Introducing Project Management Theory into a Capstone Design Sequence

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Abstract— **The capstone design sequence in the Electrical Engineering Program at Western Kentucky University is a two semester sequence. Student teams design and execute a solution to an industrial or applied research problem during the academic year. In order to improve the capstone sequence, project management techniques have been introduced into this sequence. These techniques include acquainting students with project management theory and teaching students to manage the projects more effectively. This paper will present the basic structure of the sequences, discuss the assessment results which led to this new focus in the sequences, describe the project management techniques incorporated into the courses, and explain the impact the new emphasis has had on the capstone design sequence.**

Keywords- capstone design, senior project, project management

I. Introduction

The Electrical Engineering (EE) program within the Department of Engineering at Western Kentucky University (WKU) has a project rich curriculum. Our students take a design course each academic year that provide opportunities for completing projects. As the students mature through the curriculum the amount of work effort, design, and project size increases, until the capstone sequence of their senior year. As our student numbers have increased, the effort of managing these projects has become a difficult task for the EE faculty. To address these problems, the faculty of the EE program has utilized conventional project management techniques to create a design process to manage and asses the project teams for our senior capstone experience. The subsequent work describes the capstone design sequence our senior EE students complete. Next, the assessment data alluding to the difficulty in managing these projects is presented. In an effort to address these problems, the revitalized design process is presented with much detail. This work is completed with some concluding remarks. The utilization of this design process is new within our program. As the faculty assesses its performance in helping the student complete their projects there is room for adjustments so the process has the right balance of control and flexibility such that the students are successful.

II. Design of EE Capstone Design Sequence

Students entering their final year of study in the EE program at WKU take a two semester capstone design sequence comprised of EE 400 (EE Design IV) and EE 401 (EE Design Project). In these courses, students are placed on teams and assigned projects which include industrial and applied research projects. The students design and execute a solution to the design problem during the academic year. The courses must be taken sequentially in an academic year. The first course in the sequence is EE 400. During this course, students focus on design methodology and decision-making. The course includes ethics, professional issues, and the planning and design phase of the project culminating with oral and written reports. The objectives of this course are to further develop design skills, develop teamwork skills, learn to deal with situations in an ethical manner and write the senior project proposal.

The second course in this sequence is EE 401. This course is constructed so that the student design team will assume the primary responsibility for the completion of the project. At the end of this course, students have completed a major capstone design experience and can demonstrate their ability to design, build, and test a system to meet specified criteria. Also, students exhibit their capability to communicate their project design and results in a written format and in an oral presentation.

The design sequence has multiply opportunities for faculty to provide feedback to students regarding project progress. Mandatory status meetings occur weekly in which the design teams meet to update the faculty on the status of the project and deliverables. Prior to each progress meeting, the team must submit a status report. Also, several design reviews are scheduled for each team during the academic year. At the design reviews, the teams present the status of their project. During the design reviews, the faculty evaluates team progress toward the established project milestones. Failure to meet the milestones will affect the final grade.

III. Improving Capstone Courses Through Assessment

The WKU EE program is a relatively young program producing the first graduates in May 2004. Prior to engineering programs, WKU was home to three engineering technology programs from which the new engineering programs grew. The three engineering programs at WKU (civil, electrical, and mechanical) received ABET accreditation in 2004. The capstone design sequence is heavily assessed by the WKU EE faculty in support of the ABET Criterion 3 A-K program outcomes. [1] In fact, all eleven Criterion 3 outcomes are represented by these courses. The EE program assessment plan uses several rubrics to determine if the program outcomes are being met. Also, the faculty discusses this course heavily during the course review process in which each course taught in the curriculum is examined. The major assessment results are listed in Table 1 below.

TABLE I. SUMMARY OF ASSESSMENT RESULTS FOR CAPSTONE DESIGN COURSES

Year	Assessment Result
2004	Gantt chart developed in fall semester, project driven by timeline
2004	Students noted progress in logbook through year. Logbooks found to be ineffective.
2005	Faculty noted the need for more formal project milestones through the year
2005	Students submitted weekly progress reports rather than logbooks
2006	Established monthly design reviews as well as continued weekly meetings.
2007	Course restructured with firmer deadlines so that students had a better understanding of their final grade.
2008	Incorporated three design reviews and project deadlines into requirements
2009	Include project milestones in fall and spring semester
2009	More emphasis placed on project and time management

Over the years of offering these courses, the student performance has continued to improve. However, it is noted that students continue to struggle with setting project milestones and faculty have not given adequate intermediate feedback to students during the year. Therefore it was determined through the course assessment that more formal milestone development and appraisal should be incorporated into the courses.

IV. REVITALIZING THE CAPSTONE DESIGN SEQUENCE

In an effort to teach project management as it applies to an engineering project and to create a more manageable assessment tool to gauge project progress, the faculty of the EE program at WKU has introduced a new design process for its EE400 and EE401 design sequence. The following outline known as the *Workbook Table of Contents (WTOC)* best describes the new design process. Details of each heading will be described below.

Workbook Table of Contents

I. Project Management Plan
II. Requirements documents
III. Execution and Closing

Figure 1: Workbook Table of Contents

A. Project Management Plan

In the Project Management Plan (PMP) shown in Figure 2, the students are tasked to define all attributes of the project in an effort create a detailed statement of work. The WTOC plan should be flexible enough to meet the needs of projects of varying scope and scale. As the faculty assesses possible projects at the beginning of the academic year, it is imperative that the projects have enough creative content so that the students are able to fulfill the tasks described within the PMP. If students were not able to develop the PMP for a specific project for whatever reason, the project may not be a good fit for our sequence due to a lack of learning opportunities. An additional benefit of this PMP is to force the project sponsor to agree to a written statement of work describing the project to be completed, thus driving the development of acceptance criteria. Once this is established, the student design team and the sponsor have agreed to the components of a successful project. If for any reason during the execution of the project the deliverables change or the student design team fails to meet the stated criteria, both parties will fully understand the work did not meet the sponsor's expectations. It is often the case that due to time constraints many engineering project require that the project scope will change, or the student design team will be drawn to a different solution which results in only partial project success or project failure. Through this PMP document, all parities are focused on meeting the written goals of the project.

1) Project Requirements

To create a PMP for their projects, students are asked to complete outline items A: Project Requirements, B: Scope, and C: Project Planning, seen in Figure 2. The Project Requirements is composed of the high level project overview and definition of stakeholders. This section is the first documentation the students are asked to complete once they are assigned their projects. The students are tasked with developing an understanding of the big picture of their work as it relates to their project sponsor. It is very important that the student design team understand the impact as to why they are doing this project. There could be possible safety or financial implications that if the student design team where unaware of, the task may seem meaningless. Through this task, the students can better work to meet the organizational goals the sponsor hold very important. Also, within this section of the PMP, the student engineers determine and document all the important people that are affected by their work. Often the students will list the project sponsor and their faculty sponsor who are both working to make sure the students complete a successful project. The student will need to identify all of their team members as well.

I. Project Management Plan

A. Project Requirements
   1. High level overview of project
   2. Identification of stakeholders
      a. Technical sponsor
      b. Faculty sponsors name

B. Scope
   1. Product description
   2. Product acceptance criteria
   3. Project deliverables
   4. Project exclusions
   5. Project constraints
   6. Project assumptions
   7. Preliminary budget
   8. Project risks identified

9. Change control plan
10. Patent search

C. Project Planning
1. Work Breakdown Structure (WBS)
2. Activity Sequencing
3. Gantt Chart
4. Roles and responsibilities

Figure 2: Project Management Plan of WTOC

2) Scope

The next phase of the PMP after the students identify the stockholders and come to have a "big picture" view as to the "why" of their project, the students begin to develop their project scope. As can be seen in Figure 2, the Scope section contains ten items which the students generate with consultation of their project sponsor. At the beginning of the project the faculty sponsor facilitates the initial meeting between the project sponsor and the student design team. Once this has occurred, the expectation for the students to gain the information from the sponsor in a convenient, non-burdensome way is paramount. In some instances the sponsor may not be able to give information to the student engineers for all of these items. For these cases, the students are asked to make decisions and strive for agreement with their sponsor. In practice, it is common for sponsors to have unclear requirements and it is often the engineer's task to help them decide some of the finer details.

From this list of ten items some of the most important items will be described. The Project description is a lower level statement of the project, similar to that in the Project Requirements section. As stated previously a key result of the Scope is the Project Acceptance Criteria. This criterion is vital in keeping all parties focused on the goals of the project. The project deliverables are an important list of the items to be completed or created as a result of this project. This list of deliverables is used to focus the stakeholders and students on the goals of the project. Within the scope, the constraints are documented in an effort to describe what parts of the projects will not affect existing systems that interact with the project items. When completing any project, it is good practice to list the fundamental assumptions that frame the context of the engineering work. This effort is completed by listing the project assumptions. The next item in the scope is to identify and detail the project budget. In most cases the budget is a limiting item as to what tasks can be completed through the project. This PMP is flexible enough to deal with many budgetary situations.

As the student design team comes to know more about their project through the steps of developing a project scope the students are also asked to evaluate the project risks. This can be a difficult task for some projects as it may not be clear as to what risks exists for the student's success. In most cases assistance by the faculty and project sponsor helps the students in completing this task. These risks can fall within many categories. Some risks are technical risks such as a challenging design task or a nonexistent solution. There are also manufacturing risks that could impact the outcome of the project. Some projects could have human or environmental risk to be considered. For this PMP, the assessment of risk for now is open to all categories which allows for a great degree of flexibility.

It has been alluded to that over the course of an engineering project change is enviable. There are many reasons as to why there is change to the scope of a project. With this in mind, the PMP has been designed to account for this reality. The students are supplied a change control plan by their faculty sponsor. With this plan administered, the student design team and sponsors can purpose and notify one another of scope changes with the opportunity to accept and reject the proposition. Due to the complex nature of these projects, there are numerous aspects of the project that could be affected by the smallest of changes. The team can manage these changes and the affects to the project that will take place as a result.

The student design team must also understand the intellectual property landscape that exists for their project. When designing a solution to an engineering problem, it is necessary to understand what solutions are patented as to make sure there are no legal implications to possible solutions. At the same time this knowledge can help to form a valid solution that introduces new intellectual property with the possibility of new patents. Avoiding infringement is paramount when design solutions to open engineering projects.

3) Project Planning

The last component of the PMP is Project Planning, as seen in Figure 2. This section of the PMP has four items to assist in developing and documenting the time management planning stages of the project. Student engineers are introduced to some common project tools that are widely used in both industry and academia. The first of these tools is known as the Work Breakdown Structure (WBS). Through this tool, the team graphically displays and categorizes all the significant project tasks as shown in Figure 3. The creation of this document forces the students to analyze and breakdown how they will accomplish tasks to meet the documented project scope.

Robot Platform Project Work Breakdown Structure

1.0 Old Robot
- 1.1 Disassemble
- 1.2 Draw schematics of robot
- 1.3 Reassemble with improved wiring
- 1.4 Fix program glitches

2.0 New Robot
- 2.1 Prepare vehicle
  - 2.1.1 Purchase vehicle
  - 2.1.2 Remove parts on old vehicle/disassemble
- 2.2 Redesign robot
  - 2.2.1 Define specs for redesign
  - 2.2.2 Develop design
    - 2.2.2.1 battery location
    - 2.2.2.2 junction box location
    - 2.2.2.3 linear actuator location

2.2.2.4 DAQ's/circuit board
2.2.2.5 onboard computer location
2.2.3 determine current component list
2.2.4 order components
2.2.5 mechanical components
2.2.5.1 draw new components
2.2.5.2 order components
2.2.6 electrical wiring plan/ power budget
2.2.7 circuit boards
2.2.7.1 draw circuit boards
2.2.7.2 order circuit boards
2.2.7.3 build circuit boards
2.2.8 refine and modify software
2.3 build robot
2.3.1 steering, starting, stopping
2.3.2 electric components
2.3.3 power
2.3.4 software integration
2.4 testing

Figure 3: Sample Work Breakdown Structure

From this list of tasks, the team first sequences the activities and then applies a time scale to meet the overall deliverable of the project, as defined in the Scope. These documents are used in conjunction to estimate the length of time each activity is to take. The scheduling tool used in this sequence is the Gantt chart which is shown below in Figure 4. Within a project, there are many technical and non-technical tasks that are equally important. The purchasing and procurement of components is a non-technical task that can be very time consuming and greatly impact the timeline of a project. Once an order is placed, some items take only days to process and receive while other items have significant lead-times and can drastically impact the timing of a project. Using the tools of activity sequencing and Gantt charts can be used at this early phase to determine the length of the project tasks such as design, analysis, experimental verification, purchasing, procurement, assembly, testing, and final assembly.

	Week						
Task	1	2	3	4	5	6	7
Define specs for redesign							
Determine component list							
Order components							
Design and make circuit boards							
Software integration							
Test and Troubleshoot							

Figure 4: Sample Gantt Chart

The final element of the PMP Project Planning section is to list the roles and responsibilities that address each of the WBS items. With this agreed upon by all the team members, the individual contributors can start to focus and take ownership of their items with a clear understand from the Scope as to their deliverable. By including a document that clearly lists the WBS item and the team member assigned, confusion about which team member will complete various tasks is avoided.

B. Requirements Documents

At this point in the WTOC, our student design team has a clear understand of the project scope and team member responsibilities from the WBS. The Gantt chart drives the timing and sequencing of each task. With a clear vision of what is to be done to complete a successful project, the individuals are ready to begin execution of the project. Referring back to Figure 1, the second phase of the WTOC is developing the Requirements documents as shown below in Figure 5. In this section of the WTOC the student design team completes the design and analysis task associated with meeting the project deliverables. The items from the WTOC are an example set of tasks required for most engineering projects. The list is meant to be flexible such that not all projects will require all of these tasks, or the tasks required will be similar, but not exactly as listed in this WTOC. The project and faculty sponsor can work to modify this list as best suited for that particular project.

II. Requirements documents
A. Functional block diagram (hardware and software)
B. Hardware and Embedded System Tradeoff Analysis
1. Three possible solutions
2. Pugh Matrices
C. Software Design
1. Software requirements specifics
2. Software design document including flow chart
3. Justification of embedded system solution
D. Proof of Concept (Schematics)
E. Agency Approval Requirements
F. ABET Documentation
G. Risk Management Plan
H. Final Budget
I. Demonstration of Design
1. Test plan
2. Test equipment requirements

Figure 5: Requirements Documents of WTOC

The first item in this section has the students to develop a functional block diagram of their project solution, an example is shown in Figure 6. This diagram provides a graphical representation for the design and can be very helpful in explaining the solution to sponsors, team members, and those interested in the project. From this diagram, all parts of the system should be representative and the connections from system block to system block should be clear. A good functional block diagram should speak to a mid-level project description and be more informative than the high level overview, but not as detailed as an engineering drawing or schematic.

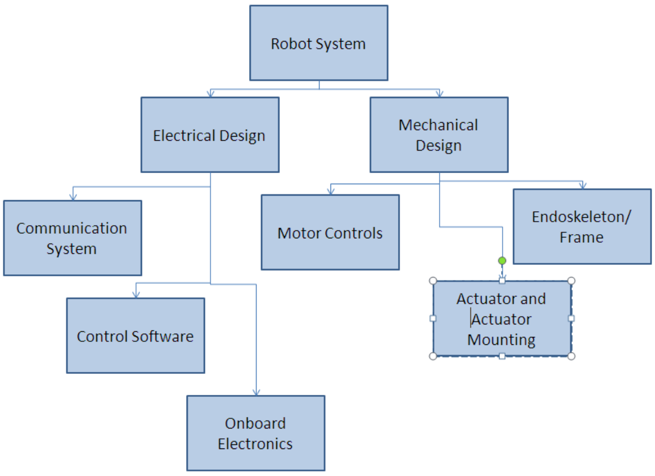

Figure 6: Functional Block Diagram

Since the focus of the course sequence is electrical engineering projects, the majority of these tasks are focused on providing the design, or the use, of an electronic embedded system to meet the project deliverables developed within the project scope. This electronic system will normally have a hardware component as well as a software component. Some project may have one and not the other, but for the WTOC both are listed for generality. In this section, the selection criterion of the embedded system is presented and the reasons the embedded system was chosen are explained.

When software is required, the student engineers are to deal with the software design as a system which includes the appropriate level of documentation is required to drive the design. With this approach the students are asked to develop a Software Requirements Specification (SRS). This document is to clearly specify the function of the software. With the SRS in place, the engineer can then design their software, and this document is called the Software Design Document (SDD). From the SDD the code is created very quickly and the team members can reference back the SDD in creating this code. With the SRS and SDD, the software task can be broken up into parts with multiple people coding in parallel all the while making sure the software meets the specification laid out in the SRS.

The remaining items of the WTOC are focused on managing constraints based on project specifics. Some projects will be approved by third party, or in house requirements. Due to this constraint, the teams document the requirements and define in their analysis and design the "how" and "why" their design will meet these constraints. These constrains may also drive tests required in the subsequently described Test Plan. As the students are completing a course, either EE400 or EE401, to meet their degree requirements, they must fulfill ABET requirements which include the documentation of how their project "meets desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability." [1] While the students are completing their design, special attention is paid to the identified risks that where identified within the Scope and an effort is made to ensure the design meets those constraints.

With the design maturing and meeting the project deliverable in the presence of constraints, the hardware schematics, SRS, SDD, and final budget of the proposed project solution is realized. With these documents created, this information is formalized and presented. It is imperative that the design team reviews their requirements from the Scope to make sure all deliverables are meet in light of the pass/fail criteria such that the proposed solution will be successful.

The student design team is asked to provide some type of design demonstration to validate their analysis. This could be a software-based simulation using a tool like Matlab or Multi-Sim, but more likely will be a partial mock up of the purposed system. This system is referred to as their Revision 0 (Rev.0) system. Using their Rev.0 system, the team is to present and complete a test plan. This test plan should represent all the constraints as defined from previous sections of the WTOC. With their Rev.0 system passing their purposed test plan, the student teams will have confidence their final design will meet all project deliverables.

C. Execution and Closing

With the Rev.0 system successfully completing the test plan, the team is ready to move to the third and final stage of WTOC, Execution and Closing. The outline of this phase is shown below in Figure 7. In this phase the team finalizes the design by fixing any problems found through the initial testing phase. At times there will be sufficient problems with the initial design that the teams will need an additional revision of the system and testing trials. The project sponsors are asked to make that decision as to when the design team is ready to move forward. When they are, the team will finalize their design and documentation. These results are flexible to the given project and the items listed in the WTOC can be modified based on recommendations from the sponsors. Normally, these items will include their design and analysis documentation, proof-of-concept simulations, hardware schematics, the software documentation (SRS, SDD, Code), testing data as defined in the test plan, list of Scope changes agreed upon by design team and sponsors, the modified Gantt Charts with actual project timing, final project budget, along with any other pertinent documentation.

III. Execution and Closing

A. Final design

B. Design Results

1. Input/output data, power requirements, ect.
2. Statement about compliance with recognized safety codes if appropriate
3. Statement of problems encountered in design and how problems were resolved
4. Discuss design changes
5. Schematics
6. Actual schedule of events
7. Cost of project

C. Results of testing

D. Conclusion
E. User's manual
F. Final presentation
G. Spec sheets
H. Status reports
I. CD (includes all documentation, code, schematics, presentations, etc.)

Figure 7: Execution and Closing of WTOC

If the project requires a user manual, this would have been identified within the Scope. To meet these requirements the student design team would be asked to create this manual based on the specification of the final design. There would be acceptance criteria as defined by the project sponsor as to the completion of this task. The manual would be present in any closing documentation.

The student design team is tasked to create a report to close out their course sequence requirements which contains the project information as described previously. The students are tasked to give presentations throughout the project sequence as well as a final presentation to summarize the results of the project in closing. All of these presentations should be included within the closing documentation. The design team is asked to make a CD or DVD of all project material with a section clearly presenting the project report and presentations.

V. CONCLUSION

The capstone design sequence in the EE program at WKU is a successful culminating sequence which prepares students for challenges they will meet in their professional careers upon graduation. Through a variety of assessment means, the EE faculty determined that these courses would be a richer and more effective experience by the incorporation of project management topics and practices into the courses. A detailed project management approached described in this paper has been incorporated into the capstone design sequence. As a result, the student projects are better managed and the students are more effective in meeting their design objectives.

VI. REFERENCES

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