Managing Interdisciplinary and Multidisciplinary Senior Capstone Projects

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Abstract

A common infrastructure employed by instructors of senior capstone project courses is to manage an assortment of projects that are insular to the discipline of the department. Within this paradigm, course management is simple. The managing a senior capstone project course is further complicated when interdisciplinary and multidisciplinary capstone projects are considered. Difficulties include communication and mitigation of issues and concerns, coordination of activity, and integration of component and sub-system products. To address this challenge, we have employed principles of systems engineering and the acquisition methods of United States DOD (Department of Defense) to organize the course and to manage the development process. The benefits of employing this course infrastructure are that capstone course instructors and student will work within their discipline, multi-term and single-term capstone project courses can be integrated; better and stronger collaboration between departments and students from different departments is promoted; students will have a broader selection of projects from which to choose, and students will also have the opportunity to experience how their education can be applied in applications not directly related to their discipline. Furthermore, we believe that this infrastructure can be employed in situations where the project teams are geographically dispersed.

Introduction

The general structure of a senior capstone design course is that students are placed into project teams; and each team is assigned a design project within the application domain of the discipline. Managing the capstone course is easy for instructors because there are direct interfaces for communicating and mitigating issues and concerns, coordinating and scheduling activities, and integrating component and sub-system products. To expand the domain of projects to include interdisciplinary and multidisciplinary projects would add a level of complexity to managing the course.

A simple way to incorporate interdisciplinary and multidisciplinary projects would be to integrate the capstone course. To implement an integrated capstone design course across all engineering disciplines would, in our case, be a "scheduling nightmare". For example our engineering program supports co-operative education, and some departments have single term capstone project and others have multi-term capstone projects. Hence, our engineering program does not have an integrated capstone course.

This paper proposes and demonstrates an organization and infrastructure for senior capstone courses such that the course can incorporate interdisciplinary and multidisciplinary projects and not necessarily be an integrated capstone course. The course paradigm integrates aspects of systems engineering and DOD acquisitions processes to address the communication, coordination, and integration challenges. What follows is a synthesis of processes.

Systems Engineering

Systems Engineering[1,2] is an interdisciplinary approach and a means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem. The "complete problem" entails operation, performance, cost and schedule, test, manufacturing, training and support, and disposal. Figure 1 shows the lifecycle of a system[3]. You can summarize the system lifecycle as the concurrent processes in effect during the "life" and "death" of a system.

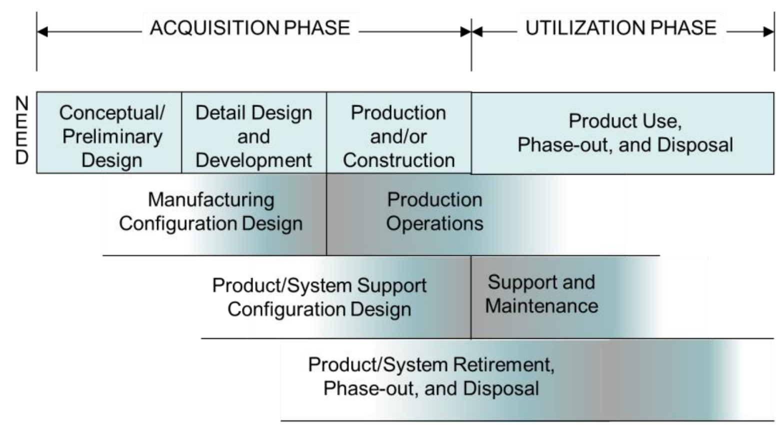

Figure 1. System Lifecycle.
(The darker color gradient indicates a higher intensity of process activity.)

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation to phase-out and disposal. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

The utility of systems engineering in the context of interdisciplinary and multidisciplinary projects is that the issues and concerns of all parties (e.g. instructors, customers, students, and departments) are addressed at the beginning and throughout the duration of the project. This has proved to increase the quality of the end product.

DOD Acquisition Process

The Department of Defense (DOD) acquisition process[4] is summarized in Figure 2. An important aspect of note regarding this process is that the DOD is not a company and therefore, all acquisitions are contracted out to publicly and privately owned companies. The DOD employs teams system engineers to ensure that the needs of the DOD are satisfied and to manage the development process. This process has been incorporated into the infrastructure of the senior capstone course.

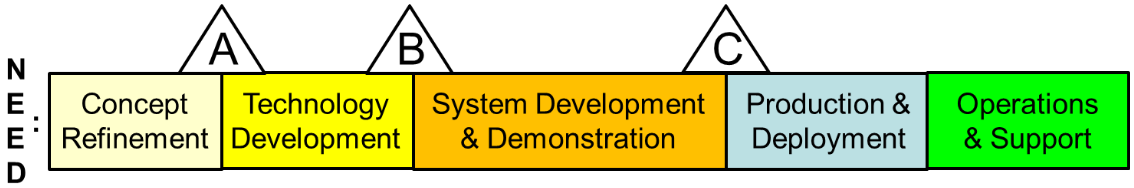

Figure 2. System Lifecycle Acquisition Process

Points A, B, and C atop the figure are acquisition milestones. These are critical points in the acquisition process were reviews of the project are done and important management decisions are made. The milestones are defined as:

A – All key performance parameters (KPPs) of the system have been identified in clear, comprehensive, and concise terms that are understandable to the users of the system.

B – The major system-level requirements (including all KPPs) are defined sufficiently to provide a stable basis for development through initial operational capability (IOC, i.e. prototype development).

C – The system has demonstrated acceptable performance in developmental test and evaluation, and in operational assessment; there are no manufacturing risks. Pre-production models of the system can begin.

The importance of the DOD Acquisition process to the organization of our senior capstone course is that like the DOD, the capstone course instructors are not the designers and implementers of the project. Those tasks are sub-contracted out to the design teams of students. And, like the DOD, capstone course instructors desire product of high quality because course assessment, and degree program accreditation is closely coupled to capstone course outcomes.

Engineering Process Models

A common engineering process model is the Waterfall model[3]. The waterfall model is a sequential process of requirements definition, specification, design, implementation, test, and maintenance. The waterfall model is a systematic and linear process. The practicality of using the waterfall model to manage interdisciplinary and multidisciplinary projects is bad due to greater risk in producing a low quality product. In this paradigm, developing a system can be a long, painstaking process that will not yield a working version of the product until late in the process, which delays testing.

The Spiral process model[3] combines the idea of iterative development with the systematic, controlled aspects of the waterfall model. The spiral model is a combination of the waterfall model and an iterative development process model. It allows for incremental releases of the product, or incremental refinement through each iteration of the process "spiral". The spiral process model reduces risk. The spiral process model is also impractical for our purpose due to increased development time and development cost.

A compromise between the Waterfall and Spiral process models is the Vee process model[4]. Shown in Figure 3, the Vee process model is a modified waterfall process model that reduces risk through decomposition, test, and integration of the system.

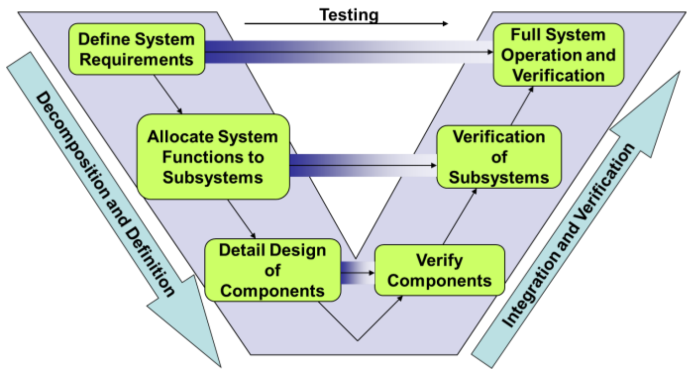

Figure 3 Vee Process Model

The Vee process model is applied at all levels in the hierarchical decomposition of the system. At the top-level, the system is decomposed to the granularity of a sub-system or component that can be implemented within a specific discipline. At the discipline-level of decomposition, the Vee process is the way design teams decompose the project into tasks for individual members

Capstone Course Organization and Infrastructure

The organizational structure of our capstone course models the Vee process model. The organizational structure facilitates a functional decomposition of a system to the granularity of a sub-system or component that can be developed within a single discipline. The person or organization at the top of the system hierarchy is responsible for defining the system requirements, decomposing the system into sub-systems and components, allocating system requirements to sub-systems, and developing the test and verification strategy for integrating the components and sub-systems of the system. It does not matter if the project is insular to a particular discipline, interdisciplinary, or multidisciplinary; the granularity constraint on the decomposition of the system ensures that all assigned design tasks are within the capabilities of the discipline.

The capstone course infrastructure that supports the organizational structure requires specific roles and responsibilities for instructors, project design teams (the students), project customers, project supervisors, department faculty and staff.

<u>Course Instructors</u>: Capstone instructors are process managers for the senior design teams. Course instructors are responsible for capstone project approval, assigning projects to design teams, instructing and guiding design teams through the design process, and mitigating conflict between customers and design teams. (Comment regarding project approval – Capstone projects must be an "engineering" project focusing on the design of a system; whereas a "research" project focuses on learning about the system. To properly engineer a system, quantitative requirements and constraints of the system must have known values. The design process

requires a certain amount of research to determine some attributes of the system. The course instructor must determine whether amount of research associated with a project is too substantial to qualify the project as an engineering project.)

Project Design Teams: Team members will collaborate to perform the dutiess of the system engineer and the development engineers for a particular project. Each team is responsible for completing their design project, which entails achieving the milestones outlined in the DOD acquisition process (Figure 2). Each team must develop a set of functional requirements for the project and have these requirement approved by the customer of the project (milestone A). The team will then work towards achieving milestone B which entails feasibility analysis of possible design concepts reaching a recommended solution for the project. The project is complete when the design team has achieved milestone C.

Project Customers, Sponsors, and/or Supervisors: The customer/sponsor for the project defines the project needs and is the owner of the system. The supervisor is the person at the top of the system hierarchy who has global knowledge of the system. The supervisor functions as a consultant to the design teams providing clarification and guidance. In some instances, the customer, sponsor, and supervisor are the same person. Sources for capstone projects are engineering faculty and research staff, industry partners, and student proposed projects that are sponsored by engineering faculty, engineering research staff, or an industry partner.

Department Faculty and Staff: Department faculty and staff serve as content experts (consultants) and process facilitators (e.g. ordering parts, access and use of CAD tools).

Managing Senor Capstone Projects and Its Challenges

In preparing to teach this course, a solicitation for discipline specific (in this case, (ECE) Electrical and Computer Engineering) design projects was sent to all faculty, administrators, directors, researchers and industry partners in the School of Engineering. The solicitation requested a title and description of the project, the project deliverables, and the names and contact information of the sponsors (i.e. the customer). Students are permitted to propose capstone projects. Student project proposals must have faculty or industry partner as a sponsor. Note that the solicitation requested "ECE" projects. Therefore, all interdisciplinary and multidisciplinary projects have been decomposed by the sponsor into discipline specific components; and additionally, the path for integrating components into a larger system is also well defined.

The course instructor scrutinizes the proposals for design content and schedule. The proposed project must be a "design" project (as opposed to research). And for a single term project, the project must be completed by the end of the academic term. The course instructor must use their best judgement to eliminate research projects and to eliminate projects that cannot be completed in the scheduled time for the course. The challenge of differentiating research and design projects is that research projects have unknown/undefined parameters and design projects have known/defined parameters. It is the responsibility of the instructor to help ensure the success of the student taking the course by maintaining the focus of the course on design and development.

The instructor forms design teams by assigning students to projects. The instructor then guides the design teams in completing their respective projects by helping each team achieve milestones A, B, and C of the DOD Acquisitions process (Figure 2). The design teams use systems engineering to manage their project assignment by following the Vee process model.

The first step in the design process is requirements generation. Each design team is responsible for communicating with their sponsor in order to (1) gain a deeper understanding of the assignment; (2) define and/or estimate unknown variables, parameters, and constraints of the system; (3) derive a set of requirements; and (4) reach an agreement with the sponsor on a set of requirements for the project. The requirements must be verified and validated (signed) by the sponsor. There are four types of requirements – behavior/performance, design constraint, production capability, and process compliance. The process of deriving a set of requirements, forces the design team to communicate with their sponsor. Completing the requirements specification demonstrates that the design team understands "what" they are doing and the sponsor knows what the expected results are before the design process begins. By having the sponsor verify and validate the requirements ensures that the sponsor's (i.e. the customer's) voice is heard and their desires are taken into account in the design of system. Validation of the requirements by the sponsor prevents the design team and the sponsor from making changes to the specification later in the project schedule. The vernacular term for this change behavior is "requirements creep", which leads to project failure in terms of cost overruns and delayed schedules. The challenge here is to get the design teams and sponsor to agree on a set of requirements. In instances where the design team and sponsor cannot agree on a set of requirements for the project, the instructor must step in as mediator. A validated set of requirements completes milestones A and B.

With a validated set of requirements, the design team is able to proceed with conceptual design. The design skills are tested by requiring each design team to derive three distinctly different, feasible solutions. Design team compare and evaluate their design alternatives and recommend a solution for implementation. This process is summarized in the conceptual design review presentation. Each team is scheduled for a conceptual design review. The class and project sponsors participate in the review. After the conceptual design review, project teams must efficiently and effectively manage their time in order to complete the development of their solution by the scheduled due date. At this time, other than technical assistance and project status reports, there is little communication with the sponsor.

Example Project: Development of a Sonotubometry Test System[5]

This project was completed by following the process described in the previous section. This was the first attempt at applying this process. This project was a single term (15 week) project. Below are excerpts taken from the final report showing the results following each stage of the development process.

<u>Introduction</u>: In developing a Sonotubometry test system, we were asked to create a system that could be used to test a person's Eustachian tube using off-the-shelf parts to make a probe and send white noise through a person's naris, or nasal opening to a sensor in ear muffs. The system uses a LabView-based environment. The purpose of this project was to be able to develop the product as well as form communication between two mechanical engineers and two electrical

engineers. The system requirements, which will be listed in the future, state rules that the test system has to abide by. Other items shown in the report will be the conceptual designs used for the electrical side, showing the programs that were considered in the experimentation, the feasibility tests and risk management in order to choose the optimal developing program and our final design as well as how we verified and tested it.

System Requirements (Weeks 1 – 3): The requirements for developing a Sonotubometry test system are to enhance a sound-based testing system currently used to characterize Eustachian tube (ET) and middle ear pressure regulation. A central focus will be to examine methods to extend the capabilities of the probe signal and output signal characterization. As this will be a joint effort between students from MEMS and EE, there are four specific aims that were necessary to follow:

1. Assess the functionality of the current test system and identify potential drivers for improvement
2. Identify and order "off-the-shelf" hardware components that can be assembled to complement the existing laboratory configuration
3. Develop a LabView-based (or equivalent) programming environment to drive the operation of a typical test protocol
4. Perform a series of validation tests to correlate with legacy data

The main focus of these requirements was to keep the experiment in line with what the UPMC lab was expecting. As a follow up to these aims to follow, the following are the four deliverables that were asked of the students:

1. An assembled hardware-based test system
2. LabView-based management, control and data collection system
3. Supporting calibration and validation documentation based on sample tests
4. Suggestions to extend the functionality of the system

These deliverables will produce a complete testing solution tailored to examine ET function to be used in an active clinical laboratory

Conceptual Design, Feasibility Study (Week 6). In considerations for the design, the system should have a simple user interface as well as properly complete the requirements. The system should be able to emit white noise, record, perform a fast Fourier transform (FFT), and emit a found noise from the transform. In order to narrow down the wide array of programs that fell under this category, we picked the programs that we were most familiar with: MATLAB, LabView, and Python.

Table 1 below shows the design matrix that was used in order to compare the programs in a simple manner. The table puts numbers to the factors we used in order to choose a program. The higher the number is, the better the program is. This shows that our design is weighted more toward availability, with the interface, application compatibility, and code ease weighted less, respectively.

Finally, each of the three different designs were given a 1, 2, or 3, with a higher value meaning it is very favored and a lower value meaning it is less favored. It should be noted that each of the values were able to be repeated in our choice, meaning the values of one did not depend on the values of another.

	Programming availability **4**	**Hardware/ Software Interface** **3**	**Ease to Code** **1**	**Compatibility with Application** **2**	**Total**
LabView	Available at basement computers **3x4=12**	NI has a lot of hardware available relevant to the project **3x3=9**	Would need to be reminded on parts of coding to be up to par **2x1=2**	Very compatible, recommended to us for use, customer preferred **3x2=6**	12+9+2+6= **29**
MATLAB	Available at every computer at the university **3x4=12**	Has hardware available, but not familiar with its use **2x3=6**	Well rounded in MATLAB **3x1=3**	Has commands that can complete our desired end product **2x2=4**	12+6+3+4= **25**
Python	Available at basement computers **3x4=12**	Works with hardware, but better programs for interfacing **2x3=6**	Both users not well equipped to use **1x1=1**	Has commands that can complete our desired end product **2x2=4**	12+6+1+4= **23**

Table 1: Feasibility Matrix

In order to view how the choice was made, each block not only displays the numbers chosen for the specific program, but they are also elaborated on. This gives more contexts to the numbers chosen rather than depending on only a number to make the choice.

Summary (Project Completion – Week 14): The development of a generalized sonotubometry test system will assist UPMC clinicians in their research of middle ear disease. By removing numerous parts and utilizing off the shelf components, a new system was constructed. The completed headset is now one integrated system with the nasal cavity probe and the ear muffs connected together. Sound transmission is improved thanks to the elliptical chamber holding the signal probe that sends the signal through the Eustachian Tube.

Redesigning the signal characteristics and signal processing of those signals was also improved. The white noise characteristics have improved and the software to accomplish this has been improved. All of the external parts being utilized in the old system have been completely removed. The new streamlined system allows for less maintenance and a lower probability for problems to arise. The beauties of using very few components that are defined as “off the shelf”, parts are that the parts can be replaced easily and removes the numerous steps of cooperation in the system. In conclusion, the new test system will give the UPMC clinicians something to work with when moving forward to completing the entire system.

Course Grading and Assessment

Each design team must write a report to document the activities and deliverables of their project. A copy of the report is given to the sponsor and to the course instructor. The course grade for each student is based on a qualitative assessment of the project and peer evaluations of each student’s performance. The qualitative assessment of the project consists of a questionnaire completed by the sponsor. The questionnaire asks the sponsor to (1) verify whether or not the developed solution was either deficient in meeting, fulfilled, or exceeded the design requirements and (2) give an overall rating of the quality of the implementation.

The peer evaluation is done within each project team. Each member of the design team anonymously evaluates the performance of their teammates. The sponsor assessment and the peer evaluation are given to the instructor. The instructor assigns the course grade based on the peer evaluation and sponsor assessment of the project. For the Sonotubometry project, the students received ‘A’ grades because the sponsor was very satisfied with the results and highly praised the efforts of the design team.

Summary

What we have shown is an organization and infrastructure for a senior capstone project course that facilitates ease in the management of interdisciplinary and multidisciplinary projects. The course organization and infrastructure incorporates aspects of systems engineering, DOD acquisition process, and the Vee process model to create an environment whereby project teams from different disciplines can easily collaborate on an engineering project. Within this environment the project (referred to as the system) is decomposed by the sponsor to the granularity of a sub-system or component that can be designed and implemented within a single discipline. Project teams within a particular discipline, further decompose the sub-system or component into design tasks for each member of the team. Project teams are responsible for the development of their component of the system. The sponsor for the project is responsible for the specification of the system, the decomposition of the system to discipline domains, and the integration and test of the products of the design teams.

A key aspect to the success of this methodology is the application of systems engineering design process. The systems engineering design process is generic to all engineering disciplines. Systems engineering facilitated functional decomposition of a system into components that could be designed and developed within a specific discipline. The systems engineering process model created a communication infrastructure whereby communication and collaboration between disciplines is done in the early stages (design phase) of the system development process and towards the end (integration phase) of the system development process. This allows disciplinary teams to work independently of one another through the development phase of the project. Furthermore, we believe that since our senior capstone course mimics the DOD acquisitions process (which also incorporates systems engineering methodology), we can apply the course organization and infrastructure paradigm to manage senior capstone projects with project teams that are geographically dispersed.

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