

2006-1983: VERTICAL-INTEGRATION FRAMEWORK FOR CAPSTONE DESIGN PROJECTS

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Vertical-Integration Framework for Capstone Design Projects

The importance of Capstone design projects within an undergraduate engineering curriculum is well established. However, through their experience in the vertical integration of lower-level Mechanical Engineering students into a senior Capstone design project at the Virginia Military Institute, the authors have found that such vertical integration yields significant educational and practical benefits, both to senior- and lower-level engineering students, beyond those realized from the traditional Capstone project structure.

For senior students, those benefits include additional and frequent occasions by which to hone their written and oral communication skills, increased emphasis and reliance on their project management and leadership skills, and the opportunity to clarify and focus their design concepts through their interaction with lower-level students. Through their integration within the Capstone design project, lower-level engineering students are given the chance to experience first-hand, and hands-on, design concepts and practices that extend beyond the skill-limited design projects typically utilized in lower-level core engineering courses. This experience not only motivates the retention of lower-level students within engineering but also provides these students the opportunity to build an experiential frame-work that will benefit their future learning of engineering principles.

In this paper, the authors discuss, through a case study of the integration of lower-class Mechanical Engineering students into the senior design and fabrication of an SAE Super Mileage car, the specific organizational and project-based framework they developed for the effective vertical-integration of lower-level engineering students into that Capstone Design project.

The engineering focus of this senior-level project was the design and fabrication of a vehicle to compete in the annual SAE Super Mileage competition in accordance with SAE rules and regulations. The project ranged over two semesters with the first semester devoted principally to the design of the vehicle and its component subsystems and the second to the fabrication and testing of the car and component subsystems. Although a small number of lower-level ME students had participated in this project on a limited basis for the preceding two years, it was determined that a more formal and structured vertical integration of a larger number of lower-level students into the project could benefit both the senior- and lower-level students. The success of this vertical integration was dependent upon early preparation in two key areas: 1) determining an effective organizational structure for the project teams and 2) developing appropriate and meaningful projects for the lower-level students.

1. Organizational Structure

We considered several criteria in our development of an effective Project Organizational structure:

- a) Logistically integrate twenty-four lower-level engineering students into the project without diminishing the focus of the six senior-level students on the actual engineering design and fabrication of the Super Mileage car.
 - We wanted senior leadership for both the car design/fabrication and the integration of the lower-level students into the project. However, we did not want to overwhelm the seniors by requiring them to simultaneously design/fabricate a car and essentially develop a course for, and ‘teach’ a class of, twenty-four lower-level students.
- b) Ensure effective communication between faculty advisors, senior student teams, and lower-level student teams.
 - Although there were scheduled weekly meetings for the faculty advisors and seniors, there were no scheduled meetings of the lower-level students with either the faculty or the senior students. Therefore, we wanted to develop an effective and seamless communication network within the organization structure.
- c) Ensure accountability for team work.
 - Since we wanted senior leadership for both the design/fabrication project work and the lower-level students, we wanted to ensure that the organizational structure provided a clear line of accountability for both the senior and lower-level students.

Our resulting Project Organizational Chart is shown in Figure 1 below. This organizational structure supported three principle areas (Technical, Communications, and Administrative/Logistic) over three tiers (faculty advisors, senior teams, and lower-level student teams). This structure provided technical support, across all three tiers, for all projects related to the design/fabrication of the Super Mileage car as well as communication, administrative, logistic, and project management support for the entire project.

Two primary faculty members advised the six Mechanical Engineering seniors who were enrolled in the two semester-long courses dedicated to this project. Two additional faculty members provided specific technical consultation to the senior design groups. The six senior ME students were subdivided, by equal number and by individual choice, into two primary component-related subgroups: the Frame/Body (F/B) Group and the Engine/Drive (E/D) Group. Each of these two subgroups was supervised by one of the two primary faculty member advisors. One senior from each subgroup was designated on a rotating basis as the subgroup leader and one senior was selected as the permanent Administrative Team Leader for the entire student team. Similarly, one of the primary faculty members also acted as the Administrative Faculty Advisor for the entire project.

Twenty-four lower-level students were also divided, by equal number and by individual choice, into the same component-related subgroups by class: two junior-class Frame/Body subgroups and two junior-class Engine/Drive subgroups; two sophomore-class Frame/Body subgroups and two sophomore-class Engine/Drive subgroups. One student from each of the eight lower-level subgroups was designated as the leader of that subgroup.

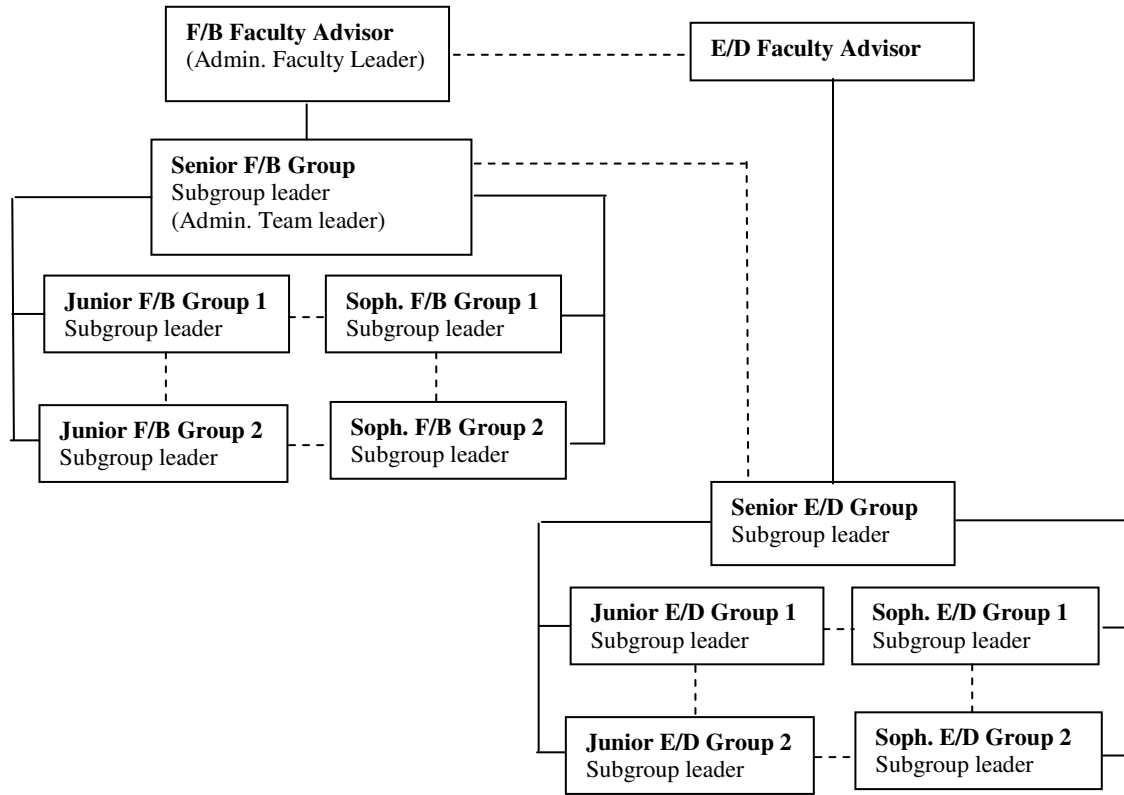


Figure 1 Project Organizational Chart

Each student subgroup was responsible for the completion of specific design and fabrication projects related to their component group. The Frame/Body group was responsible for 1) the car frame, 2) the car body, 3) steering, 4) brakes, and 5) auxiliary safety systems such as lights, kill-switches, and fire-wall. The Engine/Drive group was responsible for 1) all engine modifications, 2) fuel system, and 3) drive train.

Additionally, the senior subgroups were responsible for developing projects for their respective lower-level subgroups and working with the lower-level subgroups to ensure the successful completion of those projects. Junior-class subgroups were also responsible for helping their sophomore-class subgroup counterparts.

Senior subgroup leaders were responsible for 1) working with their subgroup to develop project schedules, 2) ensuring deadline completion of subgroup projects, 3) developing purchase requisitions, 4) communicating information to and from their subgroup faculty advisor, the Administrative Team Leader, their subgroup members, and their lower-level subgroups, and 5) coordinating meetings between senior- and lower-level subgroups. Lower-level subgroup leaders were responsible for 1) ensuring deadline completion of subgroup projects, and 2) communicating information to and from their senior subgroup leader and their subgroup members.

The senior Administrative Team Leader was responsible for 1) ensuring the integration and compatibility of both subgroup project schedules, 2) developing a master project schedule, 3) communicating information between the senior subgroup leaders, 4) coordinating purchase requisitions, and 5) coordinating all other team activities.

The project organizational structure and corresponding responsibility areas were communicated to all of students at the start of the project to ensure that each component subgroup member, subgroup leader, and the Administrative Team Leader understood their group and individual responsibilities from the beginning the project.

In practice, the project organizational structure proved to be effective. It supported efficient communication, both technical and logistic, across all three tiers. At each weekly meeting of the faculty advisors with their respective senior subgroup, the subgroup leaders reported on both the subgroup's technical work and on the work done by the lower-level subgroups. Between meetings, the subgroup leaders communicated with the faculty advisor via e-mail. The primary communication between senior- and lower-level subgroup leaders was via e-mail with the senior subgroups meeting periodically with the lower-level subgroups. This ease of communication allowed the seniors to spend the majority of their time on the Capstone project, rather than on the logistics of the vertical integration.

Another advantage of the vertically integrated project structure was that it provided seniors with numerous leadership opportunities both technical and managerial in nature. Accountability for the design of the super-mileage car as well as supervision of lower level students was an integral part of the experience for seniors taking part in this project. Seniors were required to communicate assignments to the lower-level subgroups, to present project-related technical information to the lower-level students, and to ensure the completion not only of their own work, but also the work of the lower-level student teams. In fact, very little time passed before the faculty advisors were hearing the seniors lament the woes of working with the lower-level students—late work, forgotten instructions, missed meetings—woes with which the faculty advisors were quite familiar.

The authors believe that the development of this organizational structure was a crucial component in the success of the vertical integration of lower-level students into this Capstone design project. By providing an effective, efficient, and seamless system for communication and accountability, the organizational structure did indeed allow senior leadership for both the design/fabrication of the car and the integration of the lower-level students, without decreasing the seniors' focus on the Capstone Design project.

II. Lower-level Projects

An equally crucial component to the success of vertical integration was the development of first-semester design projects for the lower-level groups that were skill-appropriate for those students and were related technically to the work of the senior subgroups. These projects were developed jointly by the faculty advisors and the senior subgroups. Again,

there were several criteria considered as we developed these projects for the lower-level students:

- a) The required work should not exceed the 0.5 hour course credit per semester awarded to lower-level students.
- b) The projects must motivate work by the lower-level students since they were receiving nominal course credit.
- c) The projects must be technically related to and support the work of the senior subgroups groups.
- d) The projects must be skill-appropriate to each lower-level class.

An overview of the resulting lower-level projects and their relationship to senior level projects is shown in Figure 2 below.

	Lower-level Projects	Related Senior Projects
Body/Frame Subgroups		
Car Body design	Concept design of car body	Concept design of car body
	Autodesk <i>Inventor</i> drawing of body shape	Autodesk <i>Inventor</i> drawing of body shape
	Written conceptual analysis of aerodynamic characteristics of body shape	<i>Fluent</i> analysis of aerodynamic characteristics of body shape
	Written conceptual analysis of stress/strain characteristics of body supported by solid mechanics principles (juniors) and Statics principles (soph. and juniors)	Analytical and <i>Ansys</i> analysis of stress/strain characteristics of body
Car Frame design	Concept design of car frame	Concept design of car frame
	Autodesk <i>Inventor</i> drawing of car frame	Autodesk <i>Inventor</i> drawing of car frame
	Written conceptual analysis of stress/strain characteristics of car frame supported by solid mechanics and material engineering principles (juniors) and Statics principles (soph. and juniors)	Analytical and <i>Ansys</i> analysis of stress/strain characteristics of car frame
Engine/Drive train Subgroups		
Engine design	Tear-down of standard engine	Tear-down of standard engine
	Determine power requirements	Determine power requirements
	Written conceptual proposal for engine modifications to meet power and fuel consumption goals.	Design engine modifications to meet power and fuel consumption goals
Drive train design	Written conceptual proposal for drive train design supported by appropriate principles.	Design drive train to meet power and fuel consumption goals.

Figure 2 Overview of Lower-level Projects

The senior subgroups were responsible for creating the instructions for each of the lower-level projects for their subgroup. Drafts of those instructions were reviewed by the subgroup faculty advisor. For each lower-level project, the seniors made a presentation to their respective lower-level subgroups that included the project instructions and an overview of the engineering principles and design criteria and consideration being used by the seniors in their own design. At these presentations, the seniors also provided relevant handouts, developed by the seniors, to the lower-level students. The seniors then acted as technical consultants to the lower-level subgroups for each project and reviewed the completed project work of the lower-level subgroups.

In practice the lower-level projects were successful. Rather than diminishing the seniors' focus on the design of the car, as originally feared by the faculty advisors, the lower-level projects provided increased motivation for the seniors to focus on relevant engineering principles and to clarify design criteria and constraints for all aspects of the car design. Additionally, through their presentations, and the resulting critiques by the lower-level students, the seniors were provided an ongoing opportunity to hone their written and oral communication skills. The senior presentations and the actual project work done by the lower-level students allowed the lower-level students to see first-hand and in practice the usefulness and applicability of the engineering theory and skills they were learning.

Conclusion

As this case study has shown, the vertical integration of lower-level engineering students into a Capstone design project can provide significant benefits to both the senior- and lower-level engineering students involved. However, successful vertical integration requires a high level of planning and preparation to ensure that the organizational structure developed is robust enough to provide sufficient technical, communication, administrative, logistic, and project management support for the entire integrated project. Additionally, lower-level projects must be developed such that they are skill-appropriate for the lower-level students and technically relevant to the senior project work. Equally important is the participation of the seniors in developing and leading those lower-level projects. Based upon our positive experiences with vertical integration this past year, we plan to expand our vertical integration of lower-level students into additional senior Capstone design projects next year.