ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #28482

APPLYING AUTHENTIC INDUSTRY CPM PROJECT MANAGEMENT TO AN HONORS R&D PROJECT (SOFTWARE AUDIO EQUALIZER)

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Abstract

In any engineering technology curriculum, students must gain mastery in applying engineering design skills, as this is a basic requirement for industry hiring and future success. Unfortunately, many courses are commonly taught in a purely academic setting, bereft of any authentic industry design experience, including capstone and PBL courses. Preparing students to become industry-ready is highly valued and demanded by hiring companies. Students with a working knowledge of project management skills are particularly attractive to employers seeking a STEM based workforce, especially in high technology product design and manufacturing [1]

In this paper, we present a model of implementing industry-accepted critical path (CPM) project management (PM) techniques to enhance student authentic industrial skills in an undergraduate Honors R&D program. These methods were applied to a specific R&D effort. The product development effort was to research and design a software-based, 3-Band audio equalizer using MATLAB and was to be delivered to a real campus customers with a real deadline. The deliverable was to demonstrate the product by applying it to adjust the audio tonality on mp3 music files in real-time at QCC's Annual STEM Honors Conference.

Our results showed this was a transformative experience for the student who acquired an acute awareness of meeting customer schedules, product requirements, managing schedule slack, and pursuing design alternatives to mitigate risk of failure as defined by a missed customer deadline. The overall learning effectiveness and design, as well as lessons learned, are discussed, including future work to create a generalized CPM Project management module for any applicable STEM discipline via OER (Open Educational Resource) availability. Lastly, the students learned to leverage outside resources by engaging industry technical consultants, and regularly met with active industry engineers to validate the best practices of critical path management (CPM). These activities, learning by doing, help the students to gain the industry-readiness experience, highly coveted by hiring technology companies.

Background and Literature Review

There is undeniable evidence supporting the value in preparing students to be industry-ready by exposing them to real-life, authentic engineering practices[1-2]. Technology employers are often frustrated at the lack of any related work experience learning that is outside the isolated academic learning environment. They highly prefer graduates with exposure to industry practices through internships, or relevant job experience. However, these direct employment opportunities are limited, especially at community colleges given the short two-year curriculum. To address this gap in skill sets, a Fall 2016 report Titled "The Key Skills and

Competencies Needed for In-Demand, Entry-Level Tech Jobs in New York City" [2] states that among the top five sought after skills are:

- Applied technical skills, or application engineering
- Demonstration of technical skills in a "real world" setting
- Students' ability to identify essential requirements to solve problems based on users, stakeholders, customers, and constraints.

Other sought after qualities in this report include "strong desire and ability to learn" and emphasizes, "...individuals must gain experience building products in a real-life setting in order to be strong candidates for NYC's select entry-level tech jobs".

In a January 2017 report [2]titled "Bridging the STEM Skills Gap: An employer / educational collaboration in New York", top technology employers pointed to the lack of professional skills that are required in all kinds of workplaces. "More than half of employers reported high or moderate difficulty finding critical thinking, communications and problem-solving skills, including time management skills….and….dependability".

Studies on the effectiveness of PBL courses have shown them to be essential in developing application engineering skills (critical thinking /synthesis)[3]. However, PBLs can vary widely in content, depth and are often bereft of any industry exposure--especially regarding project management (PM). Introducing PM skills can be an arduous and time-consuming effort for faculty, especially if there are no approved courses to serve as a framework. Hence, in many cases, authentic industry experiences are left to the discretion, motivation, and conviction of the faculty to undertake such implementation.

Recognizing the genuine benefits of real-life industry exposure, CUNY has responded to these findings with a limited series of grants [4] across its 17 schools to motivate faculty to implement such industrial learning in new and existing coursework. Although these efforts are commendable, they occur in small step initiatives, are limited in deployment, scalability, and continuity.

The purpose of this research effort is to introduce a case study model to facilitate authentic industry project management method learning, over one semester, specifically emphasizing Critical Path Methods (CPM). The model includes highly relevant industry practices in project management and is applied to a product development with a real customer delivery date and includes interaction with real industry engineers, making for a learning experience that contributes to student job-readiness while in school **[5]**. Another purpose for this model is to serve as a guide for new faculty to implement authentic PM practices in a PBL based environment, whether in a course, research project, or other applicable settings.

Methodology

To kick-off our case study, we first sampled 22 students in an AC Circuit Theory course, comprised of 6 contact hours per week. All qualifying and interested students were interviewed (minimum 3.0 GPA) for entry to QCC's Honors Research Contract Program**[6],** which is a formal, structured, and monitored undergraduate research activity granting three "honor" credits to the student. The interview purpose was to pre-screen candidates to ensure student time commitment (no outside work conflicts), motivation, technical ability, and good general character traits such as enthusiasm, dependability, and willingness to learn independently. Student motivation was of particular importance given the expanded scope of the R&D effort to include the PM component with regular industrial meetings. For completeness, students were administered the ILS (Index of Learning Style) test designed by Prof. R. Felder (NCSU) to clear students of any unusual bias in learning style which could cause a mismatch for this experience. The selected student ILS result is documented in Appendix A-2.

To set students expectation, we reviewed the technical design scope, the PM methods, and emphasized that we had a real customer deliverable deadline. It's important to express that we shared our functional roles. I served as the "program manager" and the student as the "industry or hired engineer". In this way, for this case study, the student would not be overwhelmed with all the management responsibilities and could dedicate a good portion of time to the product research and design effort of the audio gain equalizer.

We choose the yearly STEM Honor Conference as our real customer. Our intention was to inspire STEM attendees to continue their studies by showcasing a working prototype developed by their peers in the exciting field of audio. Sustaining motivation is an important factor in a community college, as many socio-economic factors interfere with students' educational goals. Our student learning objectives were tailored from a subset of the TUNING-AHELO outcomes[7]:

Table 1. Project Learning Objectives / SLOs

Category	**Objectives**
Authentic Engineering Practice	1.Ability to apply knowledge and understanding to the development of designs to meet specified technical and customer requirements.
	2. Ability to select and apply relevant analytical modelling methods
	3.Ability to demonstrate knowledge of authentic CPM (critical path management) Project management and business practices
	4. Ability to demonstrate understanding and impact of customer delivery dates as drivers

Application of Critical Path Method (CPM) Project Management

Two types of project views are the Gantt and Network or PERT (Program Evaluation Review Technique) views. Strong preference was given to the Network view because of the visual appeal to students and the instant bird's-eye view of the entire project. Each task is represented as a box in flow-chart style format and easily communicates the task input and outputs. We customized the task descriptors as shown in Figure 1 below:

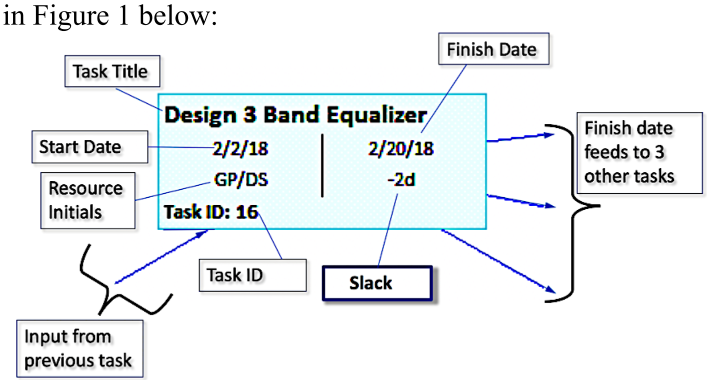


Figure 1. Task parameter descriptors in Network display view (MS Project™)

Notice Task 16 has one input task and feeds three other activities. Moreover, the task parameter “slack” indicates how much delay in task 16 completion date impacts the final project deadline. The Critical Path Method identifies all tasks with a current finish date that will delay the final project due date. For example, in Figure 1, a -2d slack indicates the task is already on the critical path and is extending the project deadline by 2 days .

Industry Scheduling Methodology

Each task was given a duration, not a start and finish date. By inputting task duration only, along with the task dependency for the successor and predecessor, each task start and finish dates are automatically calculated, allowing for automatic, real-time evaluation of the project finish date. This approach differs drastically from how this software is used by non-professionals, which is equivalent to entering tasks with start and finish dates in Excel™ as static dates. By following this procedure, a critical path (CP) is automatically calculated as shown as a bold red line in Figure 2 below. The connected path in bold-red indicates the critical path.

As acting Program Manager, we routinely made revisions to our plan (by adding resources, etc.) to bring our schedule back on course if tasks were being finished late. The student was particularly impressed with the ability to perform immediate “what-if” scenarios and understood the impact of each task on the critical path, bestowing a sense of urgency and ownership of those tasks. A typical project network view is shown in Figure 2:

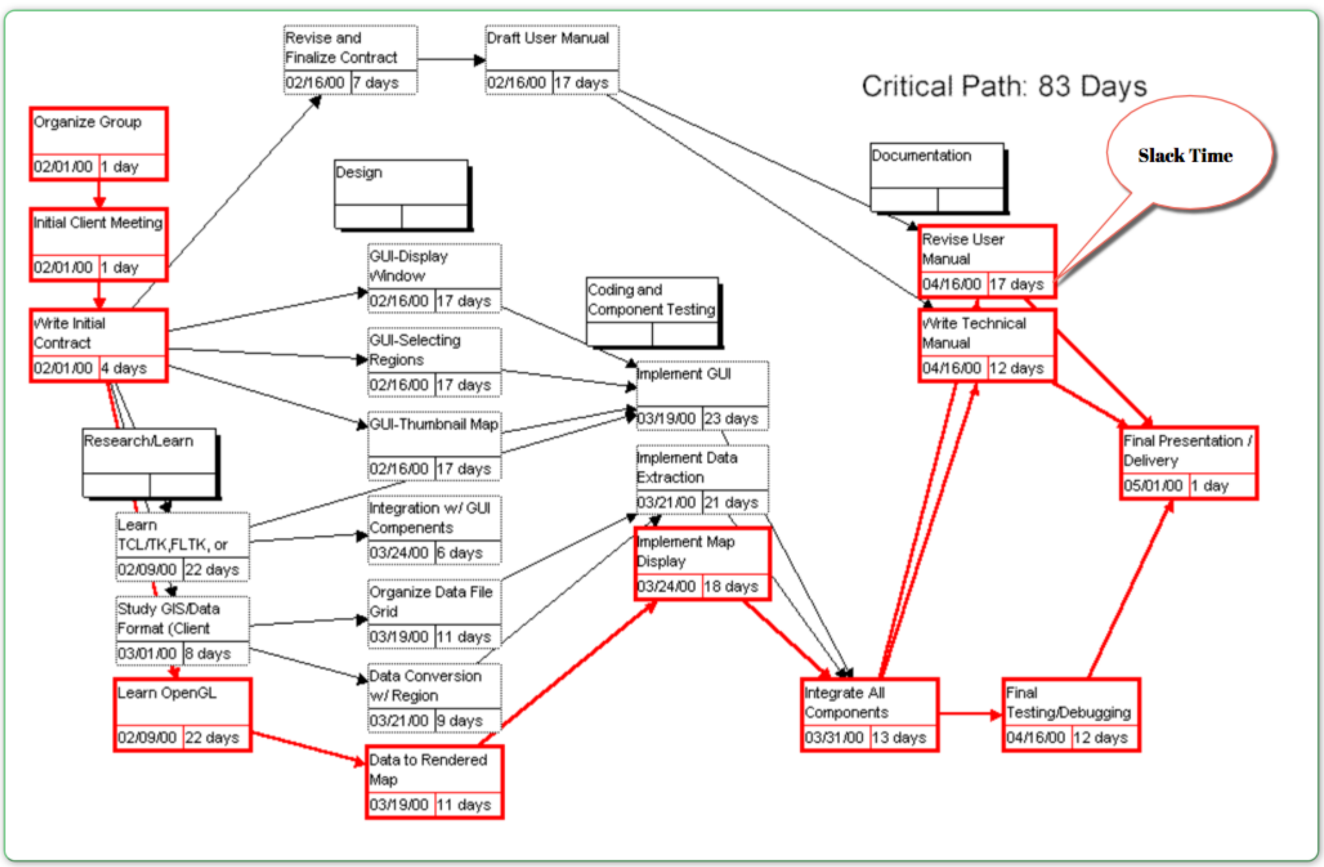


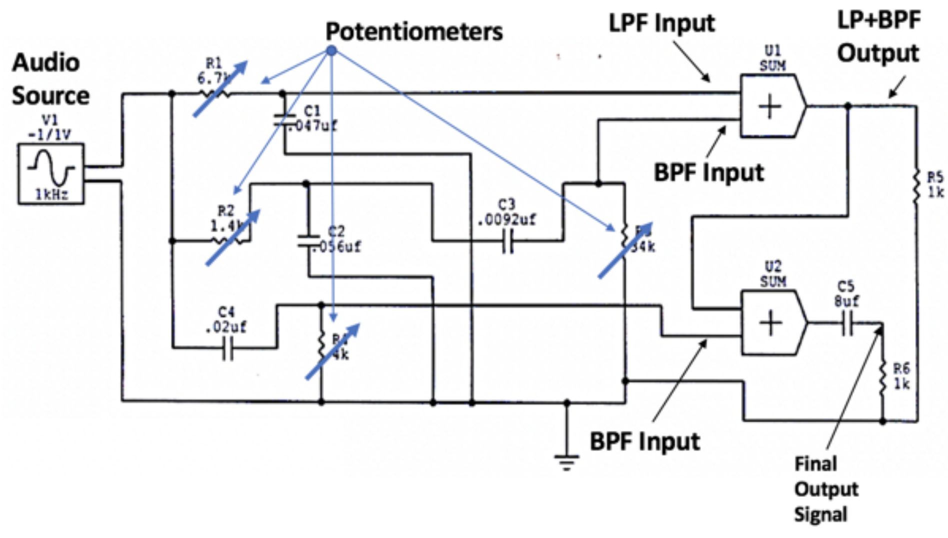
Figure 2. General example of a project in Network View: Critical Path shown in re

TECHNICAL SOLUTION: Software based 3-Band Equalizer Design

The student performed independent research on audio equalizers and human audio theory. The project team collectively performed design options tradeoffs and estimated their impact on the delivery date for the conference demonstration. All the tasks were captured in the project plan of work and all dependencies and allowable slack were monitored daily.

After looking at the literature for various filter design types and topologies [8-10], we reviewed the customer requirements and technical specification (generated by the PM) and concluded that a 3 Band, analog equalizer was a suitable solution. The purpose of the audio equalizer was to make adjustments to the frequency response of a music audio device and supply either a boost (positive gain) or cut (lower gain) at certain frequency ranges, thereby changing the sound of the audio.

The student designed a parallel cascade of a Low Pass, Band Pass, and High Pass filter, selected all the appropriate component values, to yield the requirements for each cut-off frequency. The gain flatness across the range of 0 Hz to 50 kHz was validated to be within 1.5 dB across this wide frequency band for a simple design. Op-Amps were not part of the course, hence, we had to exclude their use. With faculty consultation, the student took the initiative to address any harmful mismatch in impedance loading between each filter stage and introduced potentiometers (shown below) to shift the respective filter transfer functions according to desired bass boost or cut and treble boost or cut. Shown below is the nominal design values for our 3 band equalizer. Our circuit was first modelled and designed using Circuitmaker™ as shown below. Note the HPF drop at 20Hz at the output of U2 Summation block.



Filter Type	Design Parameter	Component Selection
Low Pass 1st order	Fc=500 Hz	R_1= 6.7 kΩ C_1= .047 µf
High Pass 1st Order	Fc=2 kHz	R_1= 4 kΩ C_1= .02µf
Band Pass (Cascade of zHPF+LPF)	F_{lower} F_{upper} 500 Hz, 2kHz	R_1= 1.4 kΩ C_1= .056 µf R_2= 34 kΩ C_2= .0092 µf

Figure 3. Circuit showing combined LPF, HPF, and BPF in parallel configuration.

Finally, the design was modelled using MATLAB in order to facilitate a good end user experience by reading input sound files and hearing the results as well as seeing them on a spectrum analyzer. See Appendix A-1

Industry Engagement

To sustain motivation and to reinforce the authenticity of our CPM management techniques, 20-minute video conferences with supervisors and program managers from General Dynamics AIS and Fujitsu Network Communications were scheduled on a bi-weekly basis. These engineers were experts in project management and systems engineering and were gracious in sharing actual accounts of failed and successful projects. These meetings were not impromptu, but planned with an agenda for each meeting. Meeting agendas covered student formulated questions and open-ended questions on attributes of good schedule management. Of particular note, the engineers openly shared that project failures (slipped schedules resulting in contract penalties) do occur, and open discussion of failures are not to be avoided but embraced as a valuable learning experience. We also used this time, to practice interviewing skills. Lastly, the idea of leveraging outside resources (MATLAB consultants) was explained as a common business practice (SLO # 3 in Figure 1) which the student appreciated.

Assessment

We mostly used qualitative assessments for the three SLOs outcomes and understand the limitation due to subjectivity [11]. However, we were encouraged that our close interaction in our roles as Program Manager and Hired Engineer formed an acceptable basis to bound the subjectivity and provide unique insights on learning given our very frequent interaction. Assessments were comprised of documented design reviews, periodic equalizer design reviews, project progress reports, and research reports on audio technology. The demonstrated ability to use CircuitMaker for prototype equalizer design followed by MATLAB / Simulink for the final design with music-file play capability, were clear indicators of SLO # 2. The report quality and content depth served as indicators in assessing critical thinking, and applied problem solving. Self-confidence surveys (Likert based) were interspersed through-out the semester and indicated a steady increase in comfort with public speaking and a customer focused awareness. We coached the student that self-confidence is not based on feelings, but rather based on demonstrated performance.

Below is a small sample of comments:

- *" ..the plan kept me on track, and not in the dark. I liked not having to depend on seeing the program manager to tell me what to do because the schedule task has my name on it and saw who could delay me and how I could mess up other task"*
- *"….I am very quiet and shy and don't share my feelings. I felt much less shy as my confidence grew during my teamwork with the program manager. The industry engineers made me feel like I was an engineer and not a student. It did take time though. I feel very different about speaking up now"*
- *"..Using the Project software makes me feel I can have control over things I had no idea about. If I take time, I can better understand what has to get done and that make me feel a little confident. For small stuff, I don't think I would spend the time making a plan".*

Reflections

Overall, the introduction of authentic CPM project management techniques during this development project was a bit overwhelming at first. Spending more time selling the project as less daunting by showing a 20-minute introduction video outlining the work would have alleviated typical student anxiety. Starting small is always a good approach for introducing any first-time authentic industry practice. A tangible sense of teambuilding and trust was created as we adjusted each member's work load for the common good of meeting the customer delivery date. Having a real customer commitment provided the continuous motivation to be thorough in all aspects of the team's work. Nonetheless, the project could have taken a smaller scope given the two resources, or better, to have involved more participating students.

Conclusions and Recommendations

The outcomes of this intensive pilot study were quite varied through the early part of the project, especially during the first 2-3 weeks, where student resistance was expressed concerning the value of creating such detail planning, especially for "just a one-semester project". Initial student resistance to such organized planning is common as documented by many faculty in PBL environments[12-13]. However, as the complexity and urgency of our project unfolded, the belief in the CPM method of planning became evident and provided a sense of assurance. The student found this entire industry project management experience to be useful, transforming, and contributed to reshaping the student's behavior to be more decisive with improved confidence, including his ability to research untaught subject matter. Moreover, a sense of enablement to use project planning (in and out of the classroom) was expressed.

As continued efforts to this case study, the author is planning to refine and scale this model for further development as a stand-alone module intended to be used for deploying PM methods to STEM based curriculums. Options would include factoring the degree of industry participation, scope, and complexity. Finally, this module is planned to be offered as an OER (Open Education Resource) STEM resource for anyone looking to add authentic industry PM practices to their instruction---ranging from a laboratory course to a full scale dedicated capstone or PBL course.

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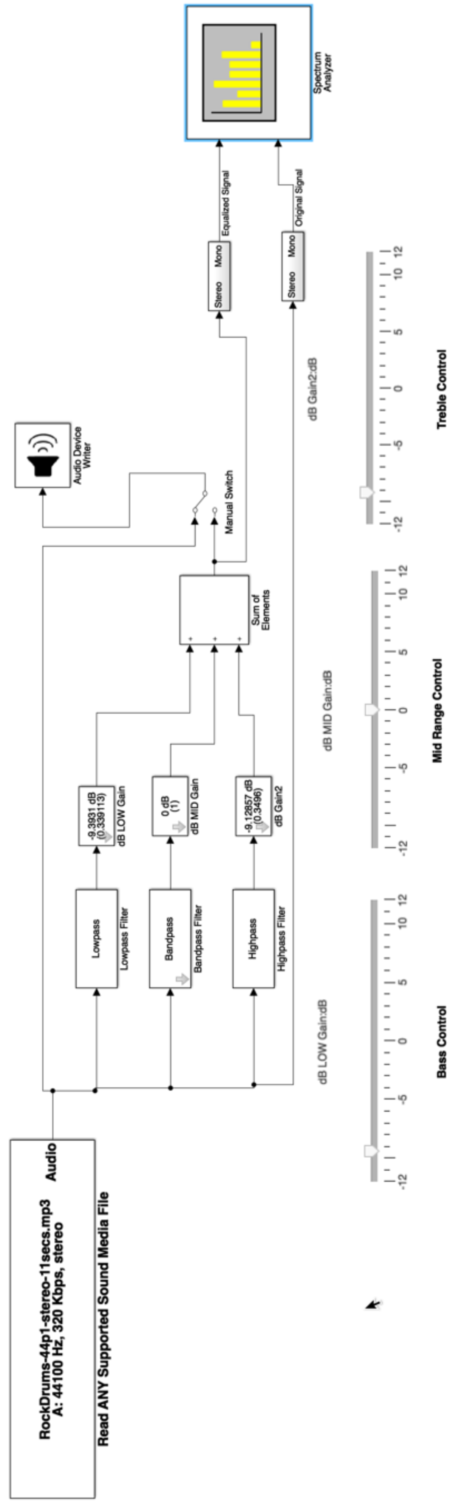
Acknowledgements

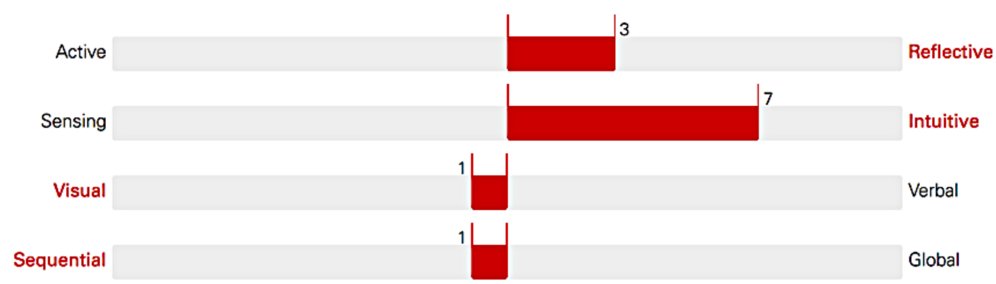
We, the project team, would like to extend a warm special thanks to the industry partners, Sr Program Manager, Peter Agrapides of General Dynamics-AIS, Mahesh Mistry, Physical Design Group Leader of Fujitsu Network Communications, and to Matt Ginn former VP of Marketing of Meru Networks. *A special thanks is in order to Prof Michael Kozma of QCC CUNY for this invaluable "industry style" consultation on prototype design validation and other help.*

APPENDIX A-1 MATLAB Simulation Model



APPENDIX A-2

For completeness, results of Index Learning Style evaluation using Richard Felder's (NSCU) test is shown below.. "A student's learning style profile provides an indication of *possible* strengths and tendencies or habits that might lead to difficulty in academic settings". The purpose of this evaluation was to screen the candidate for any "extreme" score (9-12) in a learning style that would not be compatible with our Authentic Industry CPM Project Management Case Study.



What do my results mean?

According to the model on which the ILS is based, there are four dimensions of learning style, with each dimension having two opposite categories (such as active and reflective). The reported score for a dimension indicates your preference for one category or the other.

If your score for a dimension is 1 or 3, you are fairly well balanced on the two categories of that dimension, with only a mild preference for one or the other.

If your score for a dimension is 5 or 7, you have a moderate preference for one category of that dimension. You may learn less easily in an environment that fails to address that preference at least some of the time than you would in a more balanced environment.

If your score for a dimension is 9 or 11, you have a strong preference for one category of that dimension. You may have difficulty learning in an environment that fails to address that preference at least some of the time.