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Application of a House of Quality Intervention in an Engineering Capstone Design Course

Dr. James Righter, The Citadel

James Righter is an Assistant Professor of Mechanical Engineering in the School of Engineering (SOE) at The Citadel. He earned his BS in Mechanical Engineering at the U.S. Naval Academy, his MS in Military Studies from the Marine Corps University Command Command and Staff College, and his PhD in Mechanical Engineering from Clemson University. His research interests include engineering leadership, design methods, engineering design education, and manufacturing.

Dr. Nathan John Washuta P.E., The Citadel

Dr. Nathan Washuta is an Assistant Professor in the Department of Mechanical Engineering at The Citadel in Charleston, SC. He received both his B.S. and Ph.D. in Mechanical Engineering from The University of Maryland â€" College Park. His primary research

Dr. Deirdre D Ragan, Pennsylvania State University

Deirdre Ragan is an Associate Professor in Aerospace Engineering. She holds a B.S. in Materials Science and Engineering from Rice University as well as a M.S. and Ph.D. in Materials from the University of California Santa Barbara where she studied stresses in thin films. She previously developed nanoparticle-modified glass and automotive coatings (at PPG Industries, Inc.), conducted Raman spectroscopy of materials under static high pressure (at Los Alamos National Lab), studied the physics of electrochromic devices (at Uppsala University, Sweden), and taught science, math, and reading to 4-year-olds (at a Charleston preschool) before joining the faculty at The Citadel. She enjoys teaching upper-level undergraduate and graduate Engineering courses as well as mentoring and encouraging students to be lifelong learners. Her interests include aerospace, materials, student engagement, and pedagogy.

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Abstract

Engineering students are commonly instructed on the House of Quality and required to employ this tool in the early stages of product design. This method is a valuable aid in maintaining the voice of the customer in product design and is also commonly applied in industry contexts. Student misunderstandings of how to implement the House of Quality manifest in challenges ranging from errors defining customer and technical requirements to improperly populating the correlation matrix. These errors can affect the resulting prioritized technical requirements and downstream design decisions. The House of Quality is also one phase of the Quality Function Deployment process that can span the design process from planning to detail design. The later phases beyond the initial House of Quality are less commonly instructed or applied in capstone courses or more generally in the undergraduate curriculum. A previous study has implemented the second matrix during embodiment design on a limited scale in a mechanical engineering senior design course. It has also identified inconsistencies in the requirements incorporated from the first matrix— the House of Quality.

An intervention was applied in a senior year engineering design capstone course, capitalizing on previous efforts to enhance the House of Quality in addition to insights from a previous study of Quality Function Deployment (QFD) in a capstone course. The exercise was completed by teams in a single class session following the presentation of their first House of Quality during the initial design review panel. The resulting matrices are analyzed by faculty to assess the intervention's impact on requirements development in terms of quantity and type.
This intervention may also serve to provide a list of technical requirements at a more consistent level of abstraction to enable the effective implementation of the following phases of Quality Function Deployment considering correlations between technical requirements and product characteristics, and characteristics and manufacturing processes.

Keywords

Requirements, Requirements Management, Quality Function Deployment, House of Quality, Collaborative Design

Motivation

Requirements are a foundational component of the design process and generation begins in the first stages of design [1], [2]. Requirements generation and evolution can continue through later stages of design, influencing project and product success [3]. Requirements have also been shown to impact the product and project costs [4]. They should elicit and embody the voice of

the customer and be translated into technical specifications. Ultimately, they must be managed throughout the design process and used in the testing and evaluation of the product. The House of Quality is used as a phase of the Quality Function Deployment (QFD) process to support collaborative design teams in these objectives [5]. This paper focuses on the implementation of an intervention to assist students with requirements development in a Capstone design course. This will also be used to form a basis for later efforts to employ follow-on stages of QFD in the same course.

Requirements Evolution and Management

Engineering design students are commonly taught requirements generation as a component of the problem definition phase of the design process [6]. Requirements continue to develop throughout the design process, however, this is not always addressed as explicitly in design courses. However, studies suggest that the continued development of requirements throughout design stages of a capstone project may positively affect project success. Development of functional and non-functional requirements both may correspond to improved project outcomes [3].

Requirements change management (RCM) processes assist with managing evolving requirements. Requirements changes can be categorized by type, time, origin, and reason. While RCM processes assist with tracking and managing changes that occur, students may not be aware or focused on the types of requirement changes they will encounter or on the processes and documentation to manage change [7]. Educational interventions have demonstrated promise in addressing quality and quantity of requirements in student designs. A lecture addressing requirements generation and associated tools and techniques positively influenced the variety and uniqueness of requirements [6].

Quality Function Deployment (QFD)

Quality Function Deployment is employed to ensure the “voice of the customer” is instilled in the product design. QFD is routinely employed as a tool to assist with translating these customer requirements into technical requirements or engineering specifications in the early stages of design [5], [8], [9], [10]. Holistically, QFD is a multi-phase process that spans the entire design process. The initial House of Quality is the first phase of this process and is most commonly used in undergraduate design courses [11], [12]. The subsequent matrices correlate the initial customer requirements to engineering specifications, product characteristics, manufacturing processes, and quality control [5], [13].

Previous efforts incorporated one of the subsequent phases of QFD into a Capstone Course. These efforts suggested that the use of additional phases of QFD could influence requirements evolution and management within a capstone design project. However, initial implementations of the House of Quality manifested differing levels of abstraction for initial customer and technical requirements. Technical requirements were sometimes represented as product

characteristics or were not measurable. Initial requirements also did not generally cover all of the relevant customers [14].

Methods

Mechanical engineering students at The Citadel are taught requirements generation and the House of Quality during a junior year course on the systems design process. They participate in a two-semester senior design sequence the following year [15]. Design teams are generally 4 -5 members although one larger project team may have approximately 10 members. In previous years, students completed the House of Quality and were provided feedback through design reviews and evaluation of design reports. This intervention was applied during the first semester of the senior design sequence. Unlike in previous years, this intervention allocated a course period to each team to review and re-submit their House of Quality.

A brief review of the House of Quality was provided to students prior to completing their initial product. This was then submitted as part of an initial design report at the beginning of the conceptual design phase. One House of Quality was submitted per team and represents the requirements for the entire team [16]. Approximately one week after submission, one full lecture period was dedicated to revising the matrix. Each team was provided with a protocol providing instructions to review their House of Quality with the opportunity to revise and resubmit along with the template provided as Figure 1. All students were provided a short (5-10 minutes) lecture emphasizing the points in the protocol and were instructed to fill out the provided template in accordance with the protocol.

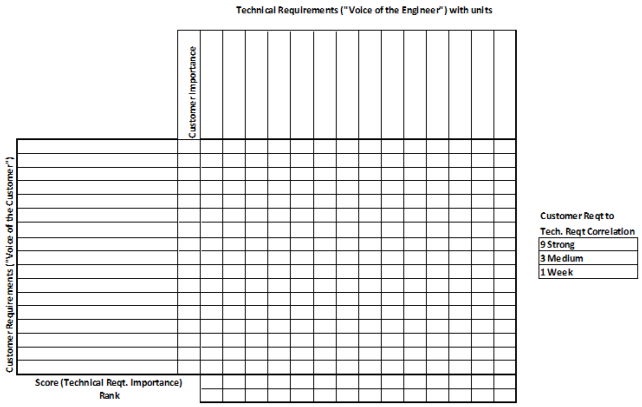

Figure 1. House of Quality template for exercise.

The protocol included as was based on a simplified version of the recommendations included in [17] and is provided as Figure 2.

House of Quality (QFD) Checklist

Review your original/current House of Quality and complete the template provided using the guidelines below. If the current HOQ meets these criteria, copy the original input.

(1) **Customer requirements**: Review your customer requirements and write in the provided template.

-Requirements should be presented in the customer's voice (as the customer would express them).

-Customers can include all phases of product lifecycle (can include production for example)

-Avoid requirements that are excessively broad (for example "ease of use" may mean both "easy to operate" and "easy to clean")

(2) **Technical requirements**: Review your technical requirements and write in the provided template.

-Technical requirements must be specified in measurable terms.

-Provide the associated units.

-For truly subjective requirements (appearance for example) designate a customer test (possibly a 1 to 10 customer rating). In this case, write CT (customer test) in the block

(3) **Customer importance**:

-Copy original importance weights unless they have been updated (additional survey results).

(4) **CR to TR correlation matrix**:

-Review correlations

-CR-TR matrix is usually 60% - 70 % blank as a general idea (every cell does not need to have a correlation.

(5) **Update the Technical Requirement Importance** Score at bottom of matrix.

(6) Be sure to **rank** in order of importance.

Submit your completed template (take a picture for your use).

Reference: M. Leary and C. Burvill (2007) *"Enhancing the Quality Function Deployment Conceptual Design Tool"*

Figure 2. Instruction sheet for reviewing and revising original House of Quality submissions.

Discussion

Quantity: Each original (Figure 3) and revised House of Quality was evaluated and recorded for the total number of customer and their derivative technical requirements. The quantity of technical requirements was then plotted versus the quantity of customer requirements. The original QFD matrix results are included as Figure 3. Out of ten teams participating, two teams recorded an increased number of customer requirements, while one recorded an increase in technical requirements. The plots show that the two lowest quantities of customer requirements were increased in the second iteration, raising the minimum of customer requirements and shifting the plot to the right. The average ratio of technical requirements to customer requirements is 1.1:1. This ratio increased slightly from 1.0 to 1.1 in the second House of Quality (not statistically significant).

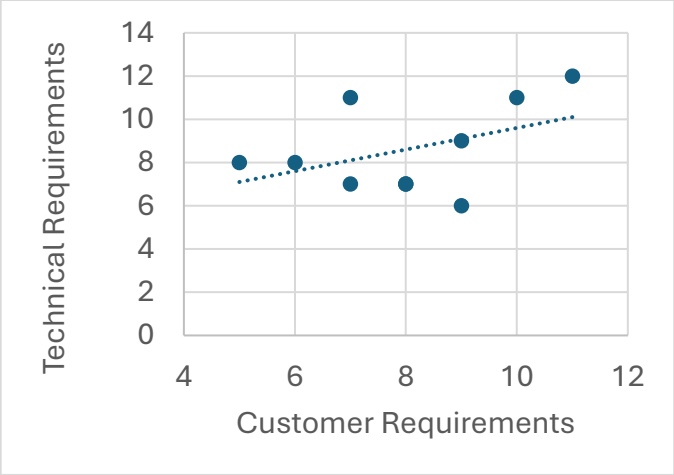

Figure 3. Number of Technical Requirements vs. number of Customer Requirements for original House of Quality.

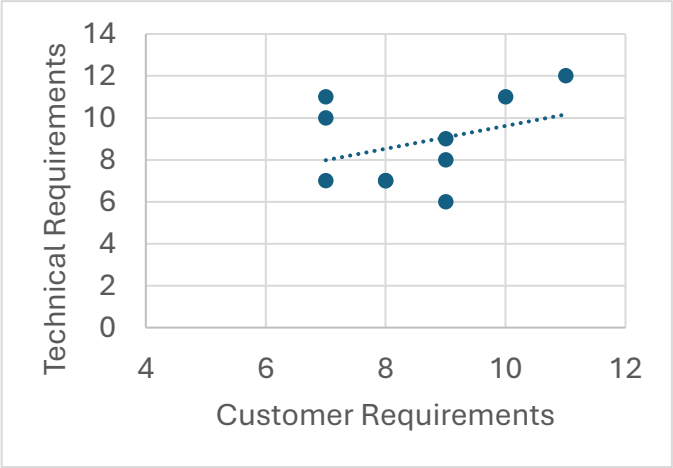

Figure 4. Number of Technical Requirements vs. Customer requirements for revised House of Quality after intervention.

Type: Many requirement changes did not result in an overall increase or decrease in the number of requirements. Requirement changes were also evaluated by type of change: add (+), remove (-), or modify (Mod). Of the ten participating teams, seven recorded changes. The requirements are summarized in Table 1. The greatest number of changes were additions, followed by modifications.

Table 1. Summary of team Customer Requirement (CR) and Technical Requirement (CR) and type (team numbers are randomly assigned).

	CR			TR		
	(+)	(-)	Mod	(+)	(-)	Mod
1			1			1
2						
3			1			
4						1
5				1	1	1
6	5	1	1			
7						
8						
9	2	1	1	3		
10				2		
Total Changes	7	2	4	6	1	3

Conclusions and Future Work

This paper addressed the development and implementation of an intervention to address requirements evolution in student engineering design projects through the use of the House of Quality. This is also intended to serve as an initial step to prepare for the implementation of further phases of Quality Function Deployment in the future and to explore their impact on requirements management in an engineering capstone course. Requirements changes were observed and categorized following the execution of a brief lecture and dissemination of an instruction sheet during a 50-minute class period. The majority of teams did modify some requirements with the most frequent types of change being additions and modifications. In most cases, the overall quantity of requirements was not changed, although it did increase the minimum number of requirements observed.

Future work will focus on the follow-on phases of Quality Function Deployment spanning the remainder of the design process. It can also address the quality of the requirements changes in addition to the quantity. Further studies could also address the impacts of team dynamics such as size, communication and leadership on the application of requirements tools and evolution [18], [19]. These studies would enable further assessment of the impact of QFD on requirements evolution in capstone product design.

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