Using Industry-Like Product Development Projects in Mechanical Engineering Capstone Design Courses

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Abstract

A good engineering education involves more than preparing students that have sound technical knowledge in a particular discipline. The undergraduate program needs to provide a comprehensive education that incorporates as many practical experiences as possible. In this regard, a carefully selected product development project sponsored by a company and involving the participation of some of its engineers as mentors, reviewers, and evaluators, can serve to closely emulate industrial practice in a capstone design course. There are many crucial activities and potential pitfalls of such an approach. Initial project selection must be appropriate in scope, involve suitable application of analytical tools, and be containable in time, cost, testing requirements, fabrication capabilities, etc. Substantial resources are required from the industrial partners and care must be taken to address any intellectual property concerns. However, the benefits far outweigh the challenges. Students solve a real industrial problem of interest to the sponsoring company following a structured product development process similar to what they will be expected to do upon graduation. Through interactions with the mentoring engineers, they are coached in many important areas, including corporate and regulatory requirements, design for manufacturing and assembly, etc. This paper will present as a case study a project sponsored by an automaker to develop a hard tonneau cover for a convertible vehicle. We will describe how some of the potential pitfalls were addressed, summarize the process that the students followed, describe the roles of the faculty member and the company personnel involved, and summarize the results obtained and lessons learned.

Introduction

Today it is widely recognized that a good engineering education involves more than preparing students that have sound technical knowledge in a particular engineering discipline. Now the end goal of the undergraduate engineering curriculum is to provide the students with a comprehensive education that will allow them to meet the expectations of prospective employers and help them to achieve success in their professional career. In addition to technical knowledge,

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students need to have a good understanding of the process, methodologies, and tools commonly used in industry to design and develop products, good written and oral communication skills, the ability to work in an effective and efficient fashion in multidisciplinary teams, good planning and time management skills, an understanding of ethical and societal issues, and the list goes on. Also, they must be exposed to meaningful practical experiences that closely resemble the "real world" practice of the engineering profession. In this regard, two approaches that have been widely used to provide undergraduate engineering students with such practical experiences have been co-op or internship programs and the inclusion of senior design project or capstone-type courses in the curriculum. Both of these approaches capitalize on the fact that learning and recall of information are known to be much better when a student is immersed in the learning environment rather than simply being told about it or asked to read about it.

Given the challenges and difficulties involved in providing practical experiences to undergraduate engineering students via co-op or internship programs, it became necessary to find other alternatives that could allow them to be exposed to the practice of the engineering profession in an academic setting. In this regard, senior design projects or capstone-type courses emerged as a first step to incorporate a substantial practical component into the curricula. The results of an extensive survey conducted by Todd et al.[1] showed that by the year 1994 many undergraduate engineering programs in the US already included courses of this kind. However, the authors also found that the capstone programs differed greatly across disciplines and even within each department. A review of papers published in the Journal of Engineering Education since 1993 (see for example Todd et al.[2], Miller and Olds[3], Dutson et al.[4], Bright and Phillips[5], Farr et al.[6], and Catalano et al.[7]) clearly shows that, throughout the years, the main focus of these courses has been changing from "solving an open-ended engineering problem requiring a substantial integration of technical knowledge acquired by the students during their previous courses" to "working in multidisciplinary teams to develop new products geared towards satisfying specific customer needs."

To support the efforts taking place in academia to incorporate relevant practical experiences at the undergraduate level, several professional engineering societies, such as the Society of Automotive Engineers (SAE) and the American Society of Mechanical Engineers (ASME), have sponsored different national competitions that require student teams to design relatively complex products based on a given set of requirements, which typically include a mixture of general customer needs and precise technical specifications. Some examples of those national competitions are the SAE Mini-Baja, the Formula SAE, and the ASME Human Powered Vehicle. Since the experience gained by the students participating on those design projects is very positive, some undergraduate engineering programs have decided to adopt them as part of their senior design project or capstone-type courses. Although following such an approach is a good option, there is still room for improvement with regard to how well those design projects emulate industrial practice.

A carefully selected product development project sponsored by a company and involving the participation of some of its engineers as mentors, reviewers, and evaluators, can serve to closely emulate industrial practice in an engineering capstone design course. In this paper some of the aspects that need to be taken into consideration to successfully implement such an approach and some of the challenges involved are discussed. A senior design project sponsored by a company to develop a hard tonneau cover for a convertible vehicle is used as a case study to illustrate some of the ideas presented.

Defining the General Scope of the Capstone Senior Design Project

Sometimes the task of defining the scope of a senior design project is completely left up to the faculty member(s) that will be supervising a given project. Also, when a company is sponsoring a project, sometimes it is allowed to basically define on its own the scope of the project that will be assigned to the students. Although there needs to be some room for flexibility when defining the scope of a particular project, in general both approaches stated above are far from adequate. It is important to keep in mind that a capstone senior design project must be more than a project that requires some technical expertise in a particular engineering discipline; it must be a meaningful and carefully defined learning experience for the students. As with any course in the curricula, there needs to be a clear set of learning objectives and outcomes associated with the senior design course or course sequence. No matter who is supervising a given project or what specific project is being done by a group of students, there must be a minimum set of knowledge, attitudes, skills, and values that the students are expected to acquire.

The type of senior design project that the students are going to perform has a substantial impact on the quality of the learning experience and the learning outcomes that can be achieved. The faculty of the Department that is offering the senior design course or course sequence needs to address this point in detail and reach a consensus. In this regard, it is a good idea to take into consideration the structure of the undergraduate engineering program, the assessment strategy in place for continuous improvement and accreditation purposes, and the input from all the relevant constituent groups, particularly the one provided by the Industrial Advisory Board (IAB) of the Department. Different alternatives can be pursued like having the faculty work together to define a new project each time the course is offered, using a design competition sponsored by one of the Engineering Societies, or the development of a "market-pull" technical product of low to moderate complexity that is of interest to a company. From our perspective, the latter constitutes an excellent option that allows providing the students with a relevant practical experience that is as comprehensive as possible. Thus, the remainder of this paper will focus on such an approach.

When the development of a technical product is going to be the focus of a capstone senior design project, the faculty needs to define the specific Product Development Process (PDP) that will be used. Each company follows a specific PDP that is suited to the type of products that it develops and its organizational structure. Obviously, trying to use the PDP employed by the company that is sponsoring a project poses the challenge of having to deal with a new model every time a different company is involved. This creates a logistic problem for both the faculty and the students. Fortunately, it is easy to find in the literature generic models that are well documented and incorporate all the key activities that are typically included in the PDP used by most companies. Three very good examples that can serve as a reference can be found in the books about product design and development by Ulrich and Eppinger[8], Otto and Wood[9], and Ullman[10]. It must be mentioned that the first two can be used for most engineering disciplines whereas the latter one is more focused towards Mechanical Engineering. Although the faculty can certainly define and document its own PDP model, we feel that it is more practical and convenient to use one presented in an existing book. Also, if the undergraduate program already has in the curricula a course devoted to the topic of product design and development, using the textbook selected for that course is the most logical choice. In the past, we have used with very good results the book by Ulrich and Eppinger[8] for teaching undergraduate and graduate courses in product design and development and as the main reference for students working in capstone senior design projects.

Selecting a generic PDP model as the framework for capstone senior design projects has several advantages. First, it constitutes a “common language” that facilitates the communication among the faculty members of the Department. In this regard, it can be used by the faculty to decide the specific product development activities that must be included as a minimum in every senior design project that is pursued. Second, if properly documented, it can provide a roadmap for the students as to what activities they are expected to do, the typical sequence in which they must be done (with some discussion of necessary iterations in the process), the specific tools and methodologies that they are expected to use for each activity, and the desired deliverables associated with each one. Finally, it can facilitate the interaction with companies that may be interested in sponsoring a senior design project. Ultimately, most graduates will be employed in a company with its own specific PDP, but we have found that: (1) Most companies’ PDP can be mapped fairly accurately onto the generic PDP model, (2) the relatively uncluttered, easy to understand generic model provides a basic foundation of knowledge about product development that enables the future graduates to better understand the “big picture” view of a company’s sometimes bulky description of their product development process, and (3) it is not uncommon for young practicing engineers to confuse the PDP with a sequence of gateways, milestones, or tollgates, and we feel a basic exposure to and understanding of the underlying *processes* is important.

Due to the amount of time and resources required to develop a product, it is obvious that it is not possible for students working on a senior design project to be involved in all the tasks corresponding to a complete, “end-to-end” (or “cradle-to-grave”) development effort. Thus, it is important to give careful consideration to which specific activities the students will carry out as part of their project and to the final outcomes that the sponsoring company will receive at the end. According to the generic PDP model proposed by Ulrich and Eppinger[8], all the activities associated with the development of a product can be conveniently divided into the following six phases: product planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up. The specific details about the main tasks and deliverables corresponding to each phase can be found in their book “Product Design and Development”[8]. In what follows, we will briefly consider each one of the phases stated above and give our point of view regarding the activities that can be included in a two-semester senior design project so that it can provide students with an experience that closely emulates industrial practice.

The initial phase of the PDP is the product planning phase. Although it is part of the PDP, in many companies it is carried out by a different team than the one that will be in charge of the remainder of the development effort. The outputs of this phase include the mission statement for each product development project that the company plans to pursue. The mission statement specifies a particular market opportunity and states the broad constraints and objectives for the project. Given the nature of this phase, we consider that it is not advisable to include it as part of a capstone senior design project. In fact, we feel that personnel from the sponsoring company and the faculty member(s) that will be supervising the project need to work together to prepare a suitable mission statement that can be given to the students during the project "kick-off" meeting.

The concept development phase of the PDP includes the following tasks[8]: identification of customer needs, competitive benchmarking, setting target specifications for the product, concept generation, concept selection, setting final specifications for the product, performing an economic analysis, and planning the rest of the development effort. Implicit in the concept generation and selection activity is creating simple prototypes and concept testing. The success or failure of a product is very closely tied to how well the activities corresponding to the concept development phase are carried out. Thus, from our perspective, all these tasks must be performed by the students as part of their capstone senior design project, including the identification of customer needs[11]. We have noticed that it is a common practice to provide the students with a set of target specifications as the starting point for their project. We do not favor such an approach. For a company to achieve success in a product development effort the engineers involved in the design and manufacturing of the product must have an excellent understanding of what the customers want (including their latent needs) and this is impossible to achieve without having a close interaction with the customers in the target market(s) for the product and all the other relevant stakeholders.

The system-level design phase of the PDP is mainly concerned with establishing the product architecture. The extent of effort associated with this phase clearly depends on the level of complexity of the product being developed. We consider that the type of products used for a capstone senior design project should be such that the students have to carry out only the basic activities associated with this phase. This will allow them to gain some understanding about the fundamental principles of systems architecting and systems engineering, which are so important in many industries.

The detail design phase of the PDP includes the complete specification of the geometry, materials, and tolerances of all the unique parts in the product and the identification of all the standard parts to be purchased from suppliers. Obviously, those activities must be performed by the students as part of their project. Furthermore, this phase provides an excellent opportunity for the students to perform detailed technical analyses of different aspects of the product with the aim to optimize it as much as possible.

The testing and refinement phase of the PDP involves the construction and evaluation of multiple pre-production versions of the product. It can be viewed as the final verification of the product and the manufacturing process before proceeding to start with its production. For the purpose of the senior design project, we recommend to limit the testing and refinement phase activities performed by the students to building a comprehensive physical prototype that is as close as possible to the final product that they have envisioned (i.e., that is as close as possible to what is typically known in industry as an alpha prototype), to use that prototype to do a final verification of the product performance, and to identify any possible improvements that can be made to the product. Based on our experience, it is appropriate to end the academic project at this point.

Finally, given the fact that most academic environments don't support mass production, and since we typically discuss but do not have the students design the required tooling and other aspects of the manufacturing system, we don't include the production ramp-up phase of the PDP as part of the scope of the academic project. Furthermore, due to the time constraint imposed by two-semesters, the project schedule is usually so tight executing all the activities of the previous phases of the PDP that is basically impossible to include any activities related to this phase, even if the students are given access to manufacturing facilities available at the sponsoring company.

In summary, our recommendation is to begin the senior design project with a mission statement for the product, to ask the students to perform all the tasks corresponding to the concept development phase, to have them define the product architecture, to require them to do all the main activities corresponding to the detail design phase, and to end the project once a comprehensive physical prototype of the product has been built and tested. Implicit in this recommendation is the fact that complexity of the products that can be considered is constrained by factors such as team size, project duration, and whether or not the students already had any formal courses about product design and development during the previous years. Obviously, the technical aspects of the project should be such that the students are required to apply several discipline specific analyses as part of the project.

Finding Industrial Partners and Project Selection

Before trying to find possible industrial partners it is necessary to define first the general scope and characteristics of the type of projects that can be considered as possible candidates. Clear guidelines must be established by the faculty of the Department(s) offering the capstone senior design project. Failure to provide specific input to possible industrial sponsors as to the type of project being sought often leads to either rejection of possible ideas proposed by potential industrial partners or proceeding with a project which ultimately proves to have issues related to scope, level of difficulty, resources needed, etc.

To facilitate the interaction with possible industrial partners, it is important to prepare a document that can attract their attention and serve as a starting point for further communications. This document can include background information about the University and the Department, describe the type of projects that the Department is looking for, provide a brief overview of the product development activities that will be performed by the students, highlight the potential benefits for the sponsoring company, state the type of support that will be required from the sponsor, provide examples of previous projects, and include the name and contact information of one or more faculty members that can provide additional details. Of course, more information can be added as deemed appropriate. As an initial step, this document can be presented to the members of the Industrial Advisory Board (IAB) of the Department to request their feedback and to ask for their help finding suitable projects. It is easy to underestimate the amount of work and time involved in identifying and implementing an industrially sponsored senior design project; we recommend the process be begun in earnest about one year prior to the beginning of the capstone senior design course.

Although a senior design project is primarily intended to be a learning experience for the students, there are also potential benefits for a sponsoring company. For example, a company that sponsors a project benefits from having one or more potentially attractive solution concepts for a real design problem that it is trying to solve. In fact, since the students are encouraged to be very creative during concept generation and they usually don't have pre-conceived ideas about possible solution concepts, in some cases they may provide new alternatives that were not originally envisioned by the company. Also, if multiple teams are working independently and in parallel on the development of the same product, it becomes possible to consider one or more "risky" designs for the downstream activities of the PDP. The sponsoring company also benefits by being in a better position to identify and attract the best future engineers.

A company interested in sponsoring a senior design project needs to understand that it will have to make a serious commitment to provide an adequate level of support. Typically, the minimum level of support that will be required is as follows:

- The company will designate a project coordinator who will serve as the liaison between the company and the students working on the project.
- The project coordinator together with the faculty member(s) that will be supervising the project will prepare a mission statement for the product development effort.
- The students will be provided access to the information, facilities, and data that will be required to carry out the project.
- The project coordinator will form an evaluation committee that will be composed of at least three company employees that are familiar with the topic of the project. This committee will provide feedback to the students at key milestones during the PDP and will evaluate the final prototypes at the end of the project.
- The company will provide the financial support and/or equipment required to carry out the project. The amount of support required will vary depending on the nature of the project.

Once a company is interested in sponsoring a project, the next step is to explore in some detail possible projects that it is willing to support and select for further consideration only those that closely fit the type of projects sought by the Department. Then the faculty member(s) that will be supervising a project must meet as many times as needed with the project coordinator to prepare a mission statement that is attractive for the company and adequate in scope from an academic perspective. In general, the mission statement must include all the following elements:

- A short product description
- The key business goals for the development effort
- The primary and secondary markets (if any) for the product
- All the relevant assumptions and constraints that need to be taken into consideration
- A list of the stakeholders that the students will be expected to interact with during the project

In the case of the senior design project corresponding to the development of hard tonneau cover (HTC) for a convertible vehicle, all the ideas presented before were followed. The "project champion," Mr. Peter Kantz, was a member of the IAB of the Mechanical Engineering Department of the University of Detroit Mercy (UDM). One of the engineers working under his supervision, Mr. Phillip Moutousis, was assigned the role of project coordinator. The project evaluation committee included representatives from different departments within the company such as marketing, design, and manufacturing. A summary of the mission statement that was given to the students at the beginning of the project is provided in Table 1. Here it must be pointed out that all the numerical values in the table were intentionally masked due to obvious reasons. So that the reader can have a better understanding of the scope of the design project and of some of the assumptions and constraints given in the mission statement, Fig. 1 shows a top view of the convertible top stowage area of the convertible vehicle.

The support requested from the sponsoring company included the following:

- Access to one prototype of the convertible vehicle
- Several "bodies in white" like the one shown in Fig. 2
- Files containing CAD information about the area surrounding the convertible top stowage area
- Access to information about the vehicle required by the students during the duration of the project
- Financial resources required for the project
- Personnel support described earlier

While working on a product development project, the development team is usually faced with making difficult trade-offs that will have a strong impact on the level of success of the end product. Thus, projects that can expose the students to this type of situation that is so common in industry have the potential to become a very valuable learning experience for them. In the case of the HTC project, a careful look at the mission statement reveals that it was expected that at some point during their development process the students were going to be faced with making trade-offs involving two or more of the requirements shown in Fig. 3.

Finally, an important point deserves special attention. The sponsoring company will often ask for intellectual property rights of the projects; this is certainly not unreasonable but must be dealt with a priori and must consider consistency with any intellectual property policies that the University may have.

Teaching the Capstone Senior Design Course Sequence and Managing the Project

Regarding teaching the senior design course sequence and managing the project, there are several important aspects that need to be taken into consideration. If the students did not have a previous formal course about product development, it is important to include a series of lectures devoted to cover the process, methodologies, and tools that they are expected to use during each phase of their development effort. If the students already had in previous semesters a formal course on product development, lectures can be included as needed to review key aspects related to the PDP or to introduce additional tools, like Failure Modes and Effects Analysis (FMEA), that are typically used by the sponsoring company. In any of the two scenarios, we recommend to select a good book about product development as a textbook. The students can use the book as a guide and it can also serve as a useful reference for the project coordinator assigned by the sponsoring company.

Table 1. Mission Statement for the Hard Tonneau Cover (HTC) for a Convertible Vehicle

Product Description	Hard, preferably self-storing, tonneau cover for the convertible that matches the current style of the vehicle, is highly reliable and durable, requires minimum maintenance, and perfectly seals the covered area.
Key Business Goals	• For a painted, self-storing, hard tonneau cover, the production cost of each cover must be less than or equal to "C1" and the required investment must be less than or equal to "I1". • For a painted, manual storing, hard tonneau cover, the production cost of each cover must be less than or equal to "C2" and the required investment must be less than or equal to "I2". • Production volume of "P1" to "P2" units per year. • The hard tonneau cover will be introduced in the "Y1" model year. The "job 1" date for this model year is month "M" of year "Y2". • At this point it has not been decided if the hard tonneau cover will only be an option or if it will be standard in all vehicles.
Primary Market	Market segment corresponding to the convertible. (Note: All the relevant details of this market segment were provided to the students)
Secondary Markets	None.
Assumptions	• Self-storing. • Perfectly seals the covered area. • The design perfectly blends with the styling of the vehicle. • Requires minimum design changes to the vehicle. • Highly reliable and durable. • Requires minimum maintenance. • Easy to use. • Easy to manufacture, assemble and install on the vehicle. • The control to operate the cover must be located within easy reach of the driver. • The convertible top cannot be modified.
Constraints	• Must satisfy all the applicable government regulations. • Cannot make any changes to the structural elements of the vehicle. • It is possible to attach components to the key structural elements of the vehicle as long as they are not weakened. • The only source of energy to provide power to any component is the electrical energy available in the vehicle. • The space available to store the cover is, in order of preference: - The space in the trunk below the convertible top stowage area. - The storage space behind the seats. • If the space behind the seats is used, the range of motion of the seats must not be affected. Also, the operation of the cover must not create discomfort to the passengers. • The only element of the body of the vehicle that can be modified is the panel behind the convertible top stowage area.
Internal Stakeholders	• Marketing. • Design Studio. • Engineering. • Manufacturing. • Customer Service. • Purchasing.
External Stakeholders	• Consumers. • Auto Dealers.

Figure 1. Prototype Vehicle Showing Stowed Convertible Top

Figure 2. "Body in White" of the Convertible Vehicle

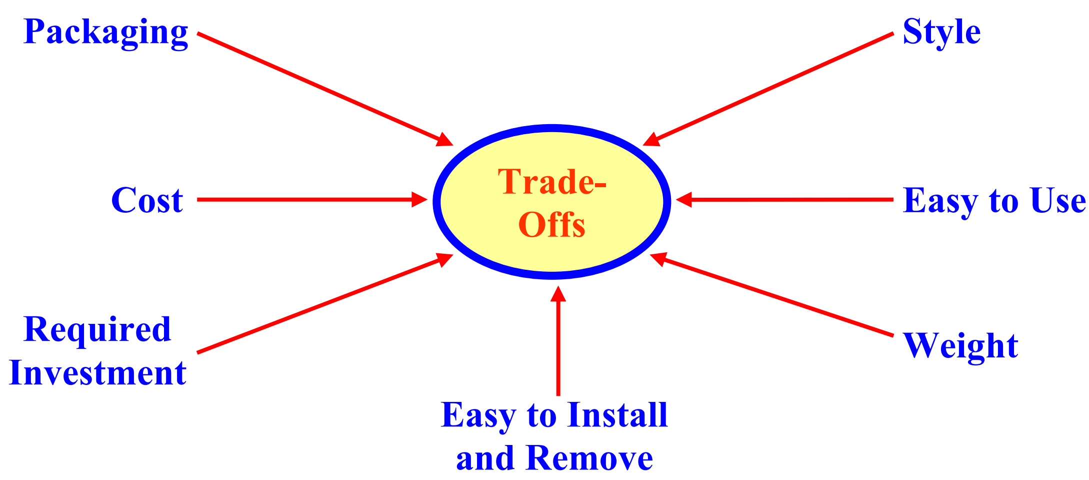

Figure 3. Potential Trade-Offs Associated with the HTC Project

The number of design projects that can be considered during a given offering of the capstone senior design course sequence depends on factors like the number of students that will be taking the course, the number of faculty members that will be involved in an active fashion in the supervision of the projects, and the number of teaching assistants that will be available to help the faculty members. We suggest that at least one faculty member and one teaching assistant be assigned to supervise each project. Since the faculty member will have the responsibility of working very closely with the students and the sponsoring company, we do not recommend having a single faculty member supervising more than one or two different projects during a given offering of the course.

Although having only one team working on each project is a possible option, we favor the idea of having several teams working independently and in parallel on the same project as if they were potential suppliers of the sponsoring company that are competing against each other to present the best product design. When such an approach is used, the faculty members, teaching assistants, and company personnel that are supervising the project should avoid sharing critical information or design ideas provided by one team with the other teams. For example, if a team identified certain customer needs that most of the other teams were unable to recognize, that information should be treated as confidential and not shared with those teams. Design reviews should be conducted separately with each team and only generic feedback can be provided when members of several teams are present at the same time. Obviously, once the teams start building comprehensive physical prototypes, it becomes difficult to avoid having one team taking a look at the product concepts that other teams have in mind. To prevent possible problems that may arise due to this situation, it is important to have a "conceptual design freeze" before the teams start building comprehensive physical prototypes.

We have found that when only a single team is working on a particular project, at times the students are not strongly motivated to give their best effort. Also, during concept generation, sometimes they are not as creative as they are expected to be. There is a risk that the team may feel that no matter what product concept it decides to select and implement, it will be a "good solution" if it is capable to satisfy most of the basic requirements that the team was able to identify during its interactions with the potential customers. Since there are no other competitors working on the same project and under the same circumstances, the team may feel that the final design that it is going to present is the "best alternative" (or at least a "very reasonable one") that a team composed of senior students could have conceived given the available time and resources. In today's global economy, we can say that for most consumer products competition constitutes a very strong driver for continuous improvement and innovation. We feel that the same is true for the case of senior design projects.

Keeping in mind that a senior design project is a learning experience for the students, we feel that it is not reasonable to expect that most of the teams working on a senior design project will come up with a very successful product at the end of their effort. In fact, if few companies are highly successful more than half the time[8], how can we expect that every team will come up with a great product? The expectation is that the teams will do their best effort and that they will follow a structured PDP applying in a conscientious manner all the methodologies and tools that they have been taught. If only one team was working on a specific project, how can that team have a good measure of the degree of success that it was able to achieve? Furthermore, how can that team identify some of the wrong decisions that it made during the PDP? Time and time again we have been able to observe that when several teams are working on the same project in an independent fashion, many valuable "lessons learned" for the students have emerged after all the teams have made their final presentations and prototype demonstrations. This is very similar to what happens in industry. Product development teams sometimes discover what went wrong during their PDP when a competitor launches a superior product into the marketplace.

With respect to the size of the teams, our experience has been that having more than six students per team can result in different types of teaming issues that can have a severe negative impact on the efficiency of the team and its ability to complete the project on time. On the other hand, if a team has less than four students, critical aspects of the learning experience of working in a team may be lost. Individual accountability is also harder to assess as team size increases. Hence, our suggestion is to select projects based on the desired team size rather than finding a project and then deciding how many students should be on the team. To form the teams, two approaches can be followed. One is to let the students decide who their teammates will be and the other is to have the instructor divide the class into teams without requesting input from the students. Although the latter more closely resembles what happens in industry, we usually employ the former. Our rationale for following such an approach is to try to minimize the time required by the team to reach the "norming" stage (and, ideally, the "performing" stage) of team development[12]. The teams have a limited amount of time to work on the project. If the students already know each other from previous semesters, then it is likely that the amount of time that they will need to spend in the "forming" and "storming" stages of team development may be substantially reduced.

Managing a senior design project sponsored by a company and corresponding to the development of a product requires careful planning by the faculty member(s) supervising the project. In what follows, we present some suggestions in this regard. Before the project starts, the faculty member(s) together with the project coordinator from the sponsoring company need to prepare a high-level Gantt chart that the students can use as a guide from the beginning of the project. As a minimum, that Gantt chart should indicate when the students are expected to start and complete each main task of the development effort. It must also specify when each major progress report is due, when the design review meetings with company personnel will take place, when the comprehensive physical prototype and the final report must be ready, and the date of the final presentations and prototype demonstrations. Critical milestones and events must be clearly indicated. Also, the sponsoring company and the faculty member(s) need to negotiate in advance when the specific resources needed for the completion of the project will be provided.

In the case of a two-semester project, we suggest to perform all the following activities during the first semester:

- Identification of customer needs
- Benchmarking of competitive products available in the market
- External search of information (patents, magazines, experts, etc.)
- Set target specifications for the product
- Concept generation
- Simple models and prototypes to validate product concepts
- Concept selection
- Set final specifications for the product

Here it is important to mention that during the concept generation activity we ask the teams to represent each one of their concepts using hand sketches like the one shown in Fig. 4. However, once the teams have completed the concept selection task, we ask them to represent the final concept that they have selected in as much detail as possible using a CAD model like the one shown in Fig. 5. From our perspective, that CAD model constitutes one of the main deliverables at the end of the first semester.

During the second semester, we suggest that the students perform all following tasks:

- System-level design
- Detail design
- Build alpha prototype
- Test alpha prototype
- Incorporate minor design changes that may be needed
- Certify alpha prototype
- Reflect on the results and the process

In the case of the HTC senior design project sponsored by a company, a total of 31 students were divided into six teams: one team of six students and five teams of five students each. All the teams worked independently and in parallel on the same product development project. One faculty member supervised all the six teams with the help of a teaching assistant. The level of support that was provided by the sponsoring company and the cooperation of the company personnel involved with the project were outstanding. As shown in Figs. 6 and 7, at the end of the project each team made a final presentation and prototype demonstration that was open to the public. The feedback received from those attending, particularly the one from the evaluation committed from the sponsoring company, was very positive.

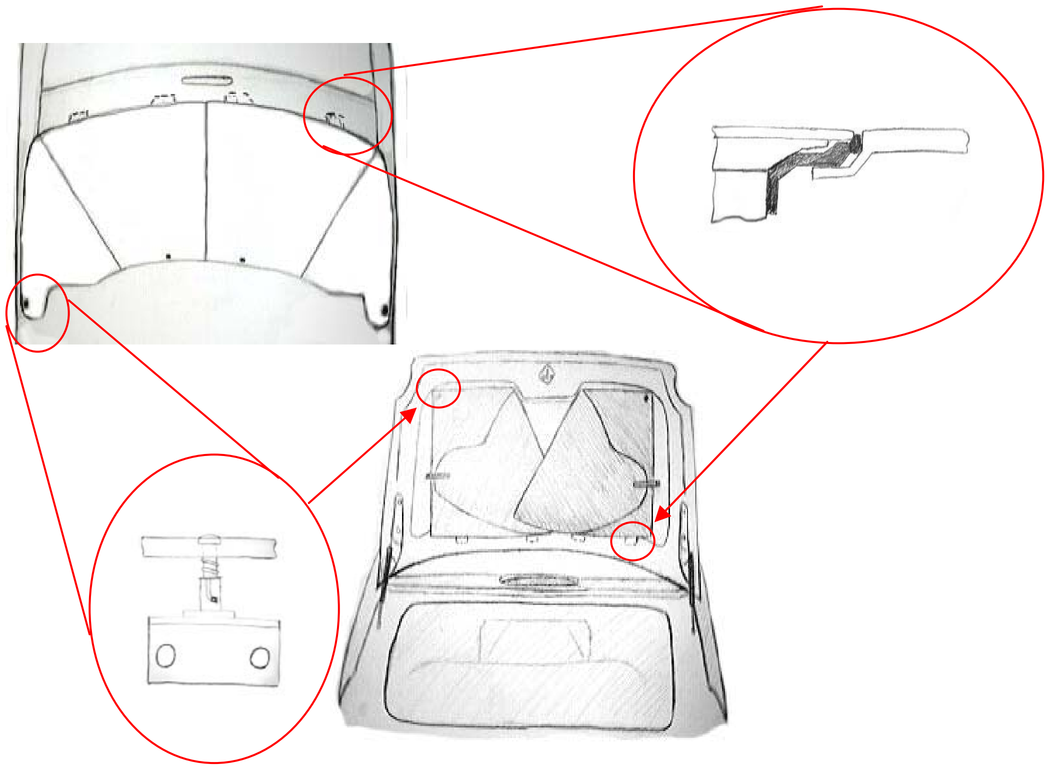

Figure 4. Hand Sketch of a Possible Product Concept Proposed by One of the Teams

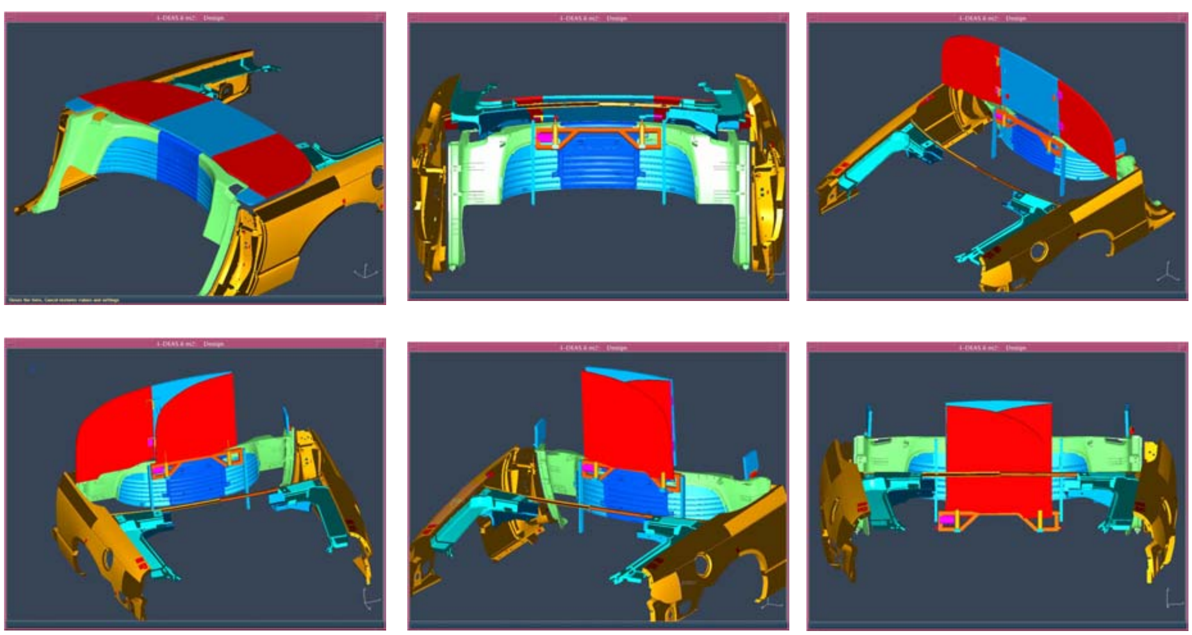

Figure 5. CAD Representation of the Product Concept Selected by One of the Teams

Figure 6. One Team's Prototype HTC

Figure 7. Another Team's Prototype HTC

Conclusion

Despite the increased workload for the faculty and the sponsoring company's engineers, we consider that the academic benefits of an approach which closely emulates industrial practice far outweigh all the challenges involved. The students solve a real industrial problem of interest and relevance to the sponsoring company. They are required to follow a structured PDP similar to what they will be expected to do upon graduation. Through interactions with the mentoring engineers, the students gain valuable experiences often not obtained in a typical undergraduate education and have the opportunity to be coached in many important areas, such as corporate and regulatory requirements and design for manufacturing and assembly (DFMA). Finally, the students participate in formal design reviews that are conducted in a manner similar to how they are carried out in industry.

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