On the Use of Design Reviews During a Two-Year Capstone Design Experience: The James Madison University Model

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Design is widely considered a central and distinguishing activity in engineering practice. In the context of undergraduate engineering education, capstone design is the central and distinguishing activity required by all ABET accredited engineering programs. At James Madison University, the capstone design experience is a two-year or four-semester experience where students are guided through four key phases of the design process: (1) planning and information gathering, (2) concept development, (3) embodiment design, and (4) detailed design. To guide and facilitate students through these four design phases, a Design Review process was recently implemented using Design Review Panels and four Oral Design Reviews: (1) System Requirements Review, (2) Preliminary Design Review, (3) Critical Design Review, and (4) Detailed Design Review. In this paper, we present details about the JMU Capstone Design Model, the Design Review Process, Design Review Panels, and an initial evaluation of the process provided by student and faculty responses. Overall, although still a new feature of the JMU Capstone Design Model, the Design Review process has proven to be successful in facilitating both formative and summative assessment of progress during the capstone design experience.

Keywords: capstone design, design reviews, capstone evaluation, faculty panels.

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Introduction

Design is widely considered to be the central or distinguishing activity of engineering.[1-2] A good education in engineering design can give students the skills required to creatively solve real-world problems and create an opportunity for them to begin the process of becoming engineering professionals. Since the late 20th century, engineering undergraduate curricula have reincorporated design course(s) to "facilitate practical engineering application" and to build upon the engineering science foundation.[3] The most common way engineering programs integrate practical design application is via capstone design experiences, which typically include a project and/or related coursework. As a result of ABET accreditation requirements for capstone design and industry calling for more practically trained engineers, these capstone design experiences continue to be revered as "the most important educational component in almost all undergraduate engineering curricula."[4]

Although the structure of capstone design experiences varies widely across programs, all ABET-accredited programs must attempt to satisfy the following ABET requirement: "Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs. Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints."[5] Although ABET requires that capstone design be a culminating learning experience, ABET does not specify what engineering design entails nor how engineering design or even capstone design projects are to be evaluated.

Evaluation of a capstone experience involves both the outcomes of the project (i.e., the artifacts produced) and individual student learning and contributions to the capstone team.[6] Capstone projects can be assessed by formative and/or summative means[6] through student peer evaluation and self-reflection, faculty advisement and mentoring, client reviews, industry panels, or other methods. [6-7] Often, capstone work is evaluated via both written and oral communications.[7]

The James Madison University (JMU) Engineering Department, which admitted its first class in 2008, was founded on the recognition that engineers are no longer constrained to disciplinary boundaries, and instead, must work across disciplines as members of global communities and multidisciplinary teams.[8-9] The program offers a single undergraduate engineering degree that focuses on sustainable design and systems

thinking. At JMU, the capstone design experience spans two years or four semesters during junior and senior year.

The purpose of this paper is to present the newly established feature of using Design Reviews during the two-year capstone experience at the Department of Engineering at James Madison University.

JMU Capstone Design Model

The capstone design model at JMU provides students with four successive semesters working on the same design project. The decision to design a four-semester capstone experience was driven by the fact that a longer duration capstone project would enable students to apply the engineering design process more thoroughly in both breadth and depth.[10] Previous publications detail the content coverage of the courses that align with the capstone design experience at JMU.[10-11]

Table 1 illustrates the vision of the JMU engineering capstone model in terms of semester foci and key design deliverables. This capstone design vision was inspired by the Dieter and Schmidt "Engineering Design" textbook[12] used in the design courses as well as an industry design model summarized in terms of four design reviews: Systems Requirement Review (SRR), Preliminary Design Review (PDR), Critical Design Review (CDR), and Detailed Design Review (DDR). The capstone experience is part of four design courses at JMU: Engineering Design III (ENGR 331), Engineering Design IV (ENGR 332), Engineering Design V (ENGR 431), and Engineering Design VI (ENGR 432).

Table 1: Two-year JMU capstone design model.

Semester	Key Design Review Deliverables
Design III-ENGR 331 (Fall Junior Semester)	
Planning and Information Gathering	***System Requirement Review (SRR)*** **–** problem statement, literature review, market analysis and/or stakeholder analysis, customer needs and system requirements, system modeling, project management plan (budget, timeline, team member roles and responsibilities), etc.
Design IV-ENGR 332 (Spring Junior Semester)	
Concept Generation, Evaluation, & Selection	***Preliminary Design Review (PDR)*** **–** iteration of system requirements, target specifications, concept generation, concept evaluation, and concept selection, functional modeling, iteration of project management plan, etc.
Design V-ENGR 431 (Fall Senior Semester)	
Design Embodiment (e.g. Prototyping, Modeling &Testing)	***Critical Design Review (CDR)*** **–** design embodiment, analytical and physical modeling, testing procedures and analysis, reliability analysis, evaluation of concept with system requirements, iteration of project management plan, etc.
Design VI-ENGR 432 (Spring Senior Semester)	
Detailed Design (e.g. Testing, Modeling & Production)	***Detailed Design Review (DDR)*** **–** analytical and physical modeling, testing and analysis, sustainability evaluation, manufacturing and production, commercialization, marketability, project management plan, etc.

During ENGR 331, the students begin the two-year capstone project in groups of four to five with one or two capstone faculty advisors. Overall, the first semester of the project is focused on problem formulation, research, and planning with some teams moving on to the concept development design phase.[10] The capstone teams continue to move through the design process through both in-class instruction and out-of-class project work as indicated in Table 1.

Design Review Panels and Design Review Process

In Fall 2013, Design Review Panels were introduced to the JMU Capstone Model to facilitate in the progression and evaluation of capstone projects. To pilot the practice, Design Review Panels were initially assigned to each senior team during their fall semester. In the future, the goal is to assign Design Review Panels to all junior capstone teams at the start of their capstone experience and maintain the same panels for four semesters.

The composition of each Design Review Panel included four members: Capstone Advisor(s), one Design Course Instructor (in the case that one was not already a capstone advisor), and other Engineering Faculty or Staff based on area of expertise. The three key goals of the piloted Design Review Panels were to: (1) provide capstone teams constructive and collective feedback on the details and progress of their capstone project, (2) evaluate individual team member understanding of the technical and non-technical aspects of the capstone project, and (3) evaluate a capstone team's process of making project decisions informed by pertinent engineering analysis. A typical semester timeline (***Figure 1***) for the Design Review Process included the submission of the preliminary design report by the capstone team within week 8 to 10, the Oral Design Review two weeks later, and the submission of the final report during the last week of the semester.

Figure 1: Typical semester timeline for reviews.

During the Oral Design Reviews, each team had 45 minutes with its Design Review Panel. No formal presentation was required, but many capstone teams elected to spend the first few minutes orienting their Design Review Panel with the key progress made during the semester. Subsequently, the key format of the Oral Design Reviews was questions posed by Design Review Panelists followed by student responses and then feedback from the Design Review Panelists. A moderator was assigned to each Oral Design Review to ensure adequate tracking of time as well as adequate

time allowance for each student to respond to questions. In all cases, the moderator was one of the Capstone Advisors.

Evaluation during the Oral Design Reviews was two-fold: *Capstone Design Report Evaluation* and *Individual Capstone Student Evaluation*. In regards to the Capstone Design Report Evaluation, Design Review Panelists provided feedback using a rubric to improve capstone design documentation and overall project progress. Given that Design Review Panelists had two weeks to review the Preliminary Design Report, each Panelist came to the Oral Design Review with a completed rubric and in some cases a marked-up report to hand the capstone team. In regards to the Individual Capstone Student Evaluation, Design Review Panelists provided an individual performance rating for each student on the capstone team. This rating was based on each team members' responses to technical questions and apparent technical understanding of the project. Scores were tallied and averaged to yield one score for each student that became part of the student's grade in the class.

During the last week of the semester, teams provided their Design Review Panels with two documents: (1) an electronic submission of the Final Design Report, and (2) an accompanying Cover Letter summarizing the feedback received and how the capstone team addressed this feedback in the Final Design Report. Using the aforementioned report evaluation rubric, panelists reviewed and evaluated the Final Design Reports. Design Review Panelists focused their feedback on the technical aspects of the project, particularly how engineering analyses informed engineering decisions. Course Design Instructors, on the other hand, focused their evaluation of the Final Design Report on design process/methods and technical writing. If capstone teams had not adequately addressed the feedback provided by the Design Review Panel to the extent to which *Major Revisions* were still needed, all team members received an incomplete for the course. Students were allowed to enroll in the next Design Course, but would be ineligible to graduate unless all "incomplete" requirements had been met.

Evaluation of Design Review Process

At the end of the fall semester, senior students and faculty were asked to evaluate the Design Review Process. Fifty students chose to participate in this evaluation and this corresponded to a 92% response rate. More specifically, senior students in class were asked to anonymously answer two questions: (1) what were positive aspects of the Design Review Process? (2) what could be improved about the Design Review Process? Thematic network analysis, recommended byAttride-Stirling[12]was deemed most appropriate because it allowed for the systematic extraction of common themes and evaluation of the relative importance of each. Two coders, a faculty member and an alumnus engineering student, developed the coding framework by noting common thematic threads surfacing in the student responses. ***Table 2*** and ***Table 3*** present the themes that emerged from the two open-ended questions, along with the frequency of responses. From the frequency of responses shown in Tables 2 and 3, it is evident that the positives of conducting Design Reviews exceeded the negatives. The feedback that the capstone teams received helped them improve the direction of their capstone project, but also their capstone reports. The feedback received from third party panelists (i.e. other faculty beyond capstone advisor, external sponsors, or engineering staff) was valued by the capstone students, as were new perspectives identified. Students even suggested that such a process should be implemented earlier and throughout the capstone experience.

Table 2: "Positive Aspects" themes emerging from anonymous senior student responses.

Emergent Theme	Frequency
The feedback received was valuable to improving the capstone project	40
There were unique and valuable perspectives identified during the Design Reviews	35
Design Reviews should be conducted throughout the capstone experience	32
The feedback received was valuable to improving the capstone report	23
The feedback received from third party panelists (other faculty, external sponsors, staff) was valuable	18
The semi-formal setting was conducive to effective and appropriate feedback	17
The composition of the Design Review Panels was good and appropriate	15
The Design Review provided the team a good reality check and evaluation of the project status	15

In regards to opportunities for improvement, it appears that some additional clarity about the purpose of the Design Reviews would benefit both the faculty/Design Review Panelists as well as the students. Some students even suggested longer Design Reviews to fully cover the amount of feedback received by the Design Review Panelists and to allow ample opportunity for all capstone team members to respond to questions. Resolving the latter issue could lead to a "fairer" assessment of individual team member performance. Allowing more time to discuss feedback could improve the clarity of feedback provided, which was also cited as an area for improvement.

Table 3: "Opportunities for Improvement" themes emerging from senior student responses.

Emergent Theme	Frequency
Some Design Review Panelists seemed to be unclear about the purpose of the Design Reviews or how to use the evaluation rubric	15
Students did not know how to prepare for the Design Reviews	15
Some of the feedback received was unclear	14
There appeared to be poor time management during the Design Reviews (i.e. more time needed, not everyone answered questions)	13
The assessment of individual team members by Design Review Panelists seemed to be unfair	13
Students experienced animosity by some Design Review Panelists	10
Some of the questions were out of context or out of the project scope	9
There appeared to be some disagreement between Design Review Panelists	8

Conclusions

Overall, the use of Design Review Panels and a formal Design Review Process has proven to be successful for our students and program. The majority of capstone teams adequately addressed their review panel's feedback and met the requirements. Such positive outcomes along with the positive feedback on the process provide justification for implementing the Design Review Panel approach earlier and throughout our two-year capstone experience. We plan to fully implement Design Review Panels and the Design Committee will continue to monitor effectiveness.

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