# Capstone Design Courses Incorporating the Optimal Problem Specification Tool

Diana C. Gronski and Peter J. Gorder
*University of Colorado*

Capstone design courses are of great benefit to undergraduate students, as they offer the opportunity for students to gain experience by applying the engineering science that they have learned to solve real engineering problems. One critical aspect of the engineering design process is problem specification, which includes the development of an appropriate engineering specification that can drive and, ultimately, validate the design. The approach known as Quality Function Deployment is described and investigated as a means of addressing the problem specification portion of the design process in an undergraduate capstone design course. An explanation of the method's advantages and disadvantages in this context are discussed. Analysis of the method is used to see whether it can be optimized during application. The ultimate goal for the research, whose introduction is reported herein, is to determine the most effective problem specification approach for undergraduate capstone design courses.

*Corresponding Author: Diana Gronski, dgronski@uccs.edu*

## Introduction

Undergraduate capstone design courses are significant for the growth and transition of students from the academic mindset to working as a practical engineer. A significant amount of coursework throughout an engineering student's undergraduate career focuses mainly on problem solving using theoretical concepts that were introduced and then applied, whereas problems in the real-world are typically less defined and don't fit neatly into discipline-specific boxes. When unfamiliar with problem specifications, an engineer can go about a solution by straying from the original concept, which leads invariably to suboptimal solutions.

Capstone design courses are intended to allow students to begin thinking more deeply on how to approach a problem, and the problem specification process is an important tool to facilitating this transition. The capstone courses provide an opportunity for students to gain an understanding in how to solve real-world problems by using problem specification methods combined with the knowledge gained throughout their undergraduate years.

For students approaching real world problems, the criticality of developing a thorough understanding of the problem to be addressed cannot be overstated. There is an undeniable tendency of eager students to start thinking of solutions without ever coming to an understanding of all of the problem at a level necessary to adequately consider all possible solutions in order to determine the overall best approach to a solution. But the question of how best to introduce this important aspect of the design process and effectively guide the students through it is an open one.

This paper provides an overview of the use of Quality Function Deployment (QFD) as a problem specification method in the context of an undergraduate capstone design course. The efficacy of this approach is evaluated for use in the capstone experience. Based on this analysis, additional research will ensue into alternatives to the QFD method, with the ultimate goal of the research effort, whose beginnings are reported herein, to identify and/or develop the optimal problem specification method for implementation in an undergraduate capstone design course.

## Background

Students enroll in an undergraduate engineering program with the goal of becoming a successful engineer. Throughout an undergraduate career, the majority of courses provide the education in the foundational knowledge necessary for students to ultimately have the ability to succeed as an engineer. Engineering problems addressed by students throughout these foundational undergraduate courses tend to be targeted to specific engineering science or practice concepts. As real world problems rarely lend themselves to such straightforward application of concepts, design courses that introduce the concept of problem specification are of great importance.

The outcome of the problem specification process is an Engineering Specification, but the benefits of going through the process far exceed the quantitative specification that the students can then design to. It is vital for students to fully understand a problem before it can be solved, and going through the problem specification process provides much needed insight into the problem domain as well as the nuances important to the "customer" that may not be obvious at all to the students, either because a lack of experience or even solely due to cultural differences. Problem specification tools can both educate the students and bring them up to speed of the problem, as well as prevent poor problem definition which can cause engineering complications further down the design chain. Studies have shown that 80% of all time delays in product development cycles come from poor problem definition[1]. Poor problem definition can be a direct result from not fully understanding the problem that is to be solved. Using problem specification methods allows for all aspects of the problem to be analyzed, which provides a guideline for the design process.

Capstone design courses frequently have the students work in teams when implementing problem specification tools. Students' thought processes vary greatly which can result in different expectations in problem definitions. Problem specification methods provide team members with guidelines that allows each member to have a common understanding of the problem that is to be solved. Having undergraduate design courses also benefits the students because it gives them experience working in design teams, allowing them to understand how each member brings their own contribution to the team and how to come to an agreement with a solution.

Many different problem specification methods can be utilized in undergraduate capstone design courses. At the University of Colorado Colorado Springs, the approach that has been used in the Department of Mechanical and Aerospace Engineering Senior Design Program is the Quality Function Deployment method, also known as QFD[2]. It is a process that keeps the customer's focus throughout the product development stages, allowing for the most optimal solution. During the course, students have the opportunity to work with companies to solve problems within an unfamiliar engineering domain. The students work with the customers to understand what features are important and what the customers are wanting to achieve through the solution. The significant desires are then ranked qualitatively to determine the priorities, which allows for metrics to be created. In the program, QFD has had both successes and failures with problem specification, but more importantly, many students are not receiving the full benefits from the method, which introduces the question whether a more optimal method can be passed down to the students.

## The Quality Function Deployment Process

The QFD process can be a long and tedious process. The most crucial and, in most cases, most difficult part of working with a customer is initially determining the problem that the customer wants to resolve. In other words, what issue does the customer actually want to solve and not what the engineer thinks the issue may be. The team should work together in understanding which aspects of the solution are most significant during the problem solving phases. Quality Function Deployment uses one or more matrices to first identify the prioritized requirements of a customer, and then to determine, based on those requirements, the appropriate Engineering Specification, a comprehensive list of quantified parameters such that satisfaction of those specifications will meet the requirements of the customer[3,4,5]. The House of Quality, also known as HOQ, is a single matrix most commonly used in QFD. HOQ is an outline to be completed that measures the relative importance of all customer requirements. The name of HOQ comes from the fact that the outline resembles a house and, therefore, each section within it can be referred to as a room. Figure 1 shows the room arrangement of the House of Quality.

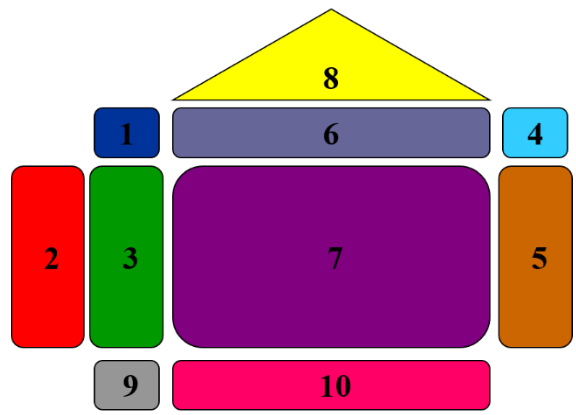


Figure 1: Room Arrangements in House of Quality

Each room of the house is intended for a different function. The first room identifies and compiles a list of customers related to the problem, where "customers" include anyone that has a stake in any design decisions that will be made, not restricted to the end-user of the problem solution. The second room of HOQ is intended for the product requirements and characteristics that are desired by the customers. When listing the product requirements, it is beneficial to consistently maintain the customer's exact wording due to the fact that many departments, such as project planners, engineers, manufacturers, sales people, etc. will all be working on the same project. The product requirements may be determined by team members coming to a general agreement based on interactions with the customer, or research from the customer's inputs. Requirements could also be determined through the demand and needs of merchants or even through statistics that were created from evaluating positive feedback that came from similar existing solutions and hypothetical ideas

The third room of HOQ is to rank the customer requirements to determine which ones are most important. The rankings help develop metrics for the customer requirement. They also are used to make trade-offs between the requirements, as some requirements are more significant than others. The fourth room is for the competitors to be identified and listed. By analyzing the competitors' solutions, the team may better understand where product improvements can be made. The fifth room of HOQ is intended for ranking the competitors' solutions on a scale of 1 to 5, where 5 meets the product requirements completely and 1 doesn't meet the requirements at all. This scale provides the team with information on how well each competitor design satisfies the customers' requirements that were listed in the second room of the house.

The sixth room of the House of Quality is for the engineering parameters that are related to the customer requirements. The sixth room is crucial because it directly relates the voice of the customer to the designs of the engineer. The seventh room is designed to show how strongly the engineering parameters listed in room six are correlated to the customer requirements. A scale of 1 to 9 is used for these relationships, where 1 is a weak relationship and 9 is a strong relationship. A blank opening signifies no relationship. The eighth room of the house is used to relate the engineering parameters to one another. This allows for the team to see if changing one feature of a product conflicts with another feature's performance, which could lead to unfaltering the original feature. The ninth room of the house should include a list of potential designs for the product being developed. This list may include competitor's designs as well. Lastly, the tenth section should give target values of the listed designs in room 9 from the ratings determined in seventh room of the house.

The QFD approach along with the House of Quality is commonly used in industries during product development, but can be implemented in coming to any type of solution that is related to engineering problem solving. The first three rooms of the house can be considered the most important because they implement and prioritize the customer's focus for the product being developed. The fourth and fifth room of the house are for the competitors. They allow the engineer to get familiar with the solutions that already exist, and how those solutions satisfy the customer requirements. The fourth and fifth room also give an idea of how improvements can be made. The sixth room is for the designers to get familiar with what engineering parameters are related to the customer requirements. The seventh and eighth rooms show how strongly related each engineering parameter from room six is to both the customer requirements and the other engineering parameters. Rooms nine and ten determine which design is most ideal based off of which engineering parameters strongly agree with the customer requirements as it uses ratings from other rooms of the house. Implementing QFD along with the House of Quality first determines the voice of the customer and then implements those customer requirements throughout the design process. The method allows for the customer's focus to be kept throughout the design process, which results in a more successful design.

## Advantages and Disadvantages of QFD

There are many advantages that come with applying QFD when trying to approach a problem. It is beneficial because the method creates a common view among all members of a design team. To completely develop the HOQ and accurately reflect the needs of the customer as well as the specifications that must be met in order to satisfy their customer, students must necessarily come to a thorough understanding of the underlying problem they are trying to address. All members within a team are forced to develop a comprehensive understanding of the problem during the problem specification phase, which gives guidance during the conceptual and final design phases. Understanding the problem becomes a common view among all members working together on a project. QFD also helps the design team make decisions based off the customer's requirements and budget.

QFD is beneficial because it is a structured approach that to determine the prioritized requirements of the "customer", and then to translate those requirements into an engineering specification that can be used throughout the design process and, ultimately, to validate the solution determined by the design team. It allows for the tasks associated with achieving a solution to be prioritized in both a systematic and analytical way by developing metrics for the specifications of the problem's solution. Implementing QFD also creates a record of why each individual decision was made, which can be useful further down the design chain.

It has been shown that companies who implement the QFD method during product development make less alterations to the design than the companies that choose to use another design process[3]. Applying QFD to product development increases customer satisfaction by keeping the customer's focus throughout the design process. During an undergraduate career, students often do not understand the importance of customer satisfaction when asked to solve a problem. If a customer desires certain qualities in a product, excluding those qualities hinders work relationships and makes the customer feel as if their wishes were ignored, thus losing trust between the customer and engineering team.

There are also many disadvantages that come with the implementation of QFD in an undergraduate capstone design course. Completing the matrices during the QFD process requires a different mindset from the students. Students are eager to rush to the design process instead of taking in consideration the design specifications that incorporates the voice of the customer. Throughout a student’s undergraduate career, the coursework allows for students to get comfortable applying concepts that were introduced. For this reason, students automatically go to the mindset of trying to initially solve the problem instead of taking in consideration the bigger picture. This method requires the student to pause and consider many factors of a design before going to the solution phases.

QFD can also be a long and tedious process. Students may not understand the significance of problem specification tools and their benefits, which leads to them feeling as if the process is more of a nuisance than a benefit. This lack of motivation can cause them to rush through the completion of the QFD process, leading to lack of thoroughness in the results. Besides being a lengthy process, some areas needing to be completed may be unclear to first time users. One of the most common struggles for students using the QFD process is in the identification of parameters associated with the requirements of their customer. Stated requirements often take various forms, from very quantified (e.g., Must weigh less than 10 lbs) to much more qualitative (e.g., Must be easy to use). While the QFD process is specifically intended to provide the means to translate all requirements, actually sitting down and doing it can be confusing for the students who lack experience with the kinds of decision needed to make these determinations.

These sections can also be difficult to complete because, even though QFD is a problem specification method, it also requires understanding of the problem prior to implementation. When students are not exposed to problem specification methods, there can be complications when implementing QFD because students are relying on QFD to understand the problem and are not prepared for the prior problem specification knowledge necessary for implementation. Without prior understanding of the problem, it can be difficult to accurately complete the requirements in the HOQ. As a result, many student teams struggle through the problem specification portion of the design process, and don’t derive all of the benefit intended for them.

The research just underway will investigate different methods of problem specification to see how their advantages and disadvantages compare to QFD, specifically in the context of undergraduate capstone design courses. The objective is to optimize the experience for the students as well as to prepare them for real-world problem solving and success in their future engineering endeavors.

## Conclusion

Capstone design courses are significant for the growth of a student to transition from an academic mindset to an applicable engineer. Problem specification is extremely important during a design process for successful results. A problem specification process such as QFD helps students develop an understanding of the problem along with the engineering specifications that should be considered during the design phases. It has many benefits that include uniting a team’s perspective, being an organized approach, leaving a trail of why each design decision was made, and keeping the customer’s focus. Disadvantages to the QFD method center on the typical protracted and tedious timetable, as well as the difficulty students tend to have relating quantifiable parameters to requirements they hear from their customers. Further analysis will be done on the QFD process to see whether it could be optimized to better suit an undergraduate capstone design course. Different methods of problem specification will also be investigated to determine their efficacy and appropriateness for application in this context. Ultimately, this research will endeavor to identify or develop a problem specification method optimized for application in capstone design courses.

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