2012

A Gated Review Process for Administering a Capstone Senior Design Course

Scott L. Post
Bradley University

A Gated Review Process for Administering a Capstone Senior Design Course

Martin Morris, Scott Post, and Julie Reyer,
Bradley University

This paper discusses the use of a gated review process for administering a capstone senior design course. A gated review process is a tool used in product and process development by companies and institutions. It is a process that systematically controls the progress of a design cycle while also managing the risks inherent with new designs. The process consists of four phased review elements. Each element terminates in a mandated gate review that is staged at key times during the lifecycle of the design projects.

Corresponding Author: Martin Morris, mjmorris@bradley.edu

Introduction

The Capstone Senior Design experience in the Mechanical Engineering Department at Bradley University spans two semesters of each student's senior year. The projects begin at the start of the fall semester and continue until the end of the spring semester. To enroll in the classes, a student must be within three semesters of graduation. The students are assigned to teams of 3-4 members with the purpose of delivering value to a client through an engineering solution to some need.

Each year members of the faculty solicit projects for the Capstone experience from clients external to campus. The pool of clients includes representatives from large corporations, small businesses, research laboratories, public institutions, and in some cases individuals. Each team project must require a significant engineering design component that is identified and documented during the solicitation process. Clients are asked to pay a participation fee as part of their commitment and with an expectation of receiving value from the team. The projects are scoped to require about 1200 hours of engineering work by the team, or 10 hours per week per student. This scope is mandated by the length of the academic year. The purpose, benefits, and outcomes of this approach is consistent with the findings reported by Dutson, et. al..[1]

A gated review process is used to administer and regulate the activities related to both the course and the individual design process required for each of the projects. The review process consists of four phased review elements that span the two semesters. The process used for the course is modeled after that of an industry process for introduction of new products[2]. Each element of the process terminates in a mandated gate review that is staged at intervals during the span of the design projects. Each gate review includes, at a minimum, the evaluation of the student team for both a written report and an oral presentation.

The gated review process is an effective tool for systematically controlling the progress of an assortment of teams while managing the risk associated with student performance on the projects. It is also an effective pacing mechanism for inexperienced and often apprehensive student teams. It has also has proven to be an effective feedback mechanism in guiding the progress of the teams. At each gateway review, the student teams get feedback from a faculty panel, student peers, and their client. The final review includes an evaluation by a panel of department alumni.

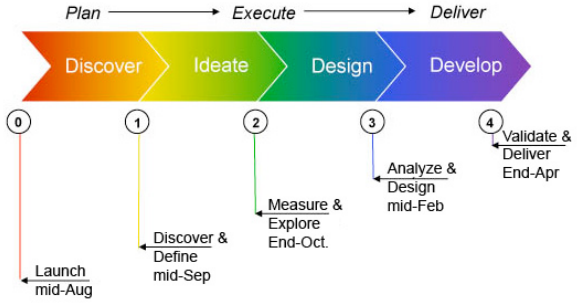

Figure 1. The Timeline of the Gated Review Process

Figure 1 shows the chronology and the related activities of the gated review process. As shown in the figure, each element of the process is not of equal duration. The first two gateway elements span a three-week and five-week period, respectively. Observation of student teams participating in this course for over a decade has shown that the student teams are slow in starting their projects. The early reviews are effective in engaging the students early and frontloading important parts of the project activity.

The project launch begins with the announcement of the teams at the beginning of the fall semester in August. The first gateway review, titled "Discover & Define", occurs in mid-September. The second gateway review occurs at the end of October and is titled, "Measure & Explore". A project proposal is produced during the period between the first and second gateway.

The third gateway review is scheduled for early in the spring semester and is titled "Analyze and Design". The third gateway review is an assessment of technical progress. The fourth and final gateway occurs at the end of the spring semester and is titled "Validate & Deliver"

An already noted, the progress of the team is evaluated at each gateway by a faculty panel, student peers, and their client. An unsatisfactory evaluation during these reviews by either the faculty or the client redirects the activities of the team onto a path of more direct and more regular faculty involvement that includes much closer scrutiny. A poor performance leads to a weekly meeting with the course instructor during which the team must develop and implement a recovery plan. These meetings continue until the team has recovered to the satisfaction of both the client and the participating members of the faculty. During the past three years, each gateway usually steers at least one team into this recovery process.

During the review process, individual performance is also evaluated. If an individual has demonstrated unsatisfactory performance, that individual is removed from the team – or "fired". That individual is given a separate but related project with an opportunity to earn the possibility of rejoining the team. Failure at the individual project results in a failing grade for the senior design course. This process happens about once per year.

Gateway 1: Discover & Define

The principle functions of this first gateway review element are to rapidly engage the students in their team's project activities, to familiarize the team with their client, and to familiarize the team with their design project. During this element of the gateway process, the students are primarily gathering, learning, and organizing information.

To facilitate the utilization of this new information, the team must develop a plan for a Quality Function Deployment (QFD)[3,4,5]. To complete the QFD, the team must define: 1) the Voice of the Customer (VOC), 2) the Voice of the Business (VOB), and 3) when appropriate, the Voice of the Regulator (VOR). This information is gathered into a draft of a "House of Quality".

The team must also begin to develop an outline for a technical approach to address the engineering requirements of the project. An important part of this activity is to develop two lists, a list of activities that are "in scope" and a list of related activities that are "out of scope". The plan and the scope of the project are both developed as a result of discussions including the client and the faculty advisors. These discussions are important because the information is used to define the scope of the overall project, a scope for which the students will be accountable at the end of the project.

Another important activity during this element of the process is for the students to identify the resources that are needed for the completion of the project. These resources include space, hardware, software, and expertise. The team must define which of those resources are already immediately available for project activities and those resources that must be acquired and at what cost. For the resources that are not immediately available, the team must develop the draft of a plan that includes a schedule and budget for acquisition or they must develop a new approach to a solution.

A written report is required that summarizes the findings of the team during this phase of the review process. This report consists primarily of information describing the client and the project. It includes background material, a description of the clients needs, a problem statement, a project scope, a discussion of resources, and a value proposition. All of this information is a foundation for future reports required at the following gateway reviews. This written report is distributed to the faculty participants and the client for review.

An oral presentation of this information is also presented to a faculty panel, peer students, interested members of the department's alumni advisory board, and the client. To facilitate access for this broad audience, the oral report is broadcasted live on the Internet as streaming video. The video feed is also archived on a computer server for later review by the team and members of the faculty. The streaming video feature has simplified participation in this oral review by the client and alumni.

At the end of the oral presentation, all of the reviewers are asked to complete a scoring rubric that evaluates: 1) knowledge of the client – values & brand, 2) appreciation of the problem, 3) technical knowledge and background information, 4) description of the required resources, and 5) presentation of information. The reviewers are also given an opportunity to provide written comments. The students are given the evaluations after the scores are recorded.

Gateway 2: Measure & Explore

The principle function of the second gateway review element is to develop a written proposal that is acceptable to the student team, the client, and the faculty participants. In addition to the information included in the first gateway report, the proposal must include a completed plan for a technical approach to the problem solution, a description of the required budget, and a list of deliverables.

The teams must develop a technical plan that uses a set based approach where they start with several concepts and converge to a single concept.[6] The project

proposal must contain a plan of activities that last until the end of the second semester and are graphically represented in a detailed Gantt chart. It must include a timeline that defines deadlines for the significant milestones defined for the project life cycle. The concept behind the development of this plan is, "Plan the work. Work the Plan."

The budget that is included in the proposal is allowed a degree of uncertainty, but must be acceptable to the client. The uncertainty is linked to the set based approach. The different concepts will likely have different costs. However, the budget in the proposal must clearly define the maximum and minimum to a range of costs that are required. The budget is specified with a degree of uncertainty, listing a maximum and minimum to the range of costs for the different design concepts.

The proposal must also include a list of deliverables. The deliverables that are specified in the proposal must be tangible items that are physically transferred to the client upon completion of the project (e.g. a report, a prototype device, a hard drive containing software or drawings, ….). This list must be developed through negotiations that include the student team, the client, and the participating members of the faculty. This is an extremely important component of the proposal because the transfer of all deliverables is a requirement for completing the course. Defaulting on any deliverable will result in a failing grade for the course. All three constituencies of the negotiation (faculty, client, and students) must sign the finished proposal indicating a consensus.

In preparing for the second gateway review, the team continues data collection and begins generating design concepts and alternatives. Any new information is integrated into the QFD. The information contained in the QFD is distilled to define the design requirements and function. It is also used to develop design specifications. Definition of the design function also leads to definition of the related modes of failure. The failure modes are assembled into a foundation for a Design Failure Modes and Effects Analysis (DFMEA)[7]. The information from this analysis is used for a preliminary description of the risks associated with the project.

The information contained within the written proposal is also presented in an oral defense of their plan by the design team. Again, the oral report of this information is presented to a faculty panel, peer students, interested members of the department's alumni advisory board, and the client. The oral presentation of the proposal is also broadcasted as a live streaming video on the Internet. For clients within a 100-mile radius of campus, the clients are allowed to request a live presentation of the proposal on their site. The video feed is also archived on a computer server for later review by the team and members of the faculty.

Similar to the first review, all of the reviewers are asked to complete a scoring rubric. This evaluation is based on: 1) a problem description, 2) the technical plan and schedule, 3) definition of the deliverables, 4) budget estimate and bounds, and 5) presentation of information. The reviewers are given the opportunity to provide written comments. The students are given the evaluations after the scores are recorded.

Gateway 3: Analyze & Design

Preparation for the third gateway review is primarily focused on the development of the design concepts using a thorough engineering analysis. The period lasts from October until February and it is a time during which much of the detailed engineering analysis is completed. During this phase of the review process the design teams must add detail to design concepts such that they satisfy the engineering requirements specified in the project proposal. Each project has different needs but activities during this phase could include the use of engineering design tools for activities such as solid modeling, finite element analysis, computational fluid dynamics, and others, to predict the performance of the leading design concepts. During this period, the design concepts could evolve to new concepts through an iterative design process. This activity is guided by the ongoing development of the QFD plan and the DFMA process. Any significant changes to the technical plan or budget must be documented in a recovery plan and approved by the client and participating faculty.

This third element of the gateway review process also includes the development of a written technical progress report. This report includes a description of the engineering analysis and a discussion of the results of the analysis. It must also include a discussion of the evolving down-select process from the original design concepts. Accompanying the discussion of the results, the report must include a plan for validating the engineering analysis. A validation plan could include building a prototype and testing or comparing the results to a complimentary analysis (e.g. other published results). As part of the third gateway review and reflecting a narrower spectrum of design concepts, the student teams are expected to deliver a budget with much less uncertainty.

The review of the third element includes a defense of the analysis presented as an oral report of the findings. As before, this presentation is delivered to a faculty panel, peer students, interested members of the department's alumni advisory board, and the client. This oral presentation is also delivered as a live broadcasted on the Internet as streaming video.

Similar to the previous reviews, all of the reviewers are asked to complete a scoring rubric. This evaluation

is based on: 1) a project status assessment, 2) the plan for completion, 3) the design analysis, 4) a line item budget, and 5) presentation of information. The reviewers are given the opportunity to provide written comments. The students are given the evaluations after the scores are recorded.

Gateway 4: Validate & Deliver

The fourth and final gateway review occurs near the end of the second semester of the class. In preparation for the fourth gateway, the team has down-selected to a final design concept, justified and validated the design analysis, communicated their findings to appropriate constituencies, and prepared to transfer the deliverables that were promised in the proposal. The team must also prepare an invoice for an amount consistent with the client-approved budget. The invoice should include all of the cost associated with completing the project.

In addition to a final written report and a final oral presentation, the last gateway review includes a public poster presentation summarizing the project. Each team must prepare a poster that includes a project description, the value to the client, the engineering analysis, and the results of the design process. The posters are displayed on campus to a panel of judges consisting of members from the Mechanical Engineering department's alumni advisory council in a venue open to the public. Each member of the judging panel completes a score sheet providing feedback on both the quality of the engineering work by the student team and on the quality of the project.

Each team must also deliver an oral presentation of their design work. The alumni advisory council selects four teams from the poster presentations for scoring by their panel of judges. Each member of the judging panel completes a score sheet providing feedback on both the quality of the engineering work by the student team and on the effectiveness of the presentation. The remaining teams deliver a final oral presentation to a faculty panel, peer students, interested members of the department's alumni advisory board, and the client. This final oral presentation is also delivered as a live broadcasted streaming video on the Internet. The video of this presentation is recorded and archived for later review. For clients residing within a 100-mile radius of campus, the student team must also deliver their final presentation to their client at their home location.

Again, all of the reviewers for the oral presentations are asked to complete a scoring rubric. This evaluation is based on: 1) a project status assessment, 2) the plan for completion, 3) the design analysis and validation, 4) a line item budget, and 5) presentation of information.

The written final report includes most of the material compiled in the previous written gateway reports. It includes background information, a problem description, a discussion of the technical approach, a discussion of the engineering analysis, a budget report, and a discussion of the result. One copy of this report is delivered to the project client, one is archived on campus, and one is sent to a panel of judges from the department's alumni advisory council. The panel of judges scores the written report on technical content and effectiveness of presentation. The score sheet also captures an assessment of the projects in satisfying the A-K outcomes required by ABET.

Conclusions

A gated review process is an effective tool for administrating and regulating the activities of a senior design capstone design experience. The four phased review elements that span the two semesters provide a structure to pace the inexperienced student teams through the design process. The mandated gate reviews provide valuable and timely feedback by both the participating faculty and the project client at intervals during the span of the design projects. The feedback helps to manage the risk associated with student teams addressing difficult design challenges often for the first time.

A measure of the success of the process is the return rate for our client base. In the three years that the gated review process has been used, more than 80% of the clients have returned the following year with a new project.

References

1. Dutson, A., Todd, R., Magleby, S., and Sorensen, C., A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses, Journal of Engineering Education, pp. 17-28, 1997.
2. Cooper, Robert G. (1993). Winning at New Products: Accelerating the Process from Idea to Launch. 2nd Ed.,Cambridge, Mass: Addison-Wesley
3. Guinta, L., Praizler, N., "The QFD book: the team approach to solving problems and satisfying customers through quality function deployment", AMACOM,1993.
4. Dieter, G., Schmidt, L., "Engineering Design," Fourth Edition, McGraw-Hill, 2009.
5. Ullman, D., "The Mechanical Design Process", Third Edition, McGraw-Hill, 2003.
6. Ward, A., "Lean Product and Process Development," The Lean Enterprise Institute, Cambridge, MA, 2007.
7. Lange, K., Leggett, S., Baker, B., "Potential Failure Mode and Effects Analysis (FMEA)," Third Edition, Automotive Industry Action Group, 2001.