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Quality Function Deployment (QFD) in Late Stages of Capstone Design

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Abstract

Quality Function Deployment (QFD) is widely used to clearly define customer requirements and convert them into detailed engineering specifications and plans to fulfill those requirements in the design process both in industry and in academia. It allows for prioritization of the tasks associated with achieving a solution in an analytical and systematic way by developing metrics for the specifications of the solution. Employing QFD also creates a record of why each individual decision was made, which can be useful further in the product timeline. Students in capstone design courses are commonly required to implement QFD in the form of the house of quality early in the design process to define the problem, establish engineering specifications, prioritize specifications, benchmark, and ensure the "voice of the customer" is not lost. This is performed during the project planning and specification development or task clarification stage. QFD has been proposed in the literature as a series of cascading charts that follow the design process throughout the project lifecycle to manufacturing and quality control. While students are commonly asked to use QFD early in the design process, it is much less common for students to return to QFD throughout their projects in order to learn this cascading process. This paper will assess the use of QFD during the later stages of a Capstone project to amplify the voice of the customer and emphasize quality control.

Mechanical Engineering students at The Citadel are historically required to develop a house of quality as part of an assignment generating requirements and constraints. In the beginning of the capstone project, students are introduced to the structured process of defining the customer's requirements and the process for transforming them into specific product designs. Students are required to establish the voice of the customer (VOC) into the design of their capstone project by creating, deploying, and analyzing a survey instrument and to incorporate the results into the house of quality. While they are encouraged to revisit the requirements and their prioritization, they are not formally required to further develop QFD techniques following the project planning phase. The results are assessed during the first formal design review and interim report. In this case study, these students will employ QFD techniques in the embodiment or detail design stages to translate the VOC into measureable design targets. The results will be assessed through a survey instrument and observation. The results will be used to develop future studies and to suggest methods to incorporate QFD throughout the capstone sequence and to emphasize student learning objectives.

Introduction

Quality Function Deployment (QFD) emerged in Japan in the 1970's with the objective of instilling quality in product development. QFD is built on the foundation of the "voice of the customer" and is intended to be applied from early stage design through production [1], [2]. It gained acceptance in Japan and in the United States and remains a popular component of the design process [3], [4]. QFD techniques are often implemented by multi-functional teams that define the customers' requirements early in the design process and translates them into engineering specifications [5]–[7]. It is then intended to be used to analyze components and manufacturing processes, and serve as a tool for later quality assurance efforts [6].

QFD is often incorporated in undergraduate engineering capstone design courses as an integral part of the design process while eliciting and prioritizing requirements as a best practice. In this implementation, the students construct and complete a quality matrix known as the house of quality [4], [8]–[10]. It has also been proposed and used as an assessment tool for design success and a contract between the design teams and faculty regarding assessment benchmarks [11].

QFD also includes additional matrices that can assist with connecting the "voice of the customer" to the later stages of the design process. These matrices follow a structured approach to connect:

(1) customer requirements to quality requirements, or engineering specifications,

(2) engineering specifications to product characteristics,

(3) product characteristics to manufacturing processes, and

(4) manufacturing processes to quality controls.

In this approach, the results of each matrix flow into the succeeding matrix in a waterfall process [1], [3], [12]. This paper addresses the use of selected QFD matrices, beyond the initial house of quality, in a senior capstone design course for mechanical engineers.

Design Process and Coursework

Students at The Citadel are introduced to the engineering design course through a one semester long course on mechanical engineering system design during their junior year. This course includes instruction on all phases of the design process and includes routine in class application of design tools and methods. Students also complete a simple design project that requires them to work in design teams and exercise the design process from project definition through manufacture of a prototype (water bottle rocket). All students are taught the design process using the same basic methods and textbooks [4]. Although there are multiple instructors for the course, they routinely meet to discuss course material, ensuring consistent instruction on specific design methods and tools. An overview of the design process as instructed in this course is provided below in Figure 1. This is also the basic design process overview used in senior design, although activities within "product development" are subdivided into embodiment design and detailed design.

Senior design is a two semester course for these students. The first semester includes product definition, conceptual design, and the first portion of product development (embodiment design). During this semester, students develop concepts and physical and mathematical models of their product to include a proof of concept prototype. In the second semester, they will complete detailed design and build and test their product. Some, but not all, of these designs will include a mechatronic aspect [13]. A refresher on QFD is provided during the second week of the first (fall) semester. Each team is required to survey customers to receive their input on requirements and their importance. They then incorporate this input into their house of quality, prioritize requirements, and benchmark against competitors identified in their market research. They present their house of quality in their first design review the following week. This house of quality is also included in their final design report at the end of the first semester.

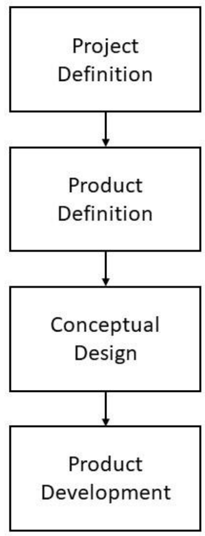

Figure 1. Design process for students in Mechanical Engineering System Design [4].

When the house of quality is completed, the students have developed requirements and surveyed their customers, but they have not yet started concept generation.

Methodology

Students from one section of senior design were asked to complete a second QFD matrix during class in the second semester, during their detailed design phase. At this point in the semester, all teams have ordered at least some portion of their bill of materials, and most are beginning to build their final prototype, although most are still refining their designs. As a result, they have knowledge of the product and component physical characteristics and behavior. The second QFD matrix requires designers to develop a list of product characteristics and relate them to their initial engineering specifications. They now have a much higher level of fidelity in their knowledge of the design than when the original house of quality was created. Two four-member teams completed the second matrix during a 45 minute session.   A third team was asked to complete the third QFD matrix. This matrix analyzes the relationships between product characteristics and manufacturing processes.

Teams were provided a brief, approximately five minute training session on how to complete the matrix. They were also provided an instruction package including one page of instructions and a second page with an example matrix. The example matrix provides an unrelated product selected from a reference paper [3]. The design team is also provided copies of a QFD template (Table 1). The engineering specifications from the team's first semester are included in the template for the team. These specifications were obtained from the first semester final report as this was the last submission including the house of quality. The importance of each specification is also populated for the team prior to the exercise. The importance ratings are percentages as determined from the normalized scores from the house of quality.

Table 1. Sample pre-populated matrix for student activity.

Quality Characteristics	Importance	Product Characteristics								
Acoustical Transparency	6									
Sensor Accuracy	16									
Lightweight Material	15									
Effective use of resources	9									
Return to home location	13									
Hold 50 Tennis balls	6									
Complete task in time (8 min target)	11									
Simplicity of Design	5									
Avoid Rocks or small objects	7									
Error Redundancy protection	12									
Score										
Rank										

For this task, all work was completed on paper. A calculator was used by designers to calculate the final scores and rankings for each characteristic (or process). The steps to complete the second matrix are:

(1) Fill in the product characteristics for your product. These characteristics are related to quality characteristics from the original QFD.

(2) Identify any existing relationships between each quality characteristic and product characteristic and characterize the relationship as "Strong," "Medium," or "Weak," or "No relationship at all." If the relationship is strong, assign a 9 in the matrix at the appropriate spot. Medium will be assigned a 3 and weak will be assigned a 1. No importance is indicated by leaving the matrix cell open or blank—this will assign a weight of zero [1], [4].

(3) Multiply the relationship value times the weight at the end of the table. Each column is summed to provide a final score for each characteristic (using calculator).

(4) Record the final rank ordering of the characteristics in the matrix.

Once the design team received their training session, they were allowed to begin the QFD exercise. The first step involved generating the list of product characteristics given their knowledge of the current design. The students were provided two questions to answer once they had completed the list of product characteristics. These initial questions are provided in Table 2. Once the matrix was completed and the final results were calculated by the design team, the designers were provided individual surveys to complete regarding their experience with the exercise. These questions are also provided below in Table 2.

Table 2. Initial survey questions to determine perceptions of criticality and risk prior to the exercise.

After completing product characteristics (manufacturing process) list	
Pre-1	What is the highest risk component (process) in your design?
Pre-2	What is the most critical component (process) in your design?
After completing exercise	
Post-1	After completing this exercise: did you find that any of your specifications have changed or are no longer relevant?
Post-2	When did you last update your specification list? 1) When building House of Quality 2) During Conceptual Design 3) After Conceptual Design, but before the end of 1st Semester 4) During the 2nd Semester
Post-3	What did you learn from completing this matrix?
Post-4	How will this impact your design?

Discussion

Each team was able to complete the exercise in a time frame ranging from 30 to 45 minutes, with the team possessing the longest requirements list taking the most time to complete the exercise.

Designers were able to rapidly understand the instructions and begin working due to their familiarity with and prior shared experiences with QFD and the house of quality. Two of the three teams consistently identified the time of the latest requirements update, with one occurring during embodiment design and the second occurring early in the second semester. The third team did not consistently identify the time of their latest update, possibly indicating that not all team members were involved in reviewing the requirements. The team that reported reviewing and updating their specifications during the second semester did not identify any new changes to their specification list. Figure 2 is a summary of the students' responses to question "Post-2: When did you last update your specification list?"

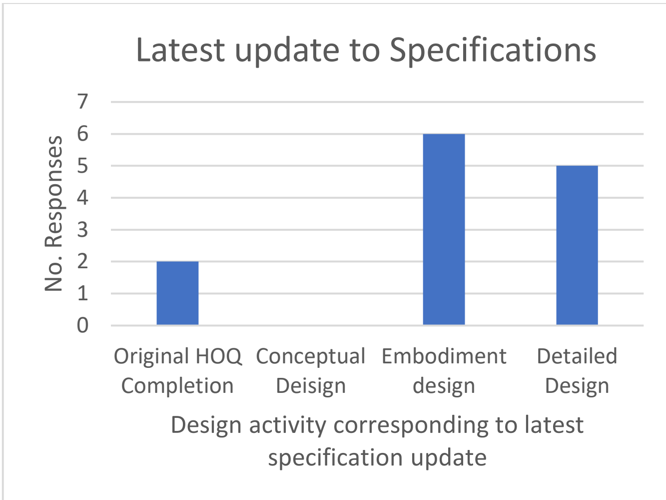

Figure 2. Event closest to latest update to specifications and requirements.

Team members did initially share a consistent view of the most critical and highest risk components in their design. Team members on all teams indicated the same two basic parts or assemblies for these two categories, although in some cases their placement was interchanged. For example, one team identified a "lever" and a "rim" as the two components. Some teammates identified the lever as the highest risk and the rim as the most critical; other teammates reversed the categories. This is likely a result of differing interpretations of the terms "risk" and "critical" than it is a lack of shared understanding of the design.

Student designers indicated that they gained an appreciation for the components and characteristics that merit additional focus from their completion of the matrix. This was conveyed either through directly stating that they learned "what needs to be the main focus for the design," or by identifying specific components or focus areas for greater emphasis: "gear ratio is very influential to our design." Two teams identified specifications that they felt required revision. In both cases, they identified this specification as having lost relevance due to changing the scope of their design to focus only on specific subsystems of the overall product. One team submitted a matrix that had no relationships between the specific quality characteristics and product characteristics. These specifications were those identified as having lost relevance. The remaining team, which had compared product characteristics to manufacturing processes, did not identify any changes to their requirements. This team also indicated they had recently reviewed their specifications list. One designer verbally stated as he left the exercise: "I learned that I need to review the requirements list and house of quality."

Limitations

Three student design teams were engaged in this exercise. Individual designers from two additional teams participated, however, their results were not analyzed and included since their teammates were not participating. Two of these teams completed QFD matrix two, and the third completed matrix three. The sample size can be increased to further understand potential effects of including these additional QFD matrices in a capstone design course.

Future Work and Discussion

Based on the experience and results of this study, the following recommendations are proposed:

1. Design reviews, in addition to the course instructor, may include guest faculty who may or may not be familiar with particular design projects. The review panels usually ask questions to the teams to gain insight and may offer recommendations. Future review panels may benefit from a quick review of some of the design tools like QFD to heighten their awareness of what the teams are presenting and how they arrive at their requirements. Faculty advisors have an important role in steering the students and evaluating the technical merit of their projects, requiring a considerable investment in time. They should also receive some training and guidelines, so they will have a common understanding of the conceptual design process and how the students' work is to be evaluated.

2. Summary reports of design reviews may provide additional benefit for students and instructors alike. A summary sheet of tips and errors to avoid and available for all students after each review will provide focus on common mistakes so students do not do them again, and for instructors to emphasize in future offerings of the course.

3. The placement of the matrices in the course should also be adjusted. The two matrix types were completed during the same design stage (during detailed design and build). Future study will include sequencing these matrices earlier in the design process. The second matrix could be incorporated at the end of concept design and the third during embodiment design at the end of the first semester. This could be further evaluated to determine how this affects the development of the design and the students understanding of the connection of the voice of the customer to the complete design process.

4. Engineering students need practice on how to apply engineering analysis to open-ended problems before reaching the senior year. In their third year, juniors learn the design methodology and employ a number of tools such as QFD, but the limited exposure to some of these valuable tools may need another look. It may be prudent to introduce some of these tools in multiple courses their junior year for reinforcement or earlier in the curriculum so students have a more meaningful design experience as seniors. This will help having more faculty familiar and skilled in these design tools.

Conclusions

Employment of QFD during the late stages of product development required students to re-examine their engineering requirements and to assess their development of product characteristics or manufacturing choices in light of these requirements. As a result, some teams identified previously unidentified connections between requirements and design choices. Some also recognized a need to update their requirements list. Future study is planned to further explore the impact of QFD beyond the house of quality in capstone projects. This may involve adjustments to the timing of these techniques and to the number of participating teams. Regarding faculty interaction with capstone teams, consideration of the preparation of faculty to employ these tools should also be considered. One of the difficulties in senior design courses is working with the wide variety of design projects. Part of this problem can be minimized by using common tools such as QFD and ensuring faculty work more closely with the project advisors so that course requirements, tools, and expectations are well understood.

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