Structured Approach to Problem Specification in Industry Sponsored Capstone Design Project

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Capstone design experiences have long been a staple of undergraduate engineering programs, providing an opportunity for the students to tie together the fundamental engineering science they have learned and apply it to solving a problem. Implementations of a capstone design experience vary significantly from program to program, with advantages and disadvantages to each and every incarnation. The example of the Senior Design program in the Mechanical and Aerospace Engineering Department at the University of Colorado at Colorado Springs is used to illustrate the importance of including significant emphasis in the capstone experience on the generation of a detailed engineering design specification. A structured approach to the generation of the engineering specification is also shared, along with discussion of how this part of the design process has served both the student design teams and the industry sponsors served as the customer on these projects.

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Introduction

Capstone design experiences in undergraduate engineering curricula serve a variety of purposes, some obvious, some not, some quantifiable and easily assessable, some not. Beyond the obvious, and admittedly very important, opportunity for students to put the engineering science they have learned to useful purpose in solving a "typical" engineering problem, it is the expected outcome of many capstone experiences that the students also progress in a transition from a student mindset and approach to that of a practicing engineer[1]. There are many aspects of this transition, but one of the fundamental differences in the expectations placed on an engineering student and a practicing engineer is in the area of problem specification.

In undergraduate engineering course work, it is typical that problems students are asked to address are intended to assess and/or reinforce the students' grasp on a specific concept or set of concepts. As such, sufficient specification is typically provided so as to zero in on that specific aspect of the students' understanding. An important shift in thinking and approach is required for real-world problems more typical of those encountered by professional engineers, where the problem is not clearly and completely specified. This paper focuses on the use of the Quality-Function-Deployment (QFD) technique as a tool used by students in the capstone design course sequence in the Mechanical Engineering program at the University of Colorado at Colorado Springs (UCCS) to develop a detailed engineering design specification before setting out to actually solve the problem at hand.

Background

Since the inception of the Mechanical Engineering program at UCCS, the Senior Design Program has consisted of a two semester course sequence with problems brought to the students by local, and sometimes not-so-local, companies. In the beginning of the fall semester, students hear presentations from the companies about their core business and about the particular problem they would like the students to address. These problems range in scope and domain all over the map, but the requirement is that they be of importance to the company, and not simply interesting exercises that might be typical of problems addressed by engineers in their business. Working with companies to help them identify problems of importance but not problems on their critical path is a challenge and the subject for another paper.

After all of the problems have been presented, students submit a prioritized list of the problems they would like to address, and are assigned to teams of four. At this point, the students have only a very basic understanding of the problem at hand, so their first task is to develop a detailed problem specification so that they are adequately equipped to develop solutions and so that those solutions will best address the requirements of their customer.

Throughout the rest of the first semester, they are provided tools to aid their progress, including project planning and management tools, concept generation and evaluation tools, team skills, etc., but one of the most emphasized tools presented is the QFD method for fully specifying the problem to be addressed.

As with any engineering design problem, there are trade-off decisions made in developing a capstone design program. Placing emphasis on the problem specification of the design process requires a significant investment in time, both in the instruction on the specification development tools as well as in the time devoted by the design teams on the specification process, itself. In the Department of Mechanical and Aerospace Engineering at UCCS, this is accommodated by devoting two semesters to the capstone design program. It is acknowledged that this is not possible in all programs, and thus the approach presented herein may not everywhere be practical. Nevertheless, it is the opinion of the author that the investment of time on the front end of the design process is exceedingly valuable to both the students and the companies sponsoring the problems.

The QFD Method

Quality-Function-Deployment was conceived in Japan in the late 1960's as a method of new product development under the umbrella of Total Quality Management by Shigeru Mizuno and Yohi Akao[2,3]. Whole texts have been written to describe the QFD process and its origins[4], and it is not the intent of this paper to address this in detail. Rather, the basics of the method will be described to support the description of how the method is used in the UCCS capstone design program as well as the benefits derived from its use.

There are several important outcomes derived from the problem specification phase of the design process. One is providing the student design team with a thorough understanding of the problem domain. Very few of the problems brought to the table by the industry partners fit neatly into domains addressed directly in the undergraduate mechanical engineering curriculum at UCCS. Another outcome is the identification of priorities of the "customers" that can help to differentiate between potential solutions and also provide bases for trade off decisions down the road. Finally, the problem specification process is used to derive a detailed and comprehensive engineering design specification; a document containing all measurable objectives of the design that impact its success in addressing the problem. The following description is intended to demonstrate how each of these outcomes is addressed through the QFD method.

To begin the QFD process, the student teams endeavor to identify an appropriate list of "customers." The word "customers" is in quotation marks here and previously due to the intended meaning. Emphasis is placed on defining the word in the context of QFD as anyone with any stake in any design decision that will be made. While the end user of the solution and the point of contact with the sponsoring company certainly qualify under this definition, so, too, do many other constituency groups, including machinists who might be tasked with fabricating parts for the solution, assemblers, shippers, company management, etc. The student teams, through independent research as well as interaction with their point of contact with the sponsoring company, generate as complete a list of "customer" groups as possible and, too, individuals who can be queried to determine the prioritized list of customer requirements.

Significant insight is gained by the students in gathering the list of requirements from each customer group, along with the priority perspective of the different constituencies, and in many cases value is derived for the sponsoring company just through this effort. As most of the sponsoring companies tend to be engineering companies, and most of the points of contact (POCs) engineers at these companies, some idea of the solution often colors the statement of the problem. By obtaining this comprehensive perspective on the attributes of a problem solution, the true underlying requirements can allow alternative approaches to emerge.

Next, the students identify a list of "competitors," another word expressed in quotation marks here due to the broader meaning intended than is typically applied to the word. In this context, the word refers to any extant solution to all or part of the problem to be addressed. Often this is internal to the sponsoring company, as they are looking for an improvement to a current situation. Each "competitor" is then assessed on the degree to which each satisfies the customer requirements. This information will be used to help identify appropriate engineering specifications, as will be discussed shortly.

The next step in the QFD process is to identify a comprehensive list of engineering parameters, measurable quantities related to the list of customer requirements. Identification of the engineering parameters tends to be the hardest part of the whole process for the students. Many of the customer requirements they derive from their POC and interaction with other customers are, themselves, measureable, and the inclination is to generate a one-to-one listing. The challenge is to guide them to the notion of coming up with as many measurable quantities that in some way relate to each customer requirement as possible, and the approach ascribed to in the UCCS program is to take each requirement individually and generate as many different quantities as possible, combining as appropriate after all customer requirements have been addressed.

The next challenge is to identify appropriate target values for each engineering parameter. This is where the evaluation of "competitors" really pays dividends. The values of the engineering parameters for the "competitor" solutions can be used for guidance in determining appropriate targets; where corresponding customer requirements are met by the competitor, those values can be used as targets, and there customer requirements are not met by the competitor, "improved" values can be set as targets in the hopes that those values would correspond to satisfaction where the competitor falls short.

Together, the list of engineering parameters and their corresponding target values constitute the Engineering Design Specification, one of the important outcomes of the QFD process. The idea is that if a solution can be identified for which the values for the measurable quantities listed meet the target values identified, all of the customer requirements will be met, and that there are no other measurable quantities of consequence.

Finally, the QFD table is completed by correlating the engineering parameters with the customer requirements, and correlating the engineering parameters among themselves. When give and take design decisions are faces, these correlations provide a means on which to base those decisions. If a choice must be made sacrificing the satisfaction of one engineering specification for the satisfaction of another, the correlation with customer requirements indicates the relative priority requirement impacted by each.

The culmination of this phase of the design process is the presentation to the sponsoring company of the completed engineering design specification. The students are tasked with making a two step case to their sponsor in this Problem Specification Design Review (PSDR). First, they present the prioritized list of customer requirements. This does not always coincide with the input from the company itself, as significant independent research and interviews with other "customers" often refines and sometimes significantly changes perspectives of what is important. If they successfully convince their sponsor that theirs is the appropriate list of requirements, their next task is to present the engineering design specification they contend contains all relevant measureable quantities along with appropriate target values. The QFD table provides an invaluable resource to substantiate this claim. In most cases, any issues that the sponsor has with the priorities list of customer requirements can be hammered out at the PSDR, but on occasion, students are sent back to continue their design specification work and another PSDR is scheduled.

Successful conclusion of the PSDR results in a signed agreement between the team and the sponsor that the engineering design specification is complete and appropriate for this problem, and, through this process, the team has gained enough insight and expertise in the specific problem and the problem domain to begin generating concepts to meet the specification. All told, the expectation is that this portion of the design process encompasses the majority of the first semester of the course, but sets the students up for an efficient and successful design effort going forward.

Pot holes to avoid

Working with real problems brought by companies can be a challenge in and of itself. Developing a mutual understanding of the types of problems that lend themselves to both the time scale and the multitude of educational outcomes sought by the capstone program takes time, and even then, achieving buy in to the benefits of having the students undertake this significant problem specification process is not always a given. One longtime sponsor of projects for the MAE UCCS program finally confessed that, while he understood the academic value to the students, he did not see the value to him or his company. From his perspective, the time spent developing this specification was time taken from the generation and refinement of the solution to his problem.

Obviously, the level to which sponsoring companies are satisfied with the work product of the design team is greatly impacted by the design team itself; not all student design teams excel on their capstone projects, and this particular sponsor had had the misfortune of having a couple sub-par teams in a row. Requiring that problems brought by the companies be of importance to them cuts both ways, and less than useful results can easily be blamed on the process rather than the team. That all changed, however, when a problem specification presented by a subsequent design team provided new insight into that year's problem.

To promote buy in to the process by new sponsor companies, a more detailed description of not only the process itself, but the perceived benefits not only to the students, but to the sponsor companies themselves is provided up front. The example just cited is used to reinforce these benefits. This and the continued improvement of the use of the QFD process has engendered strong support by the sponsor companies.

Another pot hole to avoid is the impulse of most students to want to pay only lip service to the notion of completing the problem specification process prior to developing potential solutions. Certainly, coming up with ideas to solve the problem is more fun than the seeming tedium of completely specifying the problem, but it is stressed to them that premature concept generation will invariably influence the ultimate engineering specification, as requirements will be derived to fit the proposed solution rather than the other way around.

Strict enforcement and constant oversight, managed through weekly status meetings with the instructors assigned to the course, help to mitigate this issue. The teams are constantly challenged to justify each and every requirement and engineering specification, often resulting in dropped or modified requirements that are shown to be solution specific rather than fundamental.

Assessment

The benefits of the emphasis on the problem specification portion of the design process in the capstone design program have been alluded to anecdotally herein, but formal assessment takes place each and every year, primarily through the use of surveys gathered both from the students and the sponsor companies. Consistently, the benefits of the problem specification process are acknowledged by the students in retrospect, even if they did not recognize those benefits while going through the process. The company feedback also supports the value of this process.

Conclusion

Capstone design experiences, particularly those that include externally provided real-world problems to be addressed, serve an important role in the education of engineers. In the MAE UCCS capstone program, significant emphasis is placed on the development of a detailed comprehensive engineering specification prior to developing a solution to the problem. The QFD method is used to facilitate this effort. Benefits to the students include a much more detailed and fundamental understanding of the problem they are addressing than would be possible were an engineering specification provided. Benefits to the sponsor company include a different perspective on a problem that company personnel may be too close to. While including this emphasis requires a significant level of effort, the benefits have been found to outweigh the reduced time available to come up with and refine solutions, and the sponsor companies have been well satisfied by the results.

References

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