the same requirement of in-class time.

Let's observe the one-semester senior design. The conceptual design phase is from week 2 to week 4. The embodiment design phase is from week 5 to week 8. Because of such time constraint, only a limited number of concepts in design can be covered. Week 9 to week 15 is the prototype construction phase. Note that the students only have five weeks to construct their prototypes because week 9 is the first gathering in the design facility and week 10 is spring break. The six milestones are written in red as shown in Table 1. The grades earned are in accordance with these milestones:

- Group FSR presentation (10%); Individual FSR reports (5%)
- Group PDR presentation (10%); Group PDR report (10%)
- Group CDR presentation (10%); Group CDR report (15%), Engr. notebook (5%)
- Testing (15%)
- Group DDR presentation (10%); Group DDR report (5%), Engr. notebook (5%)

Table 1. Syllabus for a one-semester capstone senior design

WEEK	TOPIC
1	• Introduction to ME Design course, Syllabus, Engr. Notebooks • Report Format, Presentation Guidelines
2	• **Problem Introduction by sponsors** • Team Assignments • Problem Statement – Brainstorm (Instructor/Students)
3 **Training begins**	• Background, Literature Review, Personnel, References; Allocate mfg. positions • Description of Design, Simulation, Design Methodology, Schedule
4	• Feasibility Study, Optimization Method, Deliverables, Safety, Impact on Society, Ethics • **Group FSR presentation; individual FSR reports due**
5	• Assembly Details, Material Selections, Mechanisms, Design for Manufacturing • Preliminary Design Review Presentation Guidelines
6	• General Economics, Cost • **Group PDR presentation – Sponsors attend; group PDR report due**
7	• Analysis
8 **Training ends**	• Appendices – **Shop Drawing Due** • **Group CDR presentation – Sponsors attend; group CDR report, engr. notebook, peer review due**
9 - 14	• Test Design, Statistical Analysis of Data (Instructor/Students) • Prototype Construction • **Testing** (*informal demonstration of the prototype in lab*)
16	• **Group DDR presentation – Sponsors attend; group DDR report, engr. notebook, peer review due**

3. Two-Semester Capstone Senior Design

Although many design textbooks can be selected for the design phase of the course, the first challenge is to add and arrange the new design concepts in accordance with what already existed. The second challenge is to schedule the milestones throughout the entire year. The original cluster from the one-semester format and the newly added milestones must be re-aligned.

Table 2 shows the syllabus for the fall semester of a two-semester capstone senior design. Recall that in a one-semester senior design, the materials in the conceptual and embodiment design phases are covered in the first half of the semester. They are now spread out over an entire semester and placed specifically in the second meeting of the week. These materials are written in black in both tables 1 and 2.

In table 2, the newly added materials are written in blue. The new materials in design concepts [14] are placed in the first meeting of the week to complement the original materials. For example, even though only the weighted decision matrix is included in the report, Pugh chart and Analytic Hierarchy Process (AHP) are now added. By the end of the fall semester, many more concepts in design are covered in the course.

There are eight milestones in the fall semester. Note that the original milestones are still written in red as shown in table 2. However, some are underlined in blue to designate the new sequence. Also, the newly introduced milestones are written in blue as previously mentioned.

The grade breakdown according to these milestones is:

- Individual FSR reports (7%)
- Group FSR presentation (10%)
- Group PDR report (25%); certified in manufacturing (3%)
- Engr. notebook (5%)
- Group PDR presentation (10%)
- Group Mock-up Model presentation (10%)
- Group CDR report (25%); Engr. notebook (5%)

Table 3 shows the syllabus for the spring semester of a two-semester capstone senior design. Recall that in a one-semester senior design, the entire second half of the semester is used for prototype construction. They are now spread out over an entire semester. The original works are written in black in both tables 1 and 3. The newly added works are written in blue, for example, first test of the prototype, test follow-up, statistical analysis and so on. The breakdown of the grades for the spring semester course is:

- Group CDR presentation (10%)
- Group first test of the prototype (20%); Engr. notebook (5%)
- Group final test of the prototype (20%)
- Group DDR report (20%)
- Group DDR presentation (10%); Group prototype demonstration (10%)
- Engr. notebook (5%)

Even though the percentages of grades are assigned differently between a one-semester format and the two-semester format, the performance in capstone senior design remains the same.

Table 2. Syllabus for the fall semester of a two-semester capstone senior design

WEEK	TOPIC
1	• Introduction to ME Design course • Introduction to projects
2	• Section assignments; Team structure, Syllabus, Preparing for problem introduction by sponsor; Team behavior and tools (D&S 4.2-4.5, 4.8) • Syllabus, Engr. Notebooks, Report Format, Presentation Guidelines; Background, Literature Review, Personnel, References; Allocate mfg. positions
3 Training begins	• Engineering Design (D&S 1.1, 1.2, 1.4) • **Problem Introduction by sponsors**
4	• Gathering Information (D&S 5.1, 5.4, 5.6, 5.9) • Problem Statement – Brainstorm (Instructor/Students)
5	• Concept Generation (D&S 6.5-6.7) • Team Assignments; Description of Design, Simulation, Design Methodology, Schedule
6	• Decision Making and Concept Selection (D&S 7.3, 7.5, 7.6) • Feasibility Study, Optimization Method, Deliverables, Safety, Impact on Society, Ethics; **individual FSR reports due**
7	• Decision Making and Concept Selection (D&S 7.6, 7.7) • **Group FSR presentation – Sponsors attend; rough draft of FSR presentation submitted to sponsor in advance**
8	• Embodiment Design (D&S 8.2, 8.3) • Assembly Details, Material Selections, Mechanisms, Design for Manufacturing
9 Training ends	• Embodiment Design (D&S 8.4, 8.5) • General Economics, Cost; **group PDR report due**
10	• Embodiment Design (D&S 8.5, 8.6) • Analysis; Preliminary Design Review Presentation Guidelines; **engr. notebook, peer review due**
11	• Embodiment Design (D&S 8.7) • **Group PDR presentation – Sponsors attend**
12	• Embodiment Design (D&S 8.8, 8.9) • Discuss of analysis with teams; Discussion of the graded PDR report with teams
13	• Materials Selection (D&S 11.3-11.5, 11.7-11.9) • **Group Mock-up Model presentation – Sponsors attend if so desired**
15	• Design for Manufacturing (D&S 13.5, 13.6); Quality (D&S 15.2, 15.3, 15.5) • Test Design, Statistical Analysis of Data; Appendices; Preparation for CDR presentation (spring); **group CDR report, engr. notebook, peer review due**

Table 3. Syllabus for the spring semester of a two-semester capstone senior design

WEEK	TOPIC
1 - 3	• Critical Design Review presentation guidelines – **Shop Drawing Due** • Prototype Construction • **Group CDR presentation – Sponsor representatives attend**
4 - 8	• Test Design, Statistical Analysis of Data (Instructor/Students) • Prototype Construction • **Group First Test of the Prototype presentation – Sponsor representatives attend if so desired; engr. notebook, peer review due**
9	**Group testing follow up**
11 - 12	• Prototype Construction • **Group Final Test of the Prototype presentation – Sponsor representatives attend if so desired – Test Design, Statistical Analysis of Data completed**
13, 14, 15	**Group DDR report due; group DDR presentation – Sponsor representatives attend; engr. notebook, peer review due**

To reveal the advantages of the two-semester senior design, the timeline for the milestones are shown. Like the syllabi in tables 1 – 3, the original milestones are written in red, and the newly added milestones are written in blue.

4. Results from the Conversion of the Design Phase

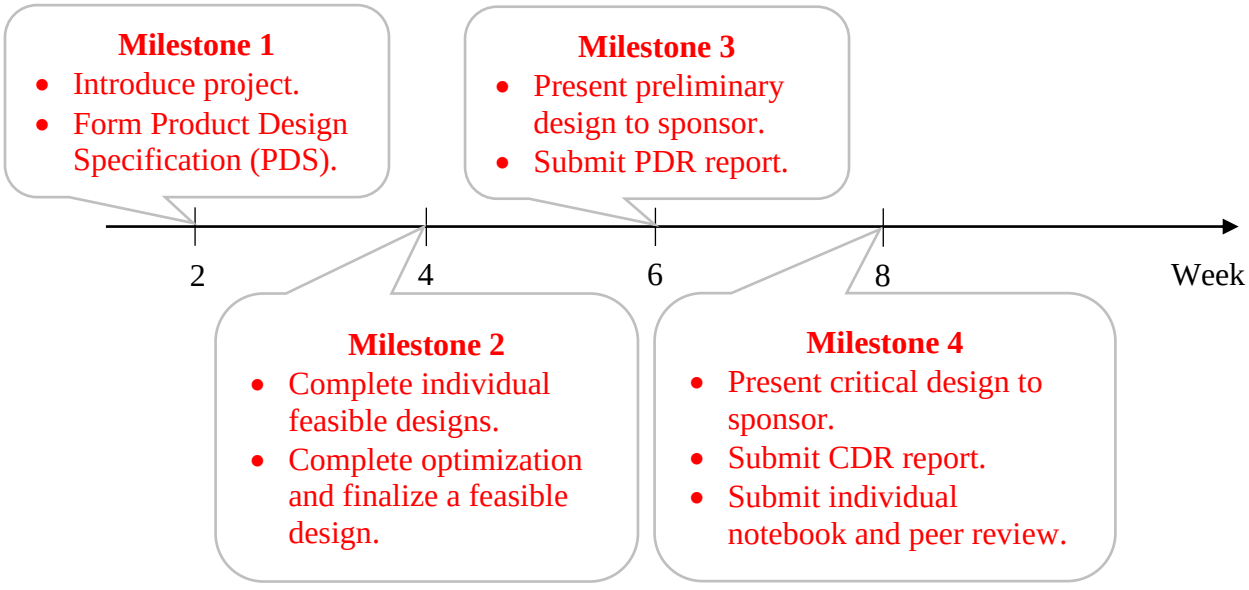

Figure 1. The first four milestones in a one-semester senior design

The timeline for the milestones in the first half of a one-semester senior design is shown in Figure 1. The drawbacks can be identified.

a. The students must form the Production Design Specification (PDS) in the same week the project is introduced (milestone 1). Note that due to the time constraint, teams are formed as soon as possible in week 3.
b. Due to the time constraint, there is no sponsor's assistance in the optimization process, resulting in higher chances for substandard solutions (milestone 2).
c. The teams receive the first feedback from the sponsor while proposing the preliminary design (milestone 3). Because the turnaround time from preliminary design to critical design is only two weeks, the opportunity for re-designing a substandard design is extremely rare (milestone 4). This results in the prototype not working or partially working. The construction of the prototypes follows immediately one week later.

Most of these milestones now are expanded into one semester (Figs. 2 and 3). The multiple tasks crowded in a milestone can now be separated, and each can become a milestone by itself. Note that two new tasks in milestone 3, and two new milestones, 5 and 7, are introduced.

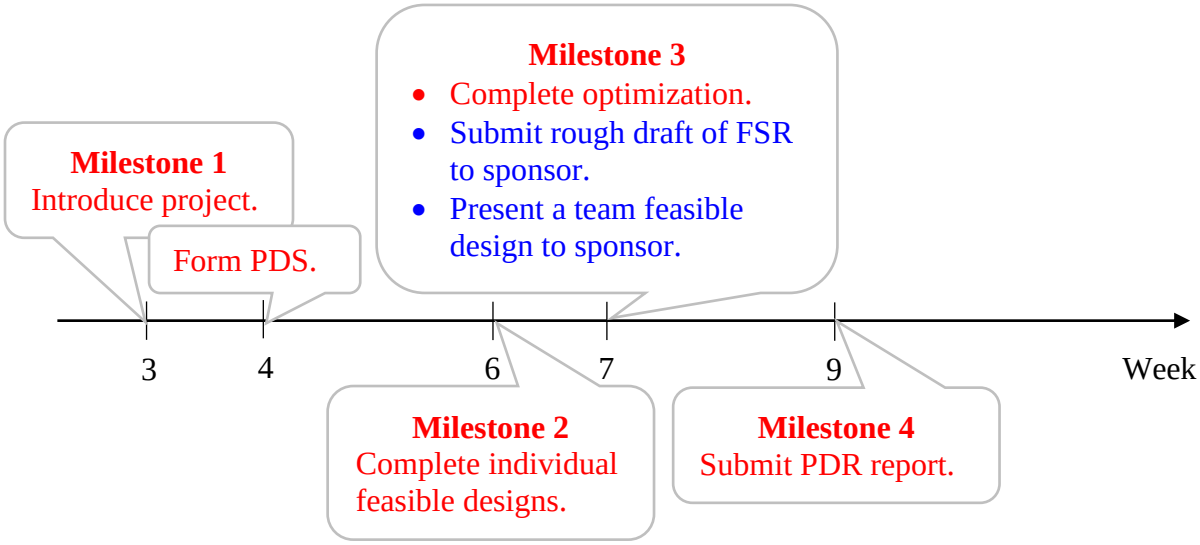

Figure 2. The first four milestones in the fall for a two-semester senior design

Compared to a one-semester senior design, the advantages in the early design phase can be seen (Fig. 2).

a. Because an extra week is available, each student is enabled to contribute to the PDS (milestone 1).
b. No time constraint forces the teams to be formed while the students are still in the brainstorming stage for individual designs. Because every student is able to complete his/her own feasible design without being influenced by teammates, more original designs become available (milestone 2). The designs are also more practical because the students can be trained in manufacturing during the brainstorming period.
c. Each team can complete the optimization process, finalize a feasible design, and present it to the sponsor. Due to the sponsor's assistance in the optimization process, the chances for substandard solutions are much lower (milestone 3).

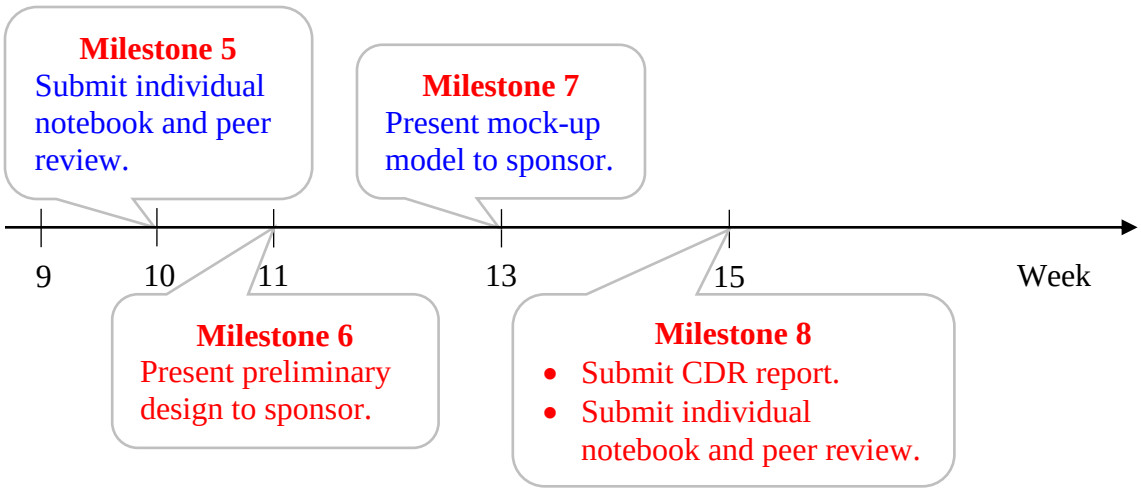

Figure 3. The last four milestones in the fall for a two-semester senior design

The advantages continue in the later phase of design also (Fig.3).

a. The two-week separation between submitting the PDR report (milestone 4) and presenting the preliminary design to the sponsor (milestone 6) allows the teams to modify the design to satisfy the existing and new criteria. Therefore, the presented design, even though labeled preliminary design, is actually the critical design at an early stage.

b. A newly added submission of individual notebook and peer review after the FSR phase provides an extra checkpoint (milestone 5) that is not available in a one-semester senior design.

c. The newly introduced mock-up model presentation, which does not exist in the one-semester senior design, provides insight into spatial constraints, relative motions of the parts, and manufacturing processes (milestone 7). Thus, the students become more practical beyond what they have learned earlier during the manufacturing training sessions.

d. The turnaround time from preliminary design to critical design is six weeks, allowing the teams to re-design and document the changes (milestone 8) in the last three weeks in the fall and continuing to do so in the first three weeks in the spring.

5. Results from the Conversion of the Construction Phase

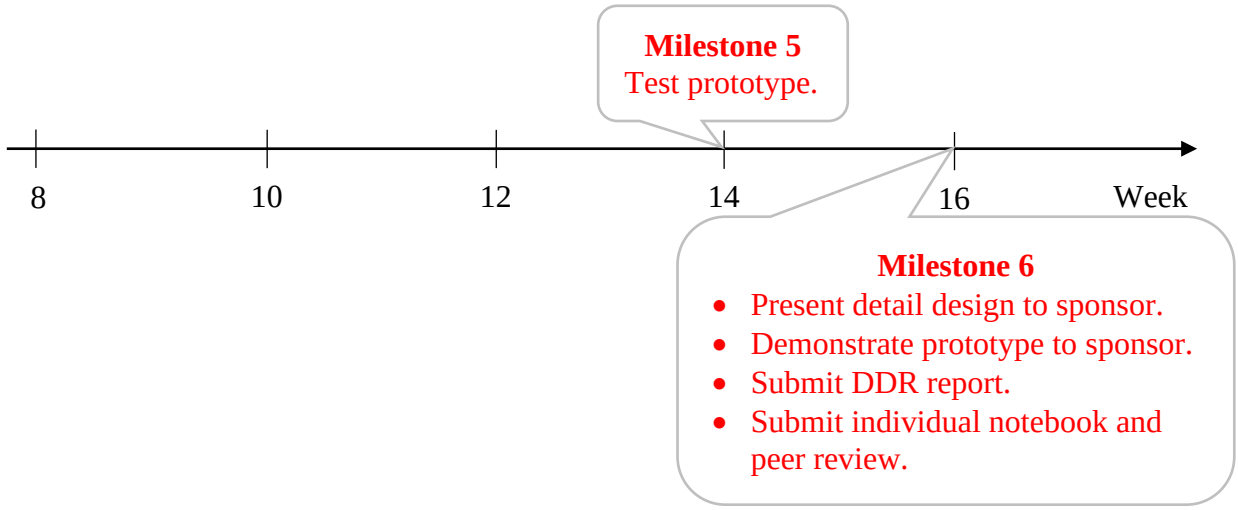

Figure 4. The last two milestones in a one-semester senior design

Observe the second half of a one-semester senior design (Fig. 4).

a. The second half is entirely for the construction of the prototype. Even so, the prototype is tested in week14, and because the teams only have at most five weeks to build the prototype, the evaluation of robustness by operating and collecting 30 or more data points is nearly impossible (milestone 5).

b. Senior day (milestone 6), an all-day public event for presenting detail design and demonstrating the prototype is often in a rush because of the interference from other tasks.

This construction phase is expanded into one semester (Figs. 5 and 6).

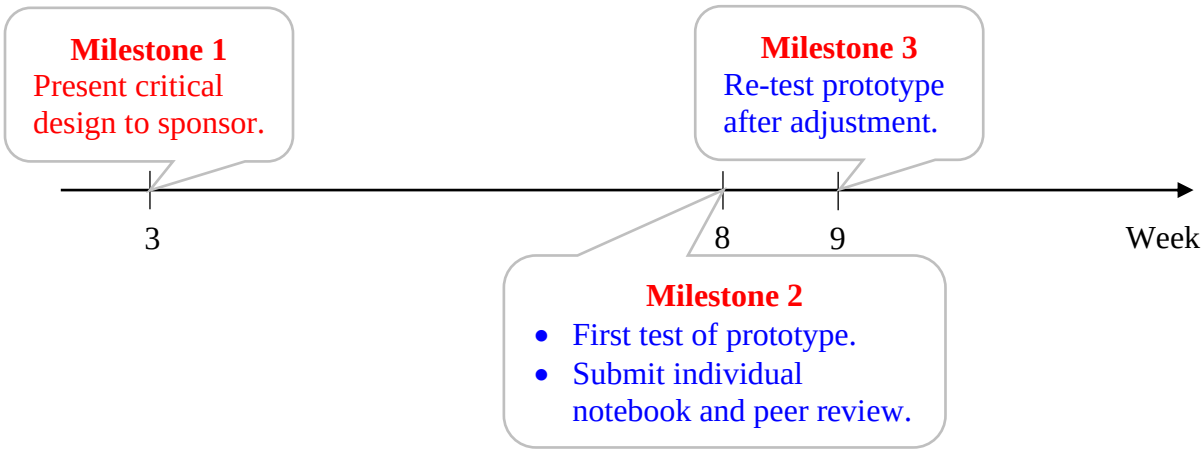

Figure 5. The first three milestones in the spring for a two-semester senior design

a. The extra three weeks at the start of the spring semester allows the teams to refine the design; thus minimizes the possibility of an unwanted reversal of the design discovered during construction (milestone 1). Note that this is the only left-over milestone from the design phase.

b. The teams are required to finish the prototypes in seven weeks which is only two weeks longer than what they have in a one-semester senior design (milestone 2). However, this test is not the final and only test of the prototype. Instead, it is the newly introduced first test of the prototype. Here the teams have an opportunity to trouble-shoot and adjust accordingly (milestone 3). Such an opportunity is not available in a one-semester senior design. Also, a newly added submission of individual notebook and peer review provides a checkpoint at the end of the construction.

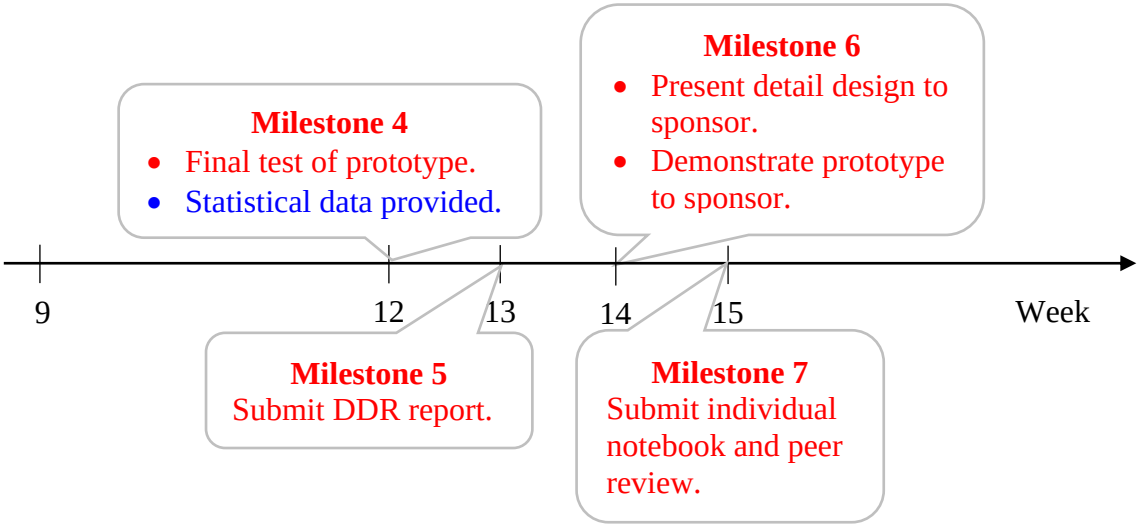

Figure 6. The last four milestones in the spring for a two-semester senior design

a. The final test of the prototype (milestone 4) contains a statistical analysis of data proving robustness of the prototype. This option is available due to the extra three weeks after the adjustment.

b. The separation of the submission of the DDR report (milestone 5), and the submission of the individual notebook and peer review (milestone 7) from senior day (milestone 6) provide a better engagement between the students and the public.

6. Conclusions

Capstone senior design has been taught in a one-semester format for many years. This format provides the rising seniors a chance to catch up with the course work when they happen to fail pre-requisite classes for senior design or to have a last-minute change of heart about joining the Cooperative Education Program in their senior year. Starting fall 2019, senior design was converted to a two-semester format. The new format puts restrictions on the graduation path for such seniors. It also takes away credit hours available for one technical elective course and requires an expansion of the design facility. However, it allows the students to take on a more challenging problem and provides the student with an opportunity to work alongside real-world engineers for an extended period. It is these occasions from which the students learn about the practicality of a solution. The timeline for the milestones shows the advantages of the two-semester format. Because time is no longer a constraint, more design concepts are taught in the design phase, the probability of a working prototype is much higher, and robustness could be evaluated in the prototype construction phase. This paper shows the conversion of capstone senior design from a one-semester format to a two-semester format.

References

[1]. Robert H. Todd, Spencer P. Magleby, Carl D. Sorensen, Bret R. Swan, and David K. Anthony, "A Survey of Capstone Engineering Courses in North America," *Journal of Engineering Education*, 1995, pg. 165-174.

[2]. Alan J. Dutson, Robert H. Todd, Spencer P. Magleby, and Carl D. Sorensen, "A Review of Literature on Teaching Engineering Design through Project-Oriented Capstone Courses," *Journal of Engineering Education*, 1997, pg. 17-28.

[3]. Susannah Howe and Jessica Wilbarger, "2005 National Survey of Engineering Capstone Design Courses," *Proceedings of the 2006 American Society of Engineering Education Annual Conference & Exposition*, Chicago, Illinois, 2006, pg. 11.4.1-11.4.21.

[4]. Bob Bond, "The Difficult Part of Capstone Design Courses," *Proceedings Frontiers in Education 1995 25th Annual Conference. Engineering Education for the 21st Century*, Atlanta, Georgia, 1995, pg. 2c3.1-2c3.4.

[5]. James Pembridge and Marie Paretti, "The Current State of Capstone Design Pedagogy," *Proceedings of the 2010 American Society of Engineering Education Annual Conference & Exposition*, Louisville, Kentucky, 2010, pg. 15.1217.1-15.1217.13.

[6]. Larry J. McKenzie, Michael S. Trevisan, Denny C. Davis, and Steven W. Beyerlein, "Capstone Design Courses and Assessment: A National Study," *Proceedings of the 2004 American Society of Engineering Education Annual Conference & Exposition*, Salt Lake City, Utah, 2004, pg. 9.286.1-9.286.18.

[7]. Manish Paliwal, and Bijan Sepahpour, "A Revised Approach for Better Implementation of Capstone Senior Design Projects," *Proceedings of the 2012 American Society of Engineering Education Annual Conference & Exposition*, San Antonio, Texas, 2012, pg. 25.100.1-25.100.13.

[8]. Mohammed El-Abd, "Preparation of Engineering Students for Capstone Design Experience through a Microprocessors Course," *International Journal of Engineering Pedagogy*, 2017, Vol. 7, No. 4, pg. 91-101.

[9]. H. I. Abu-Mulaweh, "Capstone Senior Design: A Small Engineering Program Experience," *Proceedings of the 2004 ASME International Mechanical Engineering Congress and Exposition*, Anaheim, California, 2004, Vol. 47233, pg. 153-158.

[10]. Robert H. Todd and Spencer P. Magleby, "Elements of a Successful Capstone Course Considering the Needs of Stakeholders," *European Journal of Engineering Education*, 2005, 30:2, pg. 203-214.

[11]. David S. Nobes, Curt Stout and Mark Ackerman, "The Impact of Senior Design Workload on Student Performance," *Proceedings of the 3rd International Symposium for Engineering Education*, University College Cork, Ireland, 2010, pg. 1-8.

[12]. Matthew J. Traum, Sean R. Niemi, Michael W. Griffis, Noel A. Thomas and W. Gregory Sawyer, "Implementing an Effective Large-Enrollment Engineering Capstone Design-and-Build Program," *Proceedings of the 2020 American Society for Engineering Education Southeastern Section Conference*, Auburn, Alabama, 2020, pg. 8-10.

[13]. Monika Bubacz, Deirdre Ragan, Nathan Washuta and Kevin Skenes, "Introducing Competition to Improve Design Aptitudes in Introduction to Mechanical Design Course," *Proceedings of the 2020 American Society for Engineering Education Southeastern Section Conference*, Auburn, Alabama, 2020.

[14]. George Dieter and Linda Schmidt, *Engineering Design*, 5th edition, New York, NY, Mc Graw-Hill, 2013.