Best Practices in Assessing Capstone Design Projects

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This paper reports on development, implementation, and adoption of best practices in the redesign of the mechanical engineering capstone design sequence at the University of Rhode Island during 2007-2009. Rethinking of the approach and pedagogy in capstone design also provided an opportunity for us to develop new assessment instruments and rubrics for evaluation of the design projects. A list of assessment instruments that we have created or adopted based on review of best practices in the literature, peer surveys, and our own experience is presented. Rubrics are provided for two of the major assessment instruments: critical design review and preliminary design report. Consistent assessment instruments and associated rubrics have proven to be an essential element of preparing student teams for successful design project experiences and evaluation of their work.

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Background

Since the adoption of the senior capstone design experience by ABET, Inc. in 1996 under Engineering Criteria 2000 (EC 2000)[1,2] there has been significant changes to the curricula of engineering programs. A number of excellent assessment methods have been developed, tried, and reported in the literature. [3-10] In particular, the work of Howe and Wilbarger[11] is extremely useful in identifying capstone design implementation patterns and some of the best practices.

We began a complete redesign of our mechanical engineering capstone design courses in 2007. We developed a holistic approach based on the best practices we found in the literature, survey of other engineering programs, and our own combined experience of more than 35 years of teaching and a set of rubrics for assessment of the design teams and projects. In this paper we report the best practices we have found to be useful in our experience.

The development of a consistent and well-documented framework for assessment of design teams and projects is very important to the accreditation process. Assessment rubrics are also important in teaching and communicating the complex process of design project assessment to the student teams. Student teams are better equipped to respond to the demands of the capstone experience when they have an understanding of the evaluation metrics for their projects.

Variations of the Capstone Design Sequence

In our research and review of literature, we found that capstone design courses come in many flavors and varieties at different institutions. Each institution has adopted their own customized version of the capstone design experience[11] with some of the following notable variations:

- Total semester equivalent credits vary from 3 to 6
- Total duration of time varies from one semester/quarter to one calendar year
- The students may be from a single major or multiple majors in the teams (multidisciplinary within the major to trans-disciplinary)
- One or more professors may be teaching or coordinating the course
- Project definitions may come from industry, state government, federal government agencies, design competitions, research projects, or the instructor
- Projects may be funded internally, externally, or unfunded
- Project space and access to laboratories is generally provided to the students
- Field trips to engineering companies or laboratories may or may not be required by the course/instructor
- Scope of projects and experience is affected by other factors depending on the customs, traditions, priorities, and policies of the institution
- Formal design instruction/lecture may or may not be part of the course; a textbook may be or may not be required
- Project management techniques (using software tools) may or may not be used

All of these factors affect the assessment specifics and the rubrics that may be developed for the specific capstone design course(s). In developing the mechanical engineering capstone design sequence at the University of Rhode Island, we adopted the following features for our curriculum:

- Two-semester, three-credit design sequence (one academic year starting in September and ending in May)
- Students were initially only mechanical engineering but we have experimented with including business and industrial engineering students in the design teams; class size has been 40-72 students
- Two professors team-teach/coordinate the course
- Projects are sponsored by industry, research projects, or national design competitions
- Majority of the projects are industry-funded/ sponsored; very few are internally-sponsored/ funded
- We created an engineering design studio space for the teams (range of 8 to 14 teams of 4-6 students)
- Field trips to local engineering companies is required for industry sponsored projects
- A text is required for the course[12]
- Project plan and progress must be managed and tracked with software tools

Philosophy of the Design Projects and the Process

Our philosophy in the development of the capstone design sequence is that each project must result in the development of a realized product through a formal well-documented and reproducible process. Each team is expected to follow the following processes for the development of their designs:

Fall semester

- Define the problem
- Develop design specifications
- Plan and manage the project
- Research possible solutions or supporting information
- Generate concepts (minimum of 30)
- Evaluate each concept
- Evaluate the competition
- Design using engineering tools/analysis
- Develop proof of concept(s)
- Present/defend the design through critical design reviews (2 per semester)
- Document all steps and preliminary design details in a comprehensive document

Spring semester

- Build/implement the design
- Develop a test engineering plan and test the design
- Redesign or make improvements based on the test results; implement the improvements
- Test again, improving the test scope if appropriate

- Improve the design and implement the improvements
- Present/defend the design through design reviews (2 per semester)
- Document all steps and final design details in a comprehensive document
- Present final design in a design showcase to industry representatives, faculty, fellow students, and the community at large

Assessment Best Practices

We have developed a holistic assessment system that is delivered through the Sakai[13] course management system. In designing the elements of this system, we have developed and adopted many best practices learned through literature search, informal surveys, and our experiences and experiments. Our assessment system includes the following components:

- Individual weekly progress reports submitted electronically
- Team weekly progress reports (cc to professors and sponsor)
- Individual assignments to prepare the team for problem definition and concept generation (literature/internet search, patent search, concept generation, quality function deployment analysis, resume preparation and update)
- Individual skills inventory at the beginning of the fall semester
- Team meetings with professors and sponsor(s) three times a semester – weekly team meetings
- Individual design log books – individual is required to bring to each meeting or design activity
- Team design notebooks – team is required to keep updated and present at each meeting with professors and sponsor(s)
- Mid-semester design presentations, critical design reviews
- Confidential peer evaluations by/for each team member (detailed two page form) once per semester
- End-of-semester design presentations and end-of-year design showcase
- Preliminary Design Report at the end of the fall semester (50-200 pages) documenting all aspects of the design
- Final Design Report at the end of the spring semester (end of the academic year) (100-300 pages) documents all details of the design
- A technical brochure for the product
- A 36"x24" poster for the project to be used for the end-of-the year design showcase and for team participation in conferences (for example, the Northeast ASEE conference)

- Supplemental reports including: user guide, safety guide, operation and maintenance guide, regulatory compliance documentation, test and reliability reports, recycling or disposal information

Rubrics

We have developed a rubric for each assessment instrument listed to communicate expectations to students and to assist us in a uniform and consistent evaluation of our design projects. The rubrics focus on core requirements for each assessment activity. Formal feedback is provided to the design team by reviewing their performance on key assessment activities: design presentations and design reports. Feedback on other assessment components is provided during regular professor meetings with the teams. We present here the rubrics for the critical design review presentations and the written preliminary design report. The final design report includes other elements including a test engineering plan and results, redesign, operation and maintenance, manufacturability, assembly, and other considerations (environmental impact, societal impact, political considerations, ethical considerations, health, ergonomics, and safety analysis).

Individual design logbooks are maintained by each individual student and can be inspected by professors at any time during scheduled meetings. Teams are required to maintain an updated design notebook which is a collection of all relevant information related to the design. The design notebook guidelines provide the framework for information that the teams must collect and maintain. The design notebooks are maintained in a 3-4" three-ring binder with appropriate tabs. In our experience, most teams will completely fill the 3" three-ring binder by the end of the second semester.

Design Notebook Contents

- Problem Definition -- definition and supporting materials for the problem being addressed
- Team Work -- Team minutes, weekly progress reports, e-mail correspondence
- Engineering Analysis -- Notes, sketches, preliminary analyses/calculations.
- Project Plan -- Project plan with baseline and updates, Gantt Chart and calendar of team tasks/ schedule/deadlines/milestones
- Presentations -- Any PowerPoint presentations created during the semester for the project
- Patent Search -- Results of patent search exercise collected by all team members.
- Design Approaches
- QFD - Quality Function Deployment/House of Quality analysis

- SolidWorks or hand-drawn sketches, blueprints, or plans for any of these
- BOM (bill of materials) -- connected to drawings, supplier lists, contact lists
- Systems Analysis -- Relevant analyses of systems, computational analysis (such as load bearing capacity, strength, thermal analysis, materials behavior, etc.)
- References -- Competition rules, industry material or specifications, articles, secondary research
- Supporting material, patents, industry material, other
- Modeling -- Any models, simulations in progress
- Trade Off Analysis -- Radar charts or formal model for comparing alternatives
- Financial Analysis
- Budget Plan
- Fundraising/sponsorship materials, letters, brochures, glossies
- Critical Thinking and Analysis -- Results of analysis of design with respect to economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
- Administrative -- Administrative paperwork including purchase orders, bid sheets, competition registrations, etc.
- Any other materials generated or used in the project

Rubric for Critical Design Review Presentations

Item	Points
Technical/Intellectual Merit	
Problem definition	5
Proposed solution strategy/method	5
Creativity/originality	5
Conceptualization/organization	5
Feasibility	
Scope	5
Probability of project completion	5
Qualifications of the team members for the project	5
Access to resources	5
Budget/Financial	
Budget estimates	5
Resource Development plan	5
Presentation	
Organization	5
Communication Skills	5
Interaction with the Audience (Q&A)	5
Overall Quality of the Presentation	
Value/quality of the team's work	5

Rubric for Preliminary Design Report (Fall Semester)

Item	Rating
PRESENTATION	
Abstract and Introduction	5%
Writing Clarity/Spelling/Grammar	5%
Instructor's Overall Appraisal of Report	5%
TECHNICAL MERIT	
Project Planning	5%
Economic Analysis	5%
Quality Function Deployment Analysis	5%
Literature and Patent Search	5%
Evaluation of Competition	5%
Engineering Design Specifications	10%
Conceptual Design	
Concept Generation	5%
Concept Evaluation	5%
Design for X (X for quality, safety, ergonomics, economy, etc.)	10%
Product Generation	10%
Engineering Analysis	10%
Conclusions	5%
Outlook - Future Work	5%
Total	100%

Conclusions

Capstone design projects are complex by their very nature. Open-ended design problems have many plausible solutions and there are an infinite number of ways that a project could produce a successful design. Developing a framework for the design process is a critical part of running successful capstone design courses. Consistent assessment instruments and rubrics are essential tools for assessment of capstone design projects. Rubrics are invaluable for courses that involve multiple evaluations (including professors, industry sponsors, peer evaluations, and members of industrial advisory boards).

We have presented a list of our assessment instruments and rubrics for two of our major assessment instruments. These instruments and rubrics have proven successful for our purposes.

The new capstone design sequence has been well received by our industrial partners, the industrial advisory board, and students.

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