FROM GOALS TO PRODUCTS IN A SENIOR DESIGN PRACTICUM COURSE

Ajay K. Agrawal and Zahed Siddique
School of Aerospace and Mechanical Engineering
University of Oklahoma, Norman, OK 73019

Abstract

Senior Design Capstone is a required component of many undergraduate engineering programs. The program offers numerous challenges for both faculty and students because of the wide variety of projects in a given year as well as from year to year. This paper discusses key phases for successful implementation of a Senior Design Capstone Program to achieve the desired objectives for both faculty and students. The first phase includes project solicitation, project assignment, and articulating goals and strategies. The second phase involves team organization and developing a comprehensive plan of action. The third phase involves plan execution assisted with meetings and conferences, record keeping, and evaluation. The end-result of these efforts is a product that meaningfully adds value to the participants including students, sponsor, and faculty. In this paper we provide details and issues concerning each of the above phases, implemented in a Senior Capstone Course sequence in Mechanical Engineering at the University of Oklahoma. The paper presents our experiences from developing a structured Capstone Program and an evaluation of outcomes from the past few years.

I. Introduction

A survey[1] of engineering capstone courses in North America noted that a significant number of schools are recognizing the long-term benefits of offering industrially sponsored projects to assist in the educational process. A majority of these projects are conducted in teams, with the most common team size varied between 4 and 6 students. A majority of group projects are conducted within a single department although a significant number of departments (21%) participate in inter-departmental project teams. Many schools offer a combination of industry and departmental projects. The survey noted that a significant number of schools are recognizing the advantages of offering industrially sponsored projects to assist in the educational process. Long-term benefits of industry-sponsored projects have been discussed in several publications[2,3].

The sponsored design projects typically involve three parties working in coordination as depicted in Figure 1. The faculty member coaches and examines the project. The sponsor

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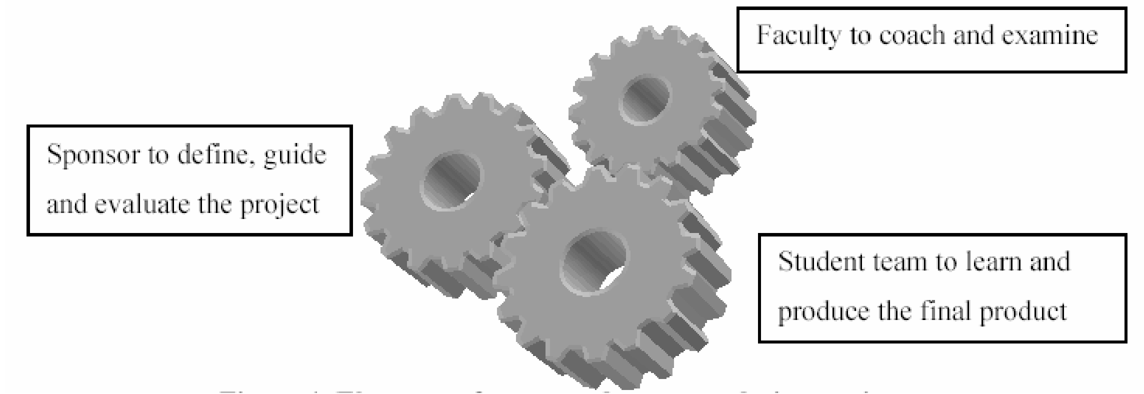

Figure 1 – Participants of sponsored capstone design project.

defines, guides, and evaluates the project. The student team learns and produces the desired end product.

The School of Aerospace and Mechanical Engineering (AME) at the University of Oklahoma is incorporating real-world experience into its curriculum through the Senior Design Practicum Program. In addition to providing a valuable product to the sponsors, the program has the following educational goals:

- Develop ability to apply the acquired knowledge to solve engineering problems, and to design realistic systems, components, and/or processes
- Develop ability to function in a team environment to gain organizational and communication skills, to understand professional and ethical responsibilities, to promote initiative, innovation, and excellence, and to foster life-long learning

The program supports the Accreditation Board of Engineering and Technology (ABET) Criterion 3 – Program Outcomes and Assessment. According to ABET, engineering programs must demonstrate that their graduate have:

(a) ability to apply knowledge of mathematics, science, and engineering
(b) ability to design and conduct experiments, as well as to analyze and interpret data
(c) ability to design a system, component, or process to meet desired needs
(d) ability to function on multi-disciplinary teams
(e) ability to identify, formulate, and solve engineering problems
(f) understanding of professional and ethical responsibility
(g) ability to communicate effectively
(h) broad education necessary to understand the impact of engineering solutions in a global and societal context
(i) recognition of the need for, and an ability to engage in life-long learning
(j) knowledge of contemporary issues
(k) ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

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In conducting project-based capstone design course, the instructor faces several challenges to ensure that the program goals are met[2-4]. This paper offers a structured approach comprising of three phases implemented during the program. The first phase involves solicitation, assignment, and articulation of goals and strategies for projects (Section II). The second phase involves student team organization and development of a comprehensive plan of action (Section III). The third phase involves plan execution assisted with meetings and conferences, record keeping, and evaluation (Section IV). The end-result of these efforts is a product that meaningfully adds value to the participants including students, sponsor, and faculty.

II. Phase I: Project Solicitation, Project Assignment, Goal and Strategic Plan

<u>Project Solicitation</u>. Phase I begins with an invitation letter to potential project sponsors. Besides delineating the above educational goals, the letter lists benefits to the sponsors, i.e.,

- A valuable end product addressing sponsors' specific technical needs
- An excellent opportunity to tap into engineering resources at the University
- Access to creative and enthusiastic students prior to graduation
- Recognition of sponsors' organization as an industrial partner for education

The sponsor is requested to consider the following issues in identifying a project suitable for the program.

- Choose a problem that should really be solved
- Choose a project that emphasizes design, experimental, and hands-on skills
- Do not choose a project involving only collection of published materials
- Choose a problem that allows teamwork and offers opportunity for creativity
- Avoid projects involving classified materials
- The project scope should require no more than 1000 person-hours
- The project schedule should be limited to about six months (mid-October to April)
- Project should not be on the critical path of a program with stringent deadlines
- Project goals must be concrete and measurable
- The criteria to determine success should be defined

The success of a project depends upon the sponsor designating a staff member as Project Liaison, serving to provide the followings functions.

- Review the product to isolate any cause for unacceptable quality
- Review student team actions and correct them if needed to achieve superior results
- Care for students so they are trained to become competent, contributing team members

The role of Technical Liaison is critical to realize maximum benefits from the program. The sponsor is asked to consider the following issues in designating the Technical Liaison.

- The liaison should have relevant technical and business background
- The liaison should expect to spend an average of 2 to 4 hours per week on the project

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- The liaison assignment should be a formal part of job responsibilities
- The liaison should have adequate authority to make timely decisions on project issues
- The liaison should have willingness to work with college students
- The liaison should understand that his/her role is to support, but not conduct the investigation
- The liaison should provide focus towards the project goals, while offering flexibility to accept unanticipated situations during the course of the project

Project Assignment. All projects selected for the program are presented to the class. If possible, the sponsor is invited and encouraged to participate in presentations. Next, teams are formed and projects are assigned using the following procedure. Each student is assigned a total of 100 points to bid among the projects. Student must bid on projects offered by at least two different instructors. Each selected project must be assigned at least 20 points and no more than 60 points. More points assigned to a project indicate students' greater interest in that project. Student is asked to rate himself/herself in the following areas: (1) planning and execution, (2) communication, (3) finance, (4) engineering analysis, (5) engineering design, (6) construction/fabrication, (7) quality control, and (8) public relations. For each area, the student provides quantitative rating of his/her (1) interests, and (2) capabilities using a scale between 1 (worst) and 5 (excellent). The student is also asked to provide names of preferred team members (if any).

The teams are formed according to the points assigned to each project. Consideration is given to personal interests and capabilities to ensure that all areas are represented in each team. The student is not guaranteed that he/she will receive his/her most favorite project although best efforts are made to accommodate requests. As a last resort, the student has the choice to exchange his/her project or team with another student willing to do so.

Goals and Strategic Plan. Once teams are formed and projects are assigned, each team develops its goals (or purposes) and a strategic plan. All subsequent team actions should be directed with the purpose of achieving the goal. Delivering the final product itself is NOT the goal. Accomplishing the goal will however result in the final product. Examples of goals are:

- Become competent engineers that are highly sought after by the industry
- Provide an engineering solution that meets or exceeds sponsors' requirements and expectations
- Develop a process exceeding the efficiency of existing options
- Become the most successful design team in the class

The strategic plan is derived once the goal (or purposes) has been established. Strategy is a statement of intended plans to actually accomplish the purpose in an efficient and swift manner, with clever use of resources and/or actions, without making mistake. It is the pathway between the starting point (current situation) and the destination (goal). Developing a strategic plan requires both an accurate evaluation of the current situation and a thorough understanding of (and alignment with) the envisioned goal. The following checklist is provided to help in developing the strategic plan:

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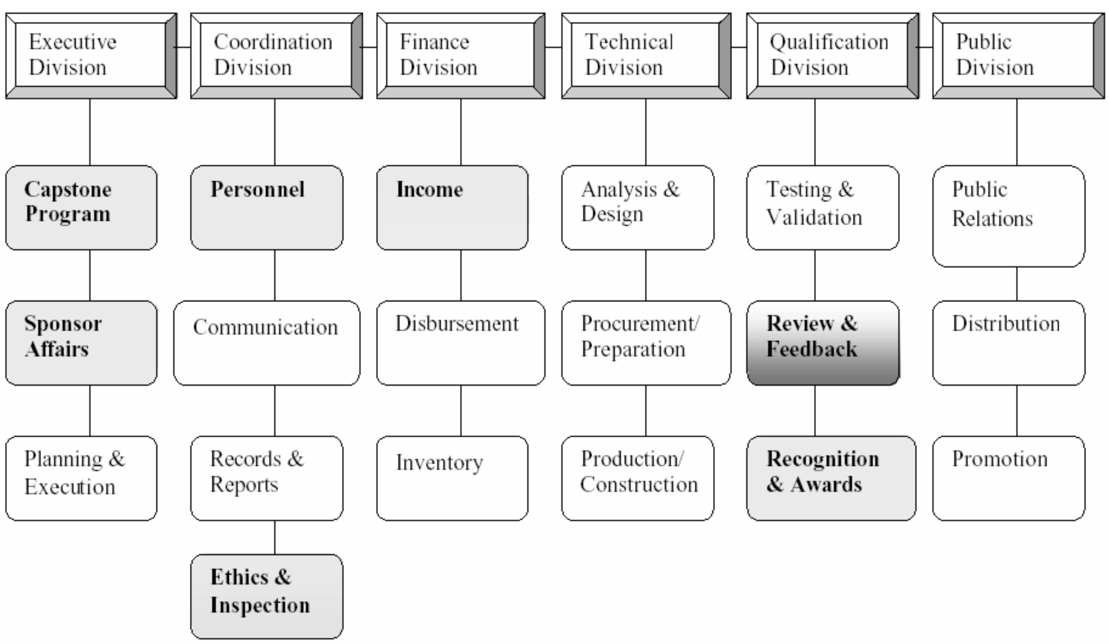
- Is there a clear statement of the purpose to be achieved?
- Is there a clear and comprehensive statement of the existing situation?
- Is the purpose consistent with the existing situation?
- Is the strategic plan aligned to and consistent with the purpose?
- Is the strategic plan clearly expressed and understandable?
- Is the strategy actually clever and bright enough to achieve the purpose?
- Is the strategic plan broad enough to fully accomplish the purpose?
- Is it doable?
- Does it take existing resources or lack of them into consideration?

The teams must operate within the framework of policy, i.e., long-range truths or facts, which are not subject to change, expressed as operational rules or guides. The policy must be known and understood by all members of the team.

III. Phase II: Team Organization and Plan of Action

Team Organization. The capstone design teams should be organized to facilitate planning and coordination for achieving high productivity accompanied with individual responsibility. Agrawal [5] presents an organizational structure encompassing important functions of a capstone course. This structure reproduced in Figure 2 offers the flexibility of adapting to small teams (4-6 students) in a department or to large multi-disciplinary teams across Colleges. The organization consists of six divisions, each with several subdivisions or departments. A director leads each division (Figure 2), and an officer heads each department. Each department performs unique functions that are clearly described. Each department has a unique product, which contributes



* Light shaded boxes are departments of the faculty coach. Dark shaded box "Review and Feedback" is sponsors' department. All other boxes represent posts taken up by student team members.

Figure 2 - Detailed Organizational Structure of a Capstone Design Course

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directly towards the final product of the organization. The production of each department is measured by the quantity and value of its products. Depending upon the type of the project, a department (or division) would involve one or more individuals. Typically the design teams consist of 4-6 students and one faculty coach, as a result a student will belong to several departments across divisions. By assigning individuals to different departments of the organization, the roles and responsibilities of the faculty, sponsor, and student teams are clearly delineated.

Conventional engineering classes typically focus on the “Analysis and Design” functions within the Technical Division. The structure in Figure 2 not only expands on technical education to include professional practice (e.g., procurement/production) but also embraces non-technical functions important in carrying out real-life projects. The effort required in each of the divisions would depend upon a particular project. Technical Division would normally constitute about half of the total efforts. The remaining half of the effort spent on non-technical activities might appear as inefficient. However, most real-life projects require group effort simply because of the physical limitations of an individual. Group efforts benefit from good organization, also necessary to raise productivity and moral.

Plan of Action. A plan of action is necessary to attain the goal. It is a broad description of actions needed to accomplish the goal. The action plan is developed in consultation with the sponsor. First, the nature and function of the final product are understood and identified. Next, the design and functional requirements and specifications are established and documented. Third, the technical approach required for the project is described in detail. The major tasks are identified and a sequence of operation is developed in the form of a flow chart. Next, a schedule is developed using Gantt chart expressing duration of each major task. A budget listing items to be purchased is prepared with approximate cost and justification. Facilities and resources needed for project completion including space, computational tools, machine and fabrication tools, and other specific needs are identified. Each team submits the plan of action documenting above details in a specific format. The goal, strategic plan, policy, and team organization are also attached to this document. Each team member certifies the document indicating his/her agreement with its contents. The plan of action is reviewed and approved by the sponsor, and accepted by the faculty coach.

IV. Meetings and Conferences, Record Keeping, and Evaluation.

Meetings and Conferences. In executing the plan of action, team meetings and conferences with faculty advisor and liaison are required.

- All members of each team meet once a week to review progress during the past week and to make plans for the next week. During the meeting, specific targets are assigned to or undertaken by each team member. The target must be finite and not a generality. It considers “What exact actions do I have to do to carry out the strategic plan to achieve the exact results necessary for this stage of the strategic plan, within the limits of available resources?”
- The meeting discussion is recorded, and a group progress report is submitted weekly to the faculty advisor at a specified time. Similarly, each team member records his/her targets, and submits his/her weekly progress report to the instructor. The format for the individual progress report is shown in Figure 3.

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To: Prof. ABC (Faculty Advisor)

From: Your Name/Your Team

Date: January x, 200x

Sub: Weekly Progress/plans

Targets Completed

List targets completed by you during the past week. Provide specific details supporting completion, e.g., part drawings, material list, test results, report prepared, discoveries made, etc. Include attachments as necessary.

Targets Not Completed/Actions Needed to Impede Incomplete Targets in the Future

List major targets planned but not completed during the week. Identify sources or causes of obstruction, and explain how you would improve your future planning to overcome them.

Plan of Action for the Next Week

List targets planned for the coming week. Identify the time and resources required by you, and how you will coordinate with other members of your team. List the sequence of actions needed to accomplish the major targets. Identify the end product(s) of your efforts. The weekly individual plan must align with the weekly group plan. The group plan should support the strategic plan and the overall plan of action.

Problems or Concerns/Achievements or Success

Explain problems or concerns of your own division or department. List your achievements and successes.

Figure 3 - Individual Weekly Progress Report Format

- Each team meets weekly at a regularly scheduled time with the faculty advisor to review progress, plans, and to seek input. Additional meetings with the advisor may be arranged as necessary.
- The team meets with the Project Liaison as necessary. At the minimum, a copy of the weekly group progress report is submitted to the Project Liaison.
- The team members meet regularly as needed to perform the project tasks.
- All teams attend the mid-term and final presentations, and provide peer evaluations
- All teams attend guest lecturers speaking on topics such as business planning, entrepreneurship, intellectual property, patent laws, ethics, and engineering codes and standards.
- The final product is displayed at a poster fair organized in the last week of the class.

Record Keeping. Proper records are important to track the progress of the project, to clarify agreements reached, to retain information and knowledge gained, to transfer results to the sponsor, and to disseminate results to colleagues or public at large.

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- Each team member acquires a page-numbered notebook to record important project developments. The notebook remains in students' possession during all project- related activities. It contains meeting minutes, thoughts, ideas, suggestions, comments, sources, sketches, data, test results, conclusions, etc. The project notebook could form the basis for any possible patent application. The faculty coach occasionally inspects the project notebook to detect and handle potential difficulties or discrepancies
- Each team maintains a neatly kept folder at the Capstone Design facility. The folder contains hardcopies and electronic files of (i) strategic plan/team organization, (ii) plan of action, (iii) weekly group progress reports, (iv) mid-term presentation, (v) mid-term report, (vi) final presentation, (vii) poster display, and (viii) final report, as they become available.
- Each team maintains orderly records of (i) files of correspondence with vendors, liaison, etc., (ii) financial records including copies of purchase receipts, (iii) users' or instruction manual of equipment purchased, (iv) technical specifications of purchased items, and (v) other project related information
- Vendor catalogs acquired during the project are stored for future use.

Evaluation. Evaluation is based on input from peers, sponsors, faculty, and external judges.

- Students are given a form to evaluate their team members (including themselves) after (i) plan of action, (ii) mid-term review, and (iii) final review. The faculty coach shares peer evaluations with the team to provide constructive feedback. Students are asked to provide suggestions if a team member is not doing his/her job or doing it poorly. Each team member is rated on a scale of 1 (unacceptable) to 5 (excellent) for the following attributes: (i) contribution towards team planning, (ii) execution of tasks undertaken/assigned, (iii) understanding of team organization/personal duties, (iv) communication and timeliness, (v) professional and ethical responsibility, (vi) report writing and record keeping, (vii) application of knowledge to achieve desired goals, (viii) initiative and innovation, (ix) quality of work performed, (x) orderliness of work area and/or tasks performed, (xi) changes necessary to improve the performance, and (xii) changes required to improve the performance.
- Students, faculty, sponsor, liaison, guests, and judges are given a form to evaluate group performance at design presentations and poster fair. Each evaluator rates the team on a scale of 1 (unacceptable) to 5 (excellent) for the following attributes: (i) considering the quality of visuals, participation of all, length of presentation, oral communication, etc., the presentation was well prepared and professionally presented, (ii) considering the continuity and clarity in describing technical details, the project description and technical approach were clear, (iii) considering concepts generated, analysis and design performed, hardware produced, the team applied appropriate techniques, skills, and modern engineering tools, (iv) considering the cleverness of solutions, ideas, products, and impact on business/society, the team demonstrated critical thinking skills, initiatives, and innovation, (v) considering the schedule, tasks completed and remaining, and budget status, the team demonstrated adequate progress within budget limitations, (vi) considering organizational structure, contributions of individuals, and multidisciplinary approach used, the team demonstrated ability to function as a group, (vii) considering the question and answer session, the presentation stimulated participation by the audience. The evaluator is also asked to provide recommendations on

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how the team might improve (a) the presentation, and (b) the methodologies used in the project. The recommendations are communicated to the team whenever possible.

- The course grade depends both upon individual and team performance. The group grade is assigned for reports, presentations, and poster fair. The individual grade is assigned for weekly progress report, participation, and subjective evaluation based on faculty impression, and input from sponsors, peers, technical staff, and project judges. Attendance is mandatory at group meetings, class meetings, and presentations.
- Awards are presented at the end of the course to recognize the excellence in quality. The "Best Presentation Award" recognizes a team with the best Final Presentation. The selection is based on the numerical score from audience. The "Best Poster Award" recognizes the team with the best poster display as determined by a panel of external judges. The "Best Project Awards" recognize teams with the best overall effort. These awards are based on numerical scores from faculty advisor/technical liaison, presentation (judged by audience), and poster display (evaluated by the panel of judges from industry). Reports, displays, and other material from award winning teams are showcased to motivate and inform design teams in the following years, and hence, to continuously improve the quality of the program.

V. Experience with the first offering of the structured program and Sample Projects

The new structure for the Senior Design Practicum program in the School of Aerospace and Mechanical Engineering at the University of Oklahoma was implemented in 2002-2003. Eighty students and five faculty members participated in the first offering of the structured design practicum program. There were thirteen industry sponsored projects, three projects sponsored by the SAE team of University of Oklahoma, and one project funded by industry for ASME Human Powered Vehicle Challenge.

Solicitation of the projects started in August 2002 and the project offerings were finalized in November 2002. Many of the companies had offices or plants in local areas to facilitate interactions among faculty, industry project liaison and student team. During November of 2002 the students were presented with the available projects and students bid for there preferred projects. Student teams were then formed according to the bid points assigned by the students.

Once the teams were formed during the next four weeks the students met with faculty advisors and/or industry sponsors to gather information about the project to develop a plan of action for the project. Project goals, design requirements, desired end products, design steps, budget, required facilities, and schedule were developed by the student teams. The student teams were required to develop an organization chart (Figure 2) and assign different team members for each of the specified tasks. The second phase was completed during December 2002. The plan of action was then used by students in Spring 2003 to guide in completion of the project.

The first activity of Spring Semester of 2003 was to gather extensive information regarding the requirements of the projects to start the design project according to the developed plan of action. It was at this point that students were able to understand the full extent of their projects and adjust their plan of action accordingly. Student groups met with their project faculty advisor every week for half an hour to discuss progress and decide on action items for the following week. Students gave a mid-term presentation and wrote a report documenting their progress.

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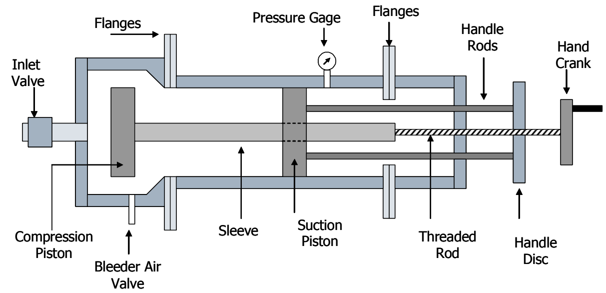
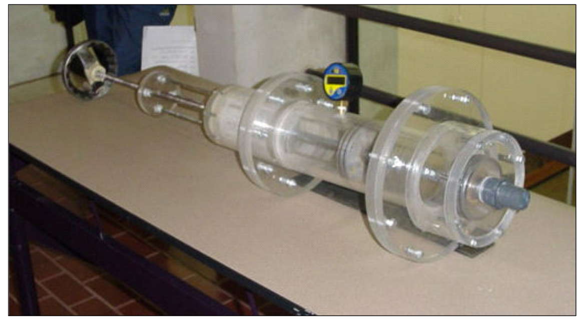
Air Entrainment Measurements in Slurries and Mixtures

The purpose of this project was to design, construct, and test a device to measure the amount of air entrained in various slurries. This device operates on the principle of fluid compressibility, only the air in the slurry is considered compressible. The device was designed, built and tested using this concept. It uses two pistons to draw in the slurry sample without contaminating it with air. A valve at the top of the device is used to extract and isolate the slurry sample. Piston movement and pressure changes are measured to yield the fluid compressibility and in turn, the entrained air. The device was built and tested at facilities of Halliburton Energy Services, the project sponsor. The project report was entered into ASME Fluid Engineering Capstone project competition. Based on this national competition, the project was placed first at the ASME IMECE in November 2003.





Human Powered Vehicle

Each year the American Society of Mechanical Engineers sponsors a Human Powered Vehicle (HPV) competition with the hope of finding a practical alternative method of transportation. An ideal vehicle must be safe, aerodynamic, lightweight, efficient, and capable of carrying everyday items such as groceries. Recently, HPV's have increased in sophistication with the addition of new space-age materials and sleek aerodynamic fairings. There are many systems involved that must function harmoniously for a good design. Principle areas of concern are: Safety - A Fast vehicle is irrelevant if it is not safe; Frame - The heart of the vehicle, that which ties all systems together; Steering - Even a very efficient vehicle is useless and potentially dangerous if it doesn't steer well; Comfort - If people are to use HPV's they must enjoy them; Cost - Our limited budget to build an HPV simulates a consumer's budget.

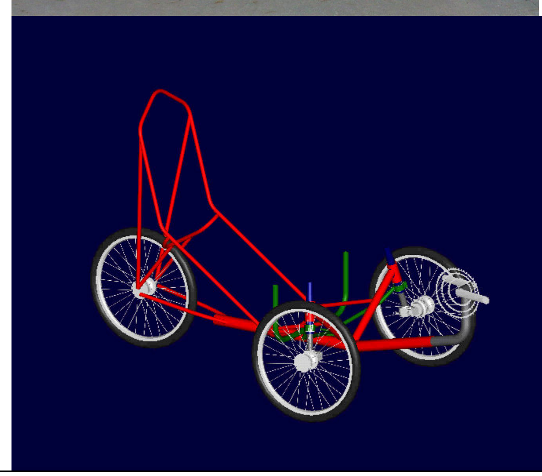


Figure 4 – Abstract and Pictures of prototypes of two projects

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The mid-term report served as a checkpoint to critically evaluate the progress of the design team. Student teams not only evaluated their progress against planned schedule, but also determined events and activities that were slowing their progress and found alternatives to complete the project in a timely manner. The final presentation, poster display and final report were due at the end of the semester. Judges from industry were invited to evaluate the posters and students projects. Abstracts and picture of prototypes for two capstone projects, constructed by students during Spring 2003 are shown in Figure 4.

During the Spring 2003, students began to realize the many difficulties associated with design and manufacturing of products. Some of difficulties and challenges faced by students are described below:

- Building the prototype is not as easily accomplished as planned. Many students had to get acquainted with equipments available at the machine shop. Many had under budgeted the time required for construction.
- Vendors and suppliers can create unwanted delays and difficulties. Some student group projects were delayed because of miscommunication with vendors and time delays.
- Industry sponsors had commitments and responsibilities other than the projects. Student teams had to learn that meetings and request for additional information from sponsors had to be scheduled in advance.
- Testing of prototype requires refinement of design, which could be a time consuming activity.

VI. Concluding Remarks

Successful implementation of the capstone design course requires a structured approach accompanied with careful planning. Improving the quality of the program requires assessment and feedback from student, sponsors', and faculty coach on a continuous basis. Although the program ventures far beyond the traditional classroom instruction, graduating students are beneficiary of a life-long learning process. A successful capstone program can facilitate achieving the educational institutions' goal, for example, of producing the most sought-after graduates by the industry.

Acknowledgements

The authors would like to thank his colleagues teaching the Design Practicum Program in the School of Aerospace and Mechanical Engineering at the University of Oklahoma. In particular, the program structure has benefited from discussions with David Baldwin, David Miller, Harold Stalford, and Mitch Burrus.

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Biographical Information

Dr. Ajay K. Agrawal is Associate Professor of Mechanical Engineering at the University of Oklahoma. He joined the Oklahoma faculty in 1993 and is the chair of the Undergraduate Design Committee. He has taught the Capstone Design Course for the past eight years and has spearheaded the program to its present structure. He holds the PhD degree in Mechanical Engineering from the University of Miami. His research interests are in the areas of fluid flow, combustion, and heat transfer.

Dr. Zahed Siddique is an Assistant Professor and Director of the Product and Process Design Laboratory at University of Oklahoma. His research focuses on product family design, CAD/CAM, design collaboration and engineering design education. Dr. Siddique received his B.Sc., M.S. and Ph.D. in Mechanical Engineering from Georgia Institute of Technology.

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