Timelines and Student Project Planning in Middle School Technology /Engineering Education Exercises

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Abstract
In the practice of professional engineering design, nearly all work is ultimately completed in a team format and under a deadline. It is therefore relevant to reflect, on some level, the demands of these real world constraints in instructional problem solving activities as well. It is our belief and experience that the integration of these concepts may be made successfully as early as grades seven and eight.

While team based interactive learning has consistently been a focus of the Tufts University/Nashoba Regional School District NSF GK-12 program, over the past academic year, the concept of student directed project planning has also been implemented. This primarily involves the creation of a project specific Gantt chart, which is a common tool in industrial project management. This has similar benefit to students as to working professionals in that advanced planning allows for the broad survey of project scope and for the allocation of time and personnel resources to various tasks that are component to its efficient and timely completion.

As the planned tasks mirror the steps of the engineering design process, this exercise also becomes a pedagogical tool to review and reinforce this material. In addition, the usefulness of the graphical representation of information is also emphasized. It is our experience that students respond well to this exercise and in the periodic charting of actual progress against initial goals, experience the reinforcement of planning skills which are broadly applicable to many types of team based problems.

It is the objective of this paper to discuss in detail the motivations, instructional methods and impacts of implementing engineering timelines into middle school technology/engineering design exercises.

Introduction to the Classroom

The Tufts University/Nashoba Regional School District NSF GK-12 program supports the inclusion of Engineering content into the curriculum of schools within that district at the 4^{th} through 12^{th} grade levels. Graduate student fellows with undergraduate degrees in engineering and computer science are typically placed within a classroom in order to develop activities that support the analysis of problems from an engineering perspective. The subject classroom for this paper is a Technology/Engineering program at Hale

Middle School in Stow, Massachusetts including students in grades 6, 7 and 8. A Tufts graduate student fellow has been in this classroom for the past two academic years.

The substantial emphasis placed on Technology/Engineering in the Massachusetts Department of Education (MDOE) State Curriculum Frameworks[1] and the relative maturity of the program offered at Hale has resulted in a primarily project based program of instruction at all grade levels. Students are taught the basic areas of technology, the universal systems model, the engineering design process and multi-view drawing in the first year. In the second year, structural analysis is introduced. Students first design, build, test and analyze static structures (e.g. bridges) and then complete a robotics unit using the same process with Lego-Dacta Robolab®. This set allows the use of desktop computer programming to control student built motorized machines that are used to complete a variety of manufacturing and transportation related challenges. In the final year, the general types and properties of engineering materials (wood, metal, plastic, etc.) are introduced and students complete a full-scale prototyping project which considers both the engineering elements of design and construction as well as economic and productivity issues related to the large scale production of the prototype.

The result of this curriculum is that students in the second and third years spend a substantial percentage of classroom time in small groups of two to four students engaged in project work which requires both the division of labor among its members and the management of the total time available to them. Typically a project involves the following steps: definition, research, design, selection, construction, testing, evaluation, redesign and presentation. This mirrors the definition of the Engineering Design Process (EDP) used by MDOE. At Hale, students are present in the Technology/Engineering classroom five days per week for approximately one third of the academic year, resulting in approximately 60 instructional days (47 hours) per year per student. The rather wide scope of the material covered and the limited time per student make the effective management of time critical for both the teacher and the student. The effective use of limited classroom time was the initial impetus toward the implementation of a project planning tool. It was also desired to give students exposure to the manner in which projects are actually managed in industry and to impart time management skills useful throughout the school day.

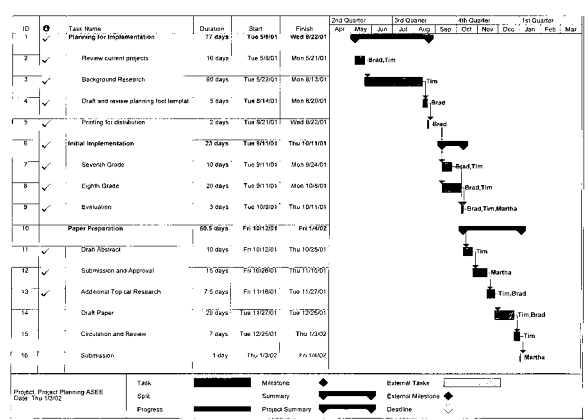

Figure 1: Example Bar (Gantt) Chart

Project Planning Tools

A variety of project planning techniques are commonly used in industrial practice. These include bar charting (Gantt), Critical Path Method (CPM), Program Evaluation and Review Technique (PERT) and Precedence Diagramming (PDM) among others[2]. The method used depends on the level of complexity and specific needs of the project or projects to be managed. Naturally, in some cases, historical precedent within a particular engineering discipline or industry can also have some influence on the method selected. Regardless of the specific technique that is chosen, one of many widely available computer software packages is usually used to guide implementation[3].

Common to all of the methods of project planning mentioned above is the resolution of a given project into a series of discrete tasks whose duration and resources can be estimated with relative confidence. This is an extension of the methods of scientific management pioneered by Frederick Taylor (1856-1915) at Bethlehem Steel in the early twentieth century. In fact, the earliest graphical project planning tool, the bar chart, is named after an early associate of Taylor's, Henry Gantt (1861-1919) who studied the order of work operations in manufacturing[4]. This simple form of project planning relies on the horizontal representation of project task duration and can be modified to include the dependency of one task on the next. While this technique is presently used industrially only for relatively simple projects or when the duration and scope of the project is not firmly fixed (e.g. research and development), its utility remains substantial. Gantt charts are commonly implemented using the Microsoft Project software package. **(Fig 1)**

Large and more complex projects such as public works construction and military projects often rely on the more complex network based techniques of CPM and PERT. These methods were developed in the 1950's specifically for the management of large industrial and military projects where multiple interdependencies are present among tasks and resources are under tight constraint. They are based on the construction of a network of interrelated project activities. As compared to bar charts, network diagrams like the PERT chart shown in **Figure 2** can offer a more direct means of visualizing the relationships between tasks. CPM, developed by Lockheed for the Polaris missile project in 1958, is focused on the management of project duration and cost through the probabilistic calculation of total project progress based on three time estimates of the completion of each task. PERT was developed nearly simultaneously by DuPont/Remington Rand Univac in 1956-1959 and uses deterministic task estimation focused on finding the optimum tradeoff of project duration and cost. The speed, cost competitiveness and complexity of many high technology projects also makes them prime candidates for planning via these network methods[4]. Network methods are often implemented using the Artemis, Primavera and Open Plan software packages.

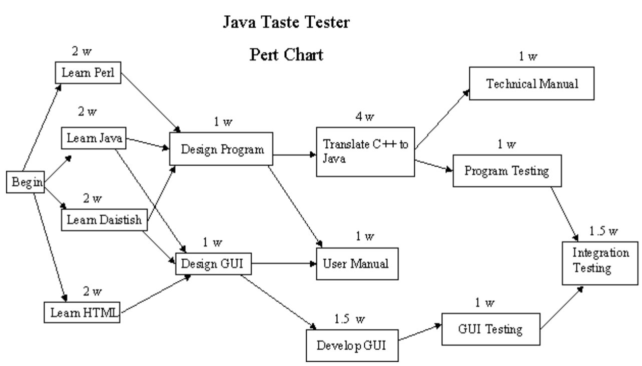

Figure 2: Example PERT Chart
(http://www.cs.unc.edu/~stotts/danish/web/sched/pert.html)

Initial Implementation of Project Timelines

Since it was desired to implement a useful project planning tool at an age-appropriate level of complexity and without the use of computer software, the bar (Gantt) chart method was chosen for use at Hale. For simplicity, the Gantt charts used were referred to as "work timelines". Templates listing the steps of the Engineering Design Process and a generic Bar Chart Template were developed from example Gantt charts constructed using Microsoft Project **(Fig3)**. Templates included task description, planned start date, planned completion date, personnel responsible and actual completion date in addition to the bar chart representing this information. One universal template was used for all groups in all projects.

ENGINEERING WORK TIMELINE BAR GRAPH

TASK:	
• *Identify the Problem*	
1.	
2.	
3.	
• *Research for a Solution(s)*	
1.	
2.	
3.	
• *Select and Develop the Solution*	
1	
2.	
3.	
4.	
• *Select Design and Construct a Prototype*	
1.	
2.	
3.	
4.	
• *Test and Evaluate the Solution*	
1.	
2.	
• *Communicate the Solution*	
1.	
2.	
3.	
4.	
• *How will the Solution will be Redesigned Based on the Test*	
1.	
2.	

ENGINEERING WORK TIMELINE

Task Name:	Start	Finish	Personnel Reponsible	Date Actually Finished
• *Identify the Problem*				
1.				
2.				
3.				
• *Research for a Solution(s)*				
1.				
2.				
3.				
• *Select and Develop the Solution*				
1.				
2.				
3.				
4.				
• *Select Design and Construct a Prototype*				
1.				
2.				
3.				
4.				
• *Test and Evaluate the Solution*				
1.				
2.				
• *Communicate the Solution*				
1.				
2.				
3.				
4.				
• *How will the Solution will be Redesigned Based on the Test*				
1.				
2.				

Figure 3: Templates Used at Hale

Students were given a one class period tutorial on the basic concepts of project planning and bar charting techniques using the template documents and were asked to complete the templates as the initial step of their problem solving process. Two classes of seventh grade students working on the design of a bridge constructed from toothpicks and two classes of eighth grade students working on an open-ended assistive bioengineering technology project were initially used. In the case of the seventh grade classes, the goal of the project was well defined: the construction of a structure to span a specific distance that maximized load carried and minimized cost. In the eighth grade, students were tasked to produce a prototype of a device assistive to the needs of a wheelchair bound middle school student. It was emphasized to all classes that the seven main headings of their templates reflected the steps of the engineering design process.

To date, two groups of four pilot classes have completed projects using the new tools. Examples of work from both grade levels is shown in **Figure 4**. Student understanding of the planning process was satisfactory with 19 of 21 project groups to date submitting accurately completed timelines. At the outset of the project work, students were asked to fill in the sub-steps beneath each of the main headings and to use this as a tool to understand what was practically required to complete the project one step at a time. This appeared to reduce the initial period of confusion and inaction which students often enter upon being given complex, open-ended problems. In addition, students were observed to consult the timelines at the beginning of the work period and to update project plans during the duration of the project. Daily consultation of the work timelines also helped to clarify the division of labor within each team.

Perceived Benefits for Students

Several benefits to the students have been observed. The first is that the basic concepts of time management and project planning along with a general tool for implementation in group project work is introduced. Time and resource constraints are ubiquitous in technology and engineering practice from initial concept through manufacturing or completion, and likewise in classroom instruction whether a lecture or a project based format is used. Where students are given challenges that require their effective management of scarce resources, a tool is provided for their success. It is easy, even with periodic milestones for students to procrastinate activities until due dates are near and often difficult to convey in a meaningful way how much class time remains until the very end. The ability to graphically represent how much time remains and to have this correlate to who in the team is responsible for each activity has allowed teams to work more efficiently. Also, since it is the work timeline (and not the teacher) which "says" that a particular project task should be completed on a given date, team self-sufficiency is also promoted.

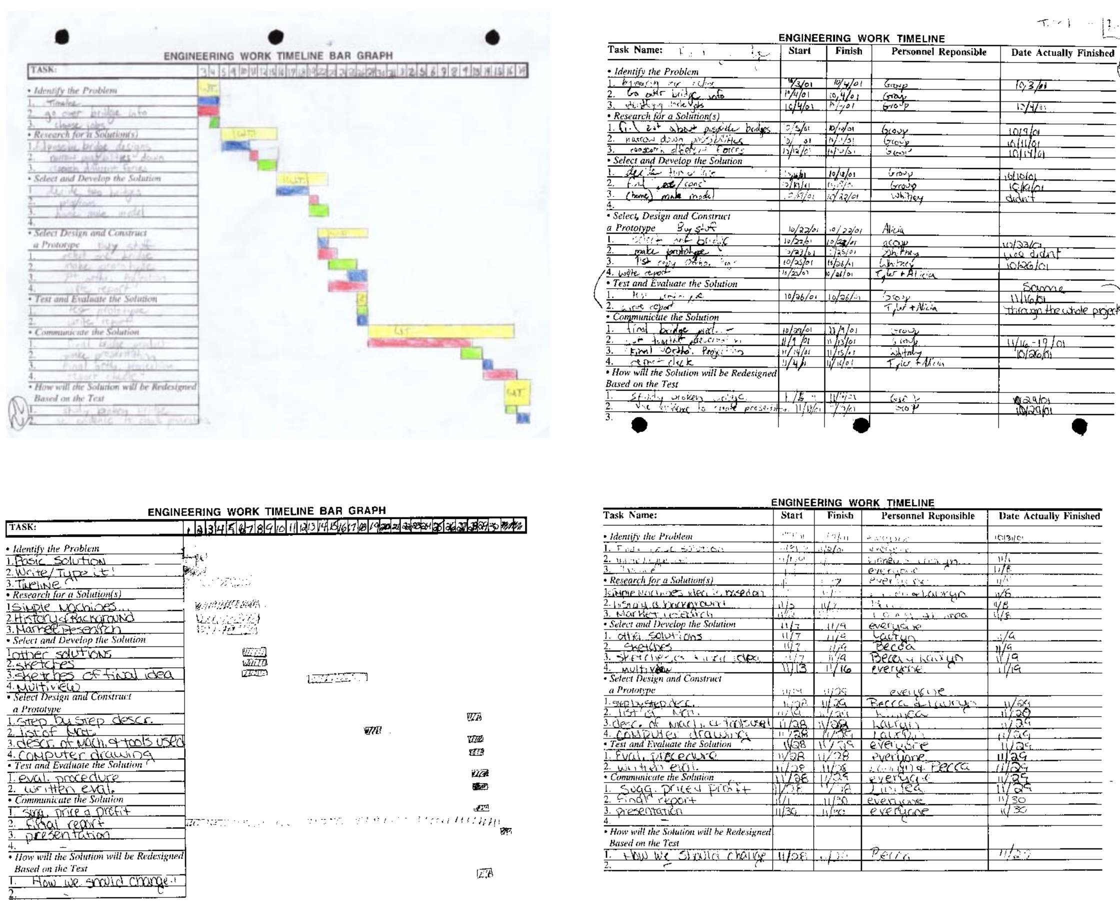

Figure 4: Examples of Student Work (Top-Grade 7, Bottom-Grade 8)

While the initial goal of a real-world practical tool for time management has been met, two other instructional benefits of the current approach seem to offer additional justification for its inclusion. The first of these is the review of the engineering design process that is facilitated. Formal structuring of the generic project planning templates around the steps of the engineering design process serves as a very effective method with which to review and enforce these basic steps as a universal process. Perhaps more importantly, the expansion of the process steps into sub-steps actually completed by project groups enhances the meaning of the each step by illustration. Ongoing review is also encouraged since students are required to revisit the Gantt chart that they have created throughout project completion. Thus the student has been reinforced in the notion of a universal engineering problem solving paradigm and has been given practical skills in its implementation. Since the individual steps of a project which require planning are not obvious even to more experienced students (and even perhaps some professionals) in the field of technology/engineering, this skill set seems relevant at a variety of instructional levels.

The second additional benefit is that students are given a practical exercise in the graphical representation of data that is immediately useful. For middle school students the construction of the bar charts is an understandable application of graphical analysis that may be extended to the analysis of data from individual or class project test results. Analogy of one graphical method to another may offer an enhanced understanding of this concept. This benefit is likely to be greater in younger students with limited exposure to this concept. However, for more advanced students, complex project planning techniques incorporating network analysis and cost management might offer similar benefit in enhancing a practical appreciation for the usefulness of engineering calculation and modeling to project success.

Conclusions and Next Steps

Convincing quantitative demonstration of the student benefits of this technique is admittedly difficult. However, what is clear is that students spent more time in review of their project activities than in the past, and did so using a tool structured around the main paradigm of the engineering field and of the state curriculum frameworks: the engineering design process. Discussion of the work timelines in written and oral project presentations by each of the student teams also indicates that the students both understand the concepts presented and find the timelines useful. Final oral presentations now also include both a discussion of how time and resources would factor into plans for redesign of the prototype following testing/analysis and how the timelines used in the current project could be improved for use in the next. Anecdotally, in the initial implementation of this tool, no significant change in project completion times was observed. However, the second group of students did seem to utilize class time more effectively, and unlike their predecessors, all teams finished in the originally allotted time.

The authors feel that the introduction of these concepts was successful as evidenced by significant accurate completion of the template documents and by positive discussion of project timeline use in student presentations. It is planned to continue the implementation of project timeline usage in all project-based work on the basis of the additional benefits discussed, with ongoing monitoring of completion times. Quantitative test assessment of improvement in comprehension of concepts surrounding the engineering design process is currently in the planning stage.

Inclusion of these methods is recommended in any technology or engineering classroom engaged in group project work at any level. They provide a valuable practical tool useful in professional engineering practice and serve to reinforce the nature of engineering as a universal and flexible process of modeling and solving all types of problems efficiently.

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