Staggered Lectures: The Learning Effect of Timing on Formal Lessons in an Engineering Capstone Design Course

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Abstract:
This paper examines how the timing of formal lessons in an engineering capstone design course effects student learning. Formal lessons provide design methodology instruction, in contrast with project working sessions that offer unstructured group work time. The SE450 one-semester project course at West Point originally had all formal content lessons at the beginning of the semester, and student feedback in 2017 precipitated a change to stagger the formal lessons with the intent of timing them for maximum impact on students’ application in their projects. Research methodologies include the use of student reflections and a textual analysis of their responses as well as analysis of course-end feedback. McKeatchie and others have established that student reflections provide value in analyzing student learning. This research sought to examine the effect of the curricular change on learning, and preliminary results suggest that staggered timing is indeed valid.

1. Introduction

Engineering education in the mid-Twentieth Century focused on providing engineers with highly technical skills steeped in theory. By the late 1980s, academic leaders realized that this drive had gone too far, with the result being that trained engineers often did not have a grounding in product design and the ability to see the limits of theory in applied settings (Durfee, 2000). Thus the need had arisen for design courses that focused on application and process.

At the United States Military Academy at West Point, all non-engineering majors are required to take a three-course engineering track from one of the accredited engineering departments. Each engineering sequence generally consists of a foundational course in the discipline, a methods course, and a one-semester capstone project course. These engineering tracks are by nature multidisciplinary, in that they include majors from all non-engineering programs. That is the context in which the Department of Systems Engineering’s Core Engineering Sequence program exists. The final course in the Systems Engineering track, SE450: Applied Systems Design and Decision-Making, pairs multidisciplinary student teams with clients who have real problems for which they seek help solving.

In the present structure of SE450, students receive a total of 5 formal lessons following the Lesson 1 introduction. The content of those lessons is mostly a review of the Systems Design Process and supporting analytical methods. Prior to Academic Term 2018-1 (AT18-1), all formal lessons occurred at the beginning of the course. Project working sessions constituted the remainder of the lessons, typical of capstone design courses. Student feedback in the spring 2017 semester indicated a strong desire to have the lessons staggered throughout the term to provide more targeted value from the instruction. The question at hand for this research is whether or not the timing of those formal lessons makes a difference on student learning. At the outset of research, the hypothesis was that timing the formal lectures to approximately coincide with where students would need the material in their projects would improve learning and application. Initial student feedback over the two semesters of Academic Year 2018 seem to validate this concept.
2. Relevant Existing Research

To examine the role of formal instruction in capstone design courses, a review of the development of such courses and their practices provides some valuable insights. Some capstone courses include formal design lessons in their curricula, while others rely on students learning foundational process methodologies in pre-requisite courses earlier in their studies. The selected case studies that follow demonstrate the development of multidisciplinary capstone courses and partially illustrate a trend of targeted formal lessons within the capstone model, with the intent of teaching relevant design process skills for application in the capstone project. Beyond some insight into the use of targeted lectures, however, there is a noticeable lack of research on the timing of specific lessons.

Colorado School of Mines – Model Curriculum for Capstone Design

In the 1990s, the Colorado School of Mines (CSM) recognized the need for multidisciplinary design in engineering education. CSM developed its Multidisciplinary Senior Design (MSD) program to meet this curricular need. As Ronald Miller and Barbara Olds documented, the MSD program paired multidisciplinary student teams with outside industrial clients “to solve complex, open-ended problems possessing numerous technical and non-technical constraints,” resulting in generally better designs due to the breadth of knowledge inherent to each multidisciplinary team (Olds, 1994). The student learning objectives of the MSD included using creativity to solve “open-ended, ‘real-world’ problems,” using a multidisciplinary approach, working with both technical and non-technical skill-sets, consider both technical and non-technical constraints, developing relationships with clients, and improving communication skills (Olds, 1994).

The MSD program at CSM included formal instruction and unstructured project working sessions. As Olds reported, students usually received one formal lecture per week and had the remainder of their class time to work on their capstone projects. The formal lectures covered project organization and management, quality, professional communication skills, the engineering design process itself, analysis techniques, liability and safety, professional considerations, and presentation and report preparation. Projects culminated in a public demonstration. Both student surveys and client feedback validated the program, and it went from a pilot project to a fixture of the institution (Olds, 1994).

Engineering & Business Capstone Program at UMinn

The University of Minnesota (UMinn), one of many engineering programs to identify and address this dynamic, undertook two initiatives to improve design application skills. First, the Department of Mechanical Engineering introduced a sophomore level design course that gave students a series of design projects and emphasized both practicality and professional communication skills in project deliverables. Secondly, UMinn developed an interdisciplinary graduate design course in which engineers and business students worked together to develop a product. That second program pertains most directly to the research at hand. William Durfee documented these efforts in 2000 and provided insights on the lessons learned from the initiative (Durfee, 2000).

UMinn’s graduate course brought together second-year Master’s in Business Administration students with graduate engineering students, partnered these interdisciplinary teams with industry, and required them to design and develop a product for their industry clients by the end of the course. Durfee stressed that providing student teams with real projects for real clients was critical, to the point of requiring the industry partners to commit to producing the final products. Durfee noted that the “formal academic component of the course should centre [sic] on learning a product development process. This is what differentiates the course from a work-study programme [sic] or company internship that does not
require formal academics… we advocate a total development process, from needs identification through product launch and beyond” (Durfee, 2000).

**University of Toledo**

More recently, the University of Toledo (Toledo) launched a senior design program in 2013 that combined engineering and business students. According to Matthew Franchetti and Sonny Ariss, Toledo sought to develop a new program that better prepared students for the complex problems they would face in the real world upon graduation, similar to the earlier programs. The Departments of Mechanical Engineering and Management created their Senior Design Clinic capstone, which targeted the need for complex, multidisciplinary problem-solving and applying skills to problems that did not have existing solutions. It utilized industry collaboration. The one-semester clinic employed weekly lectures to provide students with relevant instruction for their design and prototyping efforts. The lectures included the design process, project management topics, entrepreneurship and business planning, legal and ethical considerations, technology transfer, and communications. Toledo compared student performance in the capstone course before and after it became a multidisciplinary program and found consistent improvement across all metrics. (Ariss, 2016).

**Engineering Text: Cambridge Handbook for Engineering Education Research**

In the *Cambridge Handbook for Engineering Education Research*, Anette Kolmos and Erik de Graaff traced the development of Problem-Based and Project-Based Learning (PBL) methods in academia and provided a model framework for broad course design considerations. These included three dimensions: curriculum elements, from outcomes and types of problems/projects to faculty roles; aspects of the teacher-centered approach as it related to each curriculum element; and aspects of a student-centered approach relating to each curriculum element. The authors note that “[t]here are also lectures in the PBL curriculum, and the relation between lectures and projects – as well as the role of projects – has to be considered, as either applying the knowledge taught and/or creating new knowledge” (Kolmos, p. 152). In SE450, the course-long project requires the application of the methods taught during the formal lectures.

**Conclusions from Literature**

As the case studies and established texts demonstrate, there is a definite trend in academia of establishing multidisciplinary design capstones in engineering programs. Further, there is clearly a role for formal lectures in such programs, typically covering the design process. Lectures on the design process are critical for student application. Available research, though, is practically non-existent when it comes to examining the efficacy of formal lecture timing. The present study seeks to begin to fill that void.

3. **Methodology**

Student surveys and reflections each provide a means to capture student assessments of their learning. Wilbert J. McKeachie, in *McKeachie’s Teaching Tips*, advocates the use of open-ended questions to solicit quality feedback from students to facilitate teaching improvement (McKeachie, pp. 340-341). That methodology informs the framework for the present study. As Kolmos and de Graaff established, “Reflection is an important part of developing competences [sic] in handling the process. Studies indicate that reflection methods, such as portfolios with individual and team-based reflections, have an impact on students’ approach to the learning process” (Kolmos, p. 152).
The research effort began in October 2017 in the fall semester and continued through April 2018 with the spring semester. Throughout the study, the author’s assigned class sections provided the population for analysis (32 and 19 of enrolled 60 and 134, respectively). A standardized reflection prompt template provided the mechanism to seek student feedback on the value gained from each formal lesson, regarding content, timing, and application. In the fall term, students completed reflection essays on Decision Making (Lesson 25) and Project Management and Solution Implementation (Lesson 31). The reflection questionnaire asked students to answer three questions, shown in Figure 1 below, of which Question 2 is the focus of the present research. Additionally, at the end of the term, the course-end feedback survey asked students a variety of questions, including specific questions about the timing of the formal lessons. These took the form of a 5-point Likert scale. Unlike the reflection essays, the course end feedback system is completely anonymous and provides closed-form answers to the given questions.

<table>
<thead>
<tr>
<th>Q1</th>
<th>In a concise paragraph, answer the following question. What did you learn from the ATM value-scoring/decision-making exercise that you did not know or understand before?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2</td>
<td>Explain how the timing of the lesson supported or impeded the progress on your capstone project.</td>
</tr>
<tr>
<td>Q3</td>
<td>In a concise paragraph (or two at most), offer your perspective. Explain how you will [be able to] use the total value modeling and sensitivity analysis in your project as a result of this lesson.</td>
</tr>
</tbody>
</table>

Figure 1. Reflection Questions for Decision Making. The basic questions remained the same for all questionnaires, with only the subjects changed.

In the spring term, the research expanded to examine the range of formal lessons. Of note, there were two significant changes made in the course from the fall to spring semester. First, instructor consensus and anecdotal student feedback suggested that the Project Management & Solution Implementation (PM) lesson would provide more value earlier in the course. Second, going along with that, the instructors also agreed that it was appropriate to add a Project Action Plan (PAP) graded requirement early in the course. Adding the PAP offered to add value to the course by giving the students a mechanism to apply the PM lesson material as well as help them map out their own plans to accomplish their individual projects. With these changes in mind, students completed reflections on Lesson 3: Problem Definition; Lesson 4: Project Management and Solution Implementation; Lesson 18: Solution Design; and Lesson 25: Decision Making.

Extracting meaningful, measurable data from qualitative responses can be challenging due to the wide variance of qualitative written responses. This research sought to address that through the use of positive and critical identifier words. Examining the frequency of common key verbiage offers the ability to analyze qualitative textual responses in a standardized manner. In particular, aggregated analysis using identifier words presents a method to construct a holistic picture beyond the individually nuanced responses. Positive identifier words included support, help, good, great, perfect, optimal, allow, and beneficial, among others. Critical identifiers included such words as hinder, early, earlier, late, soon, and poor. For example, early was a critical identifier when used in a manner such as, “the lesson was too early in the semester.”

With each reflection survey, students provided their individual responses, and the de-personalized data then formed an aggregated data file. In each reflection data set, an initial scan of the responses identified common positive and critical word usage. These formed the basis for a quantitative analysis. Systematically searching all responses in the given data set for the common identifiers then provided concrete results for aggregation. Counter-factual usage of identifiers did not count, e.g., “having the
lesson any earlier would not make sense,” or language to that effect. Mariette Bengtsson, in her research on content analysis, stressed the importance of such contextualization to ensure content only counts when it is used in the manner in which it is being analyzed (Bengtsson, 2016, pp. 8-9). The common identifier words changed slightly in some versions, based purely on the responses. Previously used identifiers with zero responses were not included in the tabulated results. Beyond the standard set of identifier words for each data set, both Other Positive and Other Critical categories included words or phrases that offered either sustaining or improving language, respectively, but did not merit inclusion in the standard identifier list. Finally, it is important to stipulate that each identifier only counted once per student response, even if an individual used a particular word more than once. This method of accounting ensured that repetition by particular students would not have an outsized impact. Using other identifiers, though, does strengthen the response.

At the end of the Fall 2017 semester, the course end feedback survey included a section for students to evaluate the timing of formal lessons. The questions in the course-end survey are below in Figure 2.

| Having the Problem Definition class in Lesson 3 enabled me and my team to effectively begin using the Systems Decision Process to understand and analyze our problem. |
| Having the Solution Design Class during lesson 17 enabled me and my team to more effectively generate solution alternatives for our project. |
| Having the Decision Making class on/about lesson 25 enabled my team to more effectively analyze and compare alternative solutions with respect to total value scoring. |
| Having the Solution Implementation Class in lesson 31 enabled me and my team to better develop implementation plans and/or address the question of risk in a system lifecycle. |
| If all of the formal lessons had been taught at the beginning of the course instead of staggered throughout the semester, our group would have been able to complete all the phases of the Systems Decision Process just as well. |

Figure 2. Pertinent Questions from AT18-1 End-of-Course Feedback. Students rated each statement on a 5-point Likert scale of agreement, from Strongly Agree to Strongly Disagree.

4. Results

During both semesters of the study, the research focused on the Decision Making (DM) and Project Management/Solution Implementation (PM) lessons, providing the most comprehensive data on these lessons. The Decision Making lesson occurred on Lesson 25 in both terms. There were 32 student respondents in AT18-1 and 18 respondents in AT18-2. The aggregated results are shown below:

<table>
<thead>
<tr>
<th>Decision Making</th>
<th>AT18-1</th>
<th>AT18-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Critical</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>78%</td>
<td>22%</td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>Critical</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>79%</td>
<td>21%</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Aggregated Results of Positive & Critical Text Identifiers from Decision Making student reflections.

The aggregated results in both terms provide overwhelming support for scheduling the DM lesson on or about Lesson 25. It is particularly noteworthy that the percentages are nearly identical. The output charts that include the individual identifiers for each term follow in Figure 4 and Figure 5. Similar to the
totals, the individual identifier charts from each term are remarkably alike, differing mainly due to the number of respondents from one term to the next.

Figure 4. Individual Text Identifiers for Decision Making in AT18-1.

Figure 5. Individual Text Identifiers for Decision Making in AT18-2. All reflection surveys resulted in a similar chart of identifiers.

In the case of the Project Management/Solution Implementation (PM) lesson, though, the results bore out quite differently, depicted in Figure 6 below. As previously noted, during AT18-1 the PM lecture occurred on Lesson 31. Student and instructor feedback resulted in a course change that included a Project Action Plan requirement on Lesson 11 and the PM lecture during Lesson 4. Despite making
this change with the student feedback from AT18-1 in mind, the results proved remarkably negative.

<table>
<thead>
<tr>
<th>Project Management &amp; Solution Implementation</th>
<th>AT18-1</th>
<th>AT18-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>Critical</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>65%</td>
<td>35%</td>
<td>56%</td>
</tr>
<tr>
<td>44%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6. Aggregated Identifiers in Project Management reflections, AT18-1 and AT18-2.

In the first term, positive identifiers comprised a 65% majority, and the curriculum adjustment sought to address the relative dissatisfaction underlying the 35% critical identifiers. As the aggregated identifier numbers from AT18-2 indicate, though, the opposite result occurred. Positive identifiers still held a 56% lead, but the use of critical identifiers increased in both percentages and raw numbers. Further examination of the raw data provides additional insight. In AT18-1, 9/25 students (36%) used critical language, and in AT18-2 the number was 7/18 (38%). The raw proportions of student opinions, devoid of identifier language amplification, is very similar. It is in this case that the use of aggregated identifiers provides particular value, in that it helps illustrate how strongly the respondents felt about the issue. One critical student response in AT18-2 demonstrates the nuance of timing:

I think the lesson could have been placed a few lessons later. By frontloading all of the information, I think it gave us the incentive to try to do problem definition and the project planning at the same time. I think giving a couple working sessions after problem definition, and then a couple after the PAP [Project Action Plan] guidance, would allow later. By frontloading all of the information, I think it gave us the incentive to try to do problem definition and the project planning at the same time. I think giving a couple working sessions after problem definition, and then a couple after the PAP guidance, would allow us to focus on each part separately and make sure we give each part the correct amount of time.

Building on the first term research, the study expanded in AT18-2 to include both Problem Definition and Solution Design lessons. Both are essentially review lessons of material covered in the SE300 course, which students typically take in the previous academic year. Problem Definition has historically occurred on Lesson 3, and that remained true for both terms of the study. It is difficult to imagine having the lesson any later, but this research sought to validate that assumption. With 18 student responses, the reflections yielded 24/25 positive identifiers (96%). The overwhelmingly positive result seems to validate the hypothesis conclusively. The only critical response discussed having the lecture after the initial client meeting. This idea has merit, but it is impractical to accomplish systemically, as initial client interactions vary greatly.

In the case of Solution Design, the timing remained much more of an open question. Initial results from the AT18-1 Course End Feedback suggested that staggered timing was auspicious, warranting further analysis in AT18-2 with reflection essays. The Solution Design lecture occurred on Lesson 18, intended to approximately correspond with the end of the problem definition phase of student projects. Reflection analysis validated the timing of this lesson, with 25/27 positive identifiers (93%).

Beyond student reflections, the Course End Feedback survey from the fall semester asked respondents to evaluate the timing of the formal lessons using a 5-point Likert scale of agreement. For example, on Solution Design, the survey asked students to assess the following: “Having the Solution Design Class during lesson 17 enabled me and my team to more effectively generate solution alternatives for our project.” As a control measure, the last question asked students to consider whether
they would have gotten the same value if all of the formal lessons were held at the beginning of the course. The results of the survey, illustrated below in Figure 7 and Figure 8, seemed to validate the concept of staggered formal lectures. The total “agree” responses for the individual lesson timing questions were all high, ranging from 76% to 85%. The “disagree” responses remained low, from 5-10%. When it came to the last question about having all formal lectures up front, the total “agree” responses dropped to 58%, and the “disagree” responses jumped to 27%, suggesting that lesson timing definitely matters for a substantial portion of students.

Figure 7. Course End Feedback Analysis for AT18-1.

Figure 8. Course End Feedback for AT18-1, Agree/Disagree Totals.
5. Conclusions

As the student reflections and course survey results from 2018 demonstrate, the timing of formal lessons in a capstone project course can effect the value that students receive from such lessons. Most significantly, research results have shown that the concept of staggering formal lectures to coincide with student progress is valid. The large discrepancy on the Project Management lesson from one semester to the next, following the schedule change, is itself an indicator of the potential for lesson timing to impact how much value students take from the material. This has potentially far-reaching implications. Numerous engineering programs have capstone design courses, and many include a series of formal lectures. Any such program could potentially gain value by examining the timing of included formal lessons. There are likely opportunities for improvement, just as this study observed with the Project Management lesson. Students in engineering and business capstone courses have project deliverables that they have to meet throughout their programs. The initial results of the present research suggest that students appreciate and gain value from having formal content timed for maximum relevance in their projects.

Continuing the study will offer further data for analysis, either additional confirmation or points for adjustment. Extensions may include an analysis of historical grades, expansion across sections, or even including reflections in conjunction with project deliverables. Beyond SE450, any capstone design course could gain value from analyzing the timing of its formal lessons.

References


