Applying a Structured Development Process to an Entrepreneurial-Based Capstone Design Course

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Abstract

In the fall of 2010 the capstone course in the Electronics Engineering Technology program at Pittsburg State University was renovated. The basic premise of the course, an entrepreneurial backdrop, did not drastically change, though the focus was sharpened. The framework of the course was altered in order to improve student performance in the course. The renovation included the implementation of a structured product development process. Particularly, the structured process utilized is a form of a stage-gate process. The concept of stage-gate processes are widely utilized in industry settings. This is especially true for companies that develop and launch new products on a regular basis. This paper reports on how the stage-gate process was implemented into the course sequence. The paper will also cover the lessons learned after the first cycle of the course sequence and the future direction of the capstone course at Pittsburg State.

Introduction

Engineering technology programs often employ a senior level design course(s) in their curriculum. The objectives of these design courses vary, but the basic concept is to provide students an opportunity to devote a relatively large portion of their time and their skill set to a single applied engineering design problem. The objectives of most capstone courses are primarily design and design implementation. Additional objectives are typically included. Common objectives include teamwork, professionalism, decision making, and communication. Most capstone course structures make these objectives a natural part of the course [1-2]. For instance, communication, both written and oral is often an inherent aspect of the course. Programs may also include additional, non-traditional objectives to the course [3]. For instance, many capstone courses focus on interdisciplinary team aspects to help students adapt to working with colleagues from differing backgrounds. An intertwined aspect of capstone objectives is the source from which the capstone projects are derived. While many capstone design courses have projects developed by faculty and assigned to students, other courses may search out industry projects for students to complete while others may focus on design competitions. The objectives of the course, along with the source of derived projects, are primary factors in determining the structure of the course.

One course structure is based on an entrepreneurial approach. This suggests students are to develop their own projects. While this path may be fraught with issues, there are many

redeeming qualities as well. One drawback to such an approach is ensuring some level of parity in project complexity. The tradeoff is enhanced opportunities for student creativity. Also, allowing students to select projects in their field of interest ideally leads to more ownership in the project.

Traditionally in the Electronics Engineering Technology program at Pittsburg State, students have been allowed to develop their own project concepts and implement them. The course is designed such that the final projects are framed in an entrepreneurial / start-up setting. Over the course of two semesters, students have been expected to develop an idea, a design, a business plan, a working prototype, and a final engineering report. The general structure was to have the idea developed and the first draft of the design completed at the end of semester one. The second semester's primary focus was implementation and documentation. Specific milestones and checkpoints have been included.

The basic method utilized for the capstone course was relatively effective for many years. As with any course there are methods to improve and enhance the course. The motivating factors to renovate the course at Pittsburg State University include:

- Improve overall quality of the project designs and implementation
- Improve student timeliness
- Parity in project complexity
- Expose students to a "more realistic" design setting
- Expose students to a range of real-world engineering design issues
- Expose students to opportunities in entrepreneurialism

Quality of design and ingenuity as well as quality of prototypes are struggles inherent in the capstone course. Pushing students to produce innovative, above average projects is central to the Pittsburg State EET program as it is in many other programs as well. Another problem not unique to the entrepreneurial-based approach is timeliness. For many students, capstone projects include late or all –nighters the week that the project is due. The planned renovation of the EET program attempted to approach the timeliness aspect. This issue was to be addressed not only for timeliness sake, but also to assist in enhancing the overall quality of the project. The entrepreneurial approach means a wide variety of projects. Without safeguards, the wide variety of projects combined with student driven concepts and scope means design complexity can vary greatly. This is another aspect that the capstone instructors sought to improve.

EET Program at Pittsburg State University

Pittsburg State University is a regional four-year university located in the rural southeast corner of Kansas. The institution has approximately 7,000 students, the majority of which are full-time

undergraduate students. The Electronics Engineering Technology undergraduate program is a small program consisting of four full-time faculty, two adjuncts and approximately 70 enrolled students.

Students in the EET program are required to take three semesters of core curriculum studies in electronics engineering technology. The curriculum includes basic concepts relating to AC and DC theory, circuitry and measurement, digital logic concepts and an introduction to semiconductor devices and applications. After the completion of a 'core exam' course, students then take a selection of required upper-division courses within the EET program. Students also can select a specialization which includes, Aerospace Electronics, Control Systems, Embedded Systems, Telecommunication Electronics, and a customized emphasis. During the senior year, students are required to take a two-semester capstone design course sequence. The first semester consists of proposing, designing and developing a marketing plan for an entrepreneurial-based capstone project. The second semester has the students build a prototype of that project [4].

Stage-Gate Development Process

The stage-gate product lifecycle/development process is a structured method of product development [5]. For some time, a large majority of companies that do product innovation, from developing new product concepts to implementation, use some structured form of a product development process [6]. Structured processes, such as the stage-gate method, are used in order to develop products quickly while mitigating mistakes in resource allocation, design, documentation and in marketing strategies.

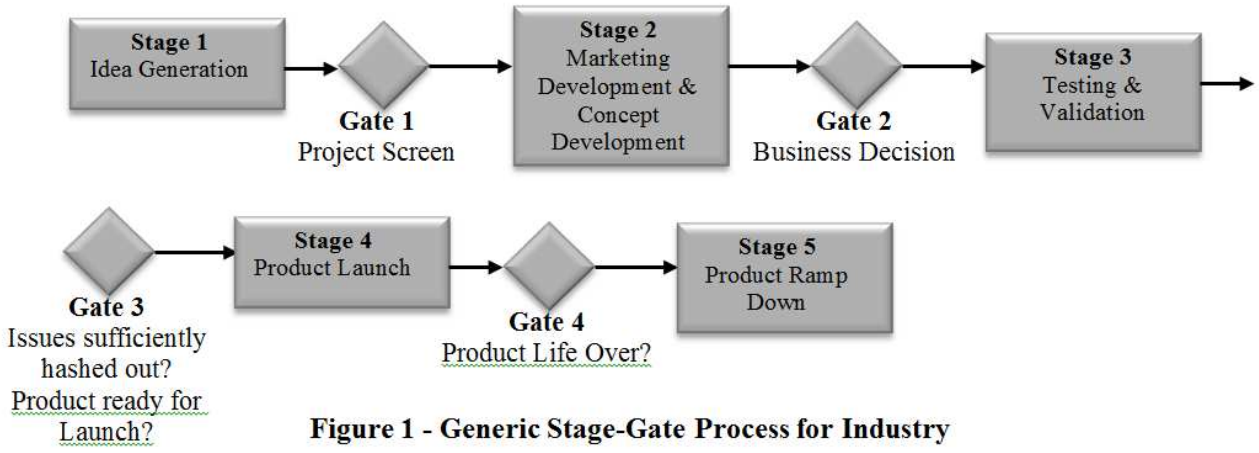

Figure 1 - Generic Stage-Gate Process for Industry

The stage-gate processes are made up of 'stages' and 'gates' (it's not just a clever name). A stage is a period of time in which a certain set of tasks are performed. A gate is a point in time where "gatekeepers" decide the status of a project, i.e. continue to fund project, recycle, terminate, etc. Gatekeepers are generally managers, executives or other decision makers for the company. Typically, at each gate a set of deliverables must be completed and submitted for

review. Deliverables vary with each gate but generally revolve around business and marketing information, design concepts and intellectual properties, concept/product validation and market validation [6]. Typical stage-gate processes can be divided into sections as shown in figure 1.

Though the number of stages and gates vary from company to company, the approach is similar. Each progressive stage generally requires a more substantial investment. At the gates, gatekeepers review the projects progress with regard to timeliness and budgetary figures. The gatekeepers often discuss major setbacks or innovations in each stage. Another important part of the process is the refinement of the marketing projections, marketing plan and cost-profit analysis. The information provided allows gatekeepers to decide the fate of the project. Projects may pass forward to the next stage without reservation, projects may be defunded and dismantled, projects may continue on with revised budgets and timelines or even a revised scope. In the event that the project moves onto the next stage, gatekeepers give approval or revisions to the action plan for the upcoming stage. In essence, the gatekeepers serve as checkpoints where a project is inspected to ensure that the project is on track and still fits within the company's vision.

Stage-Gate for Senior Design

The EET capstone course sequence at Pittsburg State University is set in an entrepreneurial / start-up setting. This means that the students produce the idea, do the marketing research for the projects, and then develop the design and implement the design. This process aligns quite well with the stage-gate process. For that reason, the EET program mapped the stage-gate process to the capstone course. The stage-gate process was selected over other development processes due to the authors' familiarity with this particular structured development process. Anticipated benefits included improvement in timeliness due to rigid checkpoints (gates), improved quality in deliverables due to the threat of gate-failure and an enhanced and realistic emulation of real-world engineering technology. The system developed for the PSU EET capstone courses was made into six gates. An overview of the six gates can be seen in Figure 2.

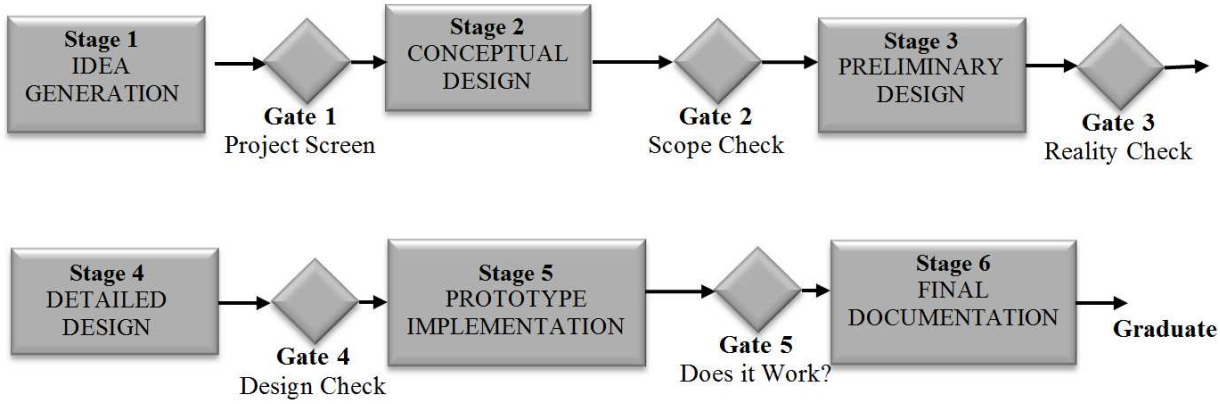

Figure 2 - Overview of Stage-Gate Process for PSU-EET

In the PSU model, gate meetings are held during scheduled weekly meeting times, with exceptions for guest lectures and presentations. Recommended gate meeting dates are provided to assist students in tracking their progress. In the first semester, passing gates 1-4 is required. Failure to complete gates results in various levels of penalties. The second semester, there is only one gate meeting, gate 5. Gate 6 was the submission of the final documentation.

The gates provide natural points for oral presentations from students. Students present their deliverables in front of the class, and are questioned concerning the design, project status and business model. Following the presentation and discussion students are assigned a gate outcome by the gatekeepers. Gatekeepers can pass, pass pending revisions, fail and hold or fail and kill a project. The kill option is generally reserved for stage one or two due to time restrictions of student semesters, but the threat brings realism to the classroom and is a powerful incentive. Besides, it's fun to threaten students.

Table 1

TABLE OF GATE OUTCOMES

STATUS	METRIC	NEXT STEP
PASSED WITHOUT RESTRICTION	All deliverables meet acceptable levels and the future action plan has been approved.	*Students move on to the next stage*
PASSED PENDING REVISIONS	Most deliverables meet acceptable levels but some corrections required and/or the future action plan needs minor revision.	*Students resubmit materials, then move to next stage*
FAILED PROJECT ON HOLD	Deliverables did not meet acceptable levels and/or the future action plan needs major revision.	*Students resubmit materials, gate meeting must be repeated*
FAILED PROJECT KILLED	Project does not meet acceptable requirements for course.	*Students develop new concept and present at gate one.*

In addition to the five gate meetings, students are also expected to give three additional presentations. These presentations include:

1. Project Proposal – Presented to the PSU EET industrial advisory committee.
2. Critical Design Review – Presented to the capstone class during gate 3.
3. Design Symposium – Final presentation / Demonstration at end of 2nd semester. *Attendees include the industrial advisory committee, graduate and undergraduate students, faculty, and general public.*

To students, the stage-gate process and the course in general is depicted as a system in which to improve their overall project. Thus at each gate meeting feedback and advice is given. The project proposal presents an additional means of feedback from several new perspectives. At the

critical design review, a detailed presentation of the complete design is presented. Students and faculty give feedback and suggestions for improvement. The result of the critical design review is a task list that must be accomplished prior to presenting at the next gate.

The design symposium's main function is to give students opportunity to show off their work. The authors have found that a great motivator is when the individual knows his/her work will be on public display. Additionally, feedback from the advisory committee is also given. Our design symposium is set in two sessions; first, an oral presentation session and second, a demonstration / poster session. The first session is limited to capstone presentations. This oral session is set in a conference context. The second session includes the capstone demonstrations and also pulls projects from elsewhere in the curriculum. The mix provides a wide variety of projects to display. The desire for the symposium is to motivate students and to give appropriate accolades and foster a sense of accomplishment.

Contents of the Stage-Gate Capstone Course

There are four major aspects to the capstone course. These aspects include product design and implementation, product verification and characterization, project management, and business and marketing. Each aspect has a part to play in each stage.

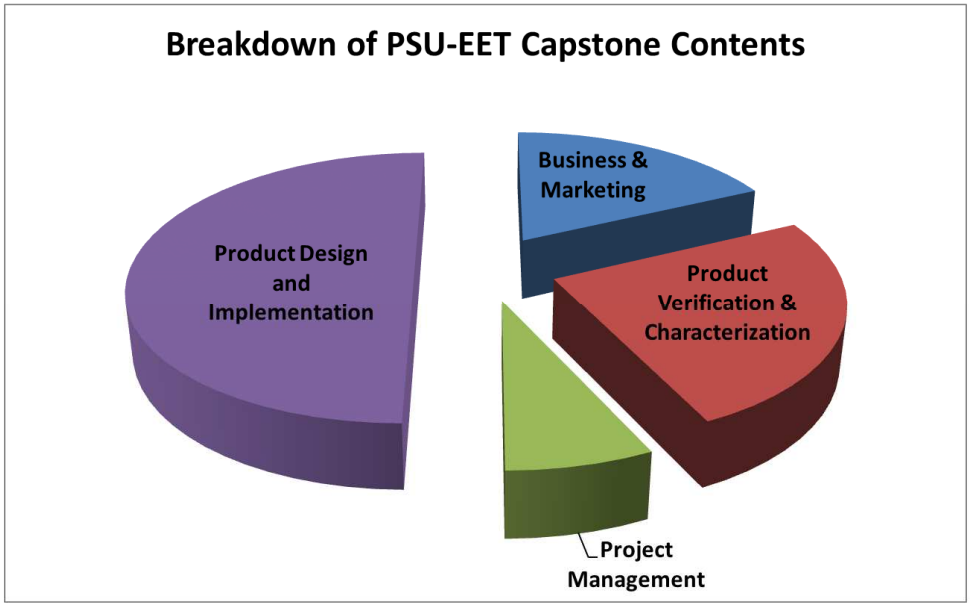

Figure 1 - Breakdown of PSU-EET Capstone Content

Deliverables are expected from each of the four categories. Although there is some overlap, the deliverables can be categorized as shown in Table 2. The deliverables in Table 2 represent the post-renovation changes. A few of the new innovations that were not contained in the prior

capstone course includes the addition of all verification deliverables, the addition of a critical design review, breaking the business plan into smaller pieces, the rearrangement of reporting (two major reports: conceptual design report and final engineering report), product leaflet and the addition of bios, team info and the elevator pitch.

Table 2
Gate Deliverables

	Design & Implementation	Verification	Business & Marketing	Project Management
Gate 1	Project Concept Abstract	---	Team name, logo, etc. Bios (written & oral) Product Description 30 sec. elevator project pitch	---
Gate 2	Signed Specifcations Conceptual Design Report	Signed Specifications	Target Customers List of competitors Market Potential Product Differentiators	Gantt Chart
Gate 3	Critical Design Review Checklist Preliminary Design Docs (schematics, code blocks, drawings, etc.)	Qualification Test Plan	Product Cost Analysis Profit margins, price points, etc. Marketing Strategies	Project Budget Estimates Schedule Update
Gate 4	Simulation Detailed Design Documents (BOMs, final schematics, code, etc.)	---	Cash Flow Analysis Income Statements Revenue Projections Expenditure Breakdown Product Website	Schedule Update Budget Update
Gate 5	Working Prototype	Qualification Test Report	Tradeshow Poster One-page product leaflet Complete tradeshow presentation	Schedule Update Budget Update
Gate 6	Final Engineering Report Logbook	---	Complete Business Plan	Project Review

Most capstone courses that the authors are familiar with emphasize the design and implementation as well as some emphasis on project management. Often the verification portion is left out. Instructors evaluate the projects based on their own criteria. When projects are assigned there are often clearly defined specifications that must be met. One advantage of the entrepreneurial model is that specifications must be clearly worked out; a common real world engineering task. This task is perhaps the most significant deliverable through the first four gates. The specification dictates the design and the qualification test plan. The qualification test plan tests each specification to ensure that the system is fully operational. A working prototype is one that meets all specifications as outlined in the signed specification deliverable. This setup necessitates that students have to develop specifications, design tests and then carry out those tests. Further, the business and marketing aspect included throughout the project gives students exposure to common business instruments and encourages them to see engineering in a business setting. Because our average student has limited exposure to business concepts, the business plan is broken down into small pieces. Lectures on various portions of business plans are discussed throughout the semester by faculty or by guest lecturers.

Results From Round One – What We Learned

The authors consider the first course sequence with the stage-gate implementation an overall success. Student project quality ratings improved from the previous year's average of 3.5 on a Likert scale to an average of 3.9 as rated by the industrial advisory committee (See Table 3 and Figure 4 below). This indirect assessment indicates an overall improvement in projects.

Table 3
Pittsburg State University EET IAC Overall Project Quality Assessment,
As Percentages 2011, 2012

Year/Likert Score	1	2	3	4	5
2011	7.5%	7.5%	40.0%	22.5%	22.5%
2012	0.0%	8.6%	25.7%	37.1%	28.6%

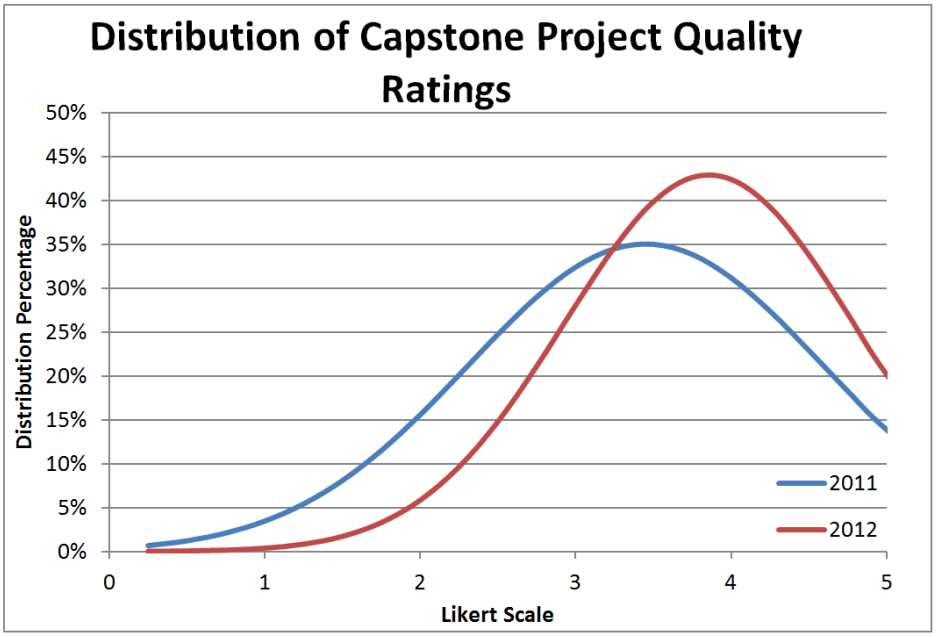

Figure 2 – Distribution of project quality scores as scored by the PSU-EET industrial advisory committee.

One particular point of success was the design symposium. The symposium was attended by a significant portion of the EET student body. Attendance provided underclassmen a glimpse of what to prepare for. The symposium also gave capstone students a meaningful setting in which to demonstrate the results of their diligent efforts, a method of giving appropriate accolades.

The main elements of the course that needed improvement included guidelines for timing of gates, adjustments in naming conventions, adjustments in timing of various deliverables, and

better dissemination of expectations for each deliverable. Also, in the first course sequence an online classroom was used for document transmission and storage. For several reasons this proved difficult to coordinate. Future document management will fall more directly into the purview of the student teams. Additional deliverables have also been added, for instance, one-page product leaflets, biographies, team names and logos, as well as oral 30 second elevator pitches about the team's product.

The project concept and the signed specifications require the most attention from faculty. This is an inherent attribute of the entrepreneurial approach to a capstone course. Having a student take a vague concept, refine it to a list of specifications and ensuring those specifications fall within the bounds of appropriate project complexity for the course is not a simple task. Future efforts will examine methods to enhance this aspect of the course.

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