

Implementation of the House of Quality as a Guiding Tool for Students and Faculty in Senior Capstone Design Courses

Ben Sherrett, John P Parmigiani
Oregon State University

How the House of Quality may be used to address several key issues facing capstone courses today is discussed. As an example, an overview of the implementation of the House of Quality in the Mechanical, Industrial, and Manufacturing Engineering Senior Capstone Design Course at Oregon State University is given. The information presented may be employed in a wide variety of capstone design course curriculums in an effort to enrich both the student and faculty experience.

Corresponding Author: John Parmigiani, parmigjo@engr.orst.edu

Introduction

Project-based senior capstone courses are commonly used at universities across the country to address criteria outlined by the Accreditation Board for Engineering and Technology (ABET). Providing students with the opportunity to apply tools learned in prior courses as they work to solve real-world, engineering problems is an important goal for these courses. However, the effective offering of this opportunity is far from simple. Some of the common capstone course issues encountered by Oregon State University (OSU) as well as other universities across the country are shown in table 1^{1,2}.

Table 1: Common issues in capstone courses with corresponding HoQ elements

Capstone Issue	HoQ Addresses by:
Difficult to assess quality of design products	Student team, project sponsor, and course instructor agree on the grade value of each project requirement, which can then be objectively measured
Students neither understand course requirements nor use them effectively to complete their project	The HoQ, created primarily by the students, provides an easy-to-understand contract describing project requirements
Grading difficult and time consuming for course instructor	HoQ provides a framework for straightforward, objective grading
Capstone experience does not feel authentic to students	Assessment based largely on students' ability to meet sponsor needs
Low sponsor satisfaction	Student course grade directly linked to meeting sponsor-approved project requirements

The House of Quality (HoQ) is currently being used to address these challenges at OSU in the School of Mechanical, Industrial, and Manufacturing Engineering (MIME). This paper will (i) give an overview of the capstone course structure at OSU MIME, (ii) provide a brief introduction to the HoQ, (iii) explain how HoQ is used in the OSU MIME course, and (iv) discuss using HoQ as an effective tool in any capstone program.

Overview of the OSU MIME Capstone Course

The capstone experience at OSU MIME occurs over two ten-week terms. Term one focuses on defining project requirements, performing a literature review, considering alternative design concepts, and fully specifying a complete design solution. Term two focuses on implementing the design solution (e.g. building a prototype), testing the implementation, and revising it to meet the requirements detailed in term one.

All undergraduate students in OSU MIME are required to complete the course prior to graduation; most take the course during their final year. Class size is typically 120 students with three students per capstone design team.

Approximately 40 projects are completed each year. Since each project includes an implementation (e.g. prototype build) funding is required. Project budgets vary from hundreds to tens-of-thousands of dollars. Project sources / sponsors are both external (industry, individuals, non-profits, government agencies, etc) and internal (faculty, university-affiliated programs, and administration) to OSU. Regardless of source, each project has a designated individual (referred to here as the sponsor mentor) who interacts directly with the student team to provide guidance and clarify requirements.

Customer Requirements	Weighting	Change Penalty	Engineering Requirements							
			Evaluation 1 Score	Evaluation 2 Score	Weight < 20 lbs	No sharp edges	No dimension > 12 "	AC of 110 V	AC of 60 Hz	Min. flow 10 in ³ /min after 1 sec
One person can carry	20			X	X	X				
Powered by standard US outlet	60						X	X		
Flow rate of 10 in ³ /min	30								X	
Flow rate ≤ 20 in ³ /min	35									X
Target (w/ Tolerance)			15 lb (+5/-15 lb)	-	10" (+2/-10")	110 (+/- 10V)	60 (+/- 0.5 Hz)	12 (>10) in ³ /min in 0.8 (<1) sec	17 (<20 in ³ /min)	
Testing Procedure			1	2	3	4	5	6	7	

Figure 1: A selected portion of a student group's HoQ (with weightings of only 145 of the 250 contained in a complete HoQ). An additional document detailing testing procedures, as noted in the "testing procedures" row, is also required in the full document.

In addition to the project sponsor, an OSU MIME faculty member is associated with each project as a technical reference (referred to here as a faculty advisor) for the student team. The faculty advisor's role is to provide guidance and technical expertise.

In addition to the HoQ, the OSU MIME course also makes use of more traditional capstone curriculum components such as oral and written reports, peer assessments, and several smaller written assignments on topics such as communication, goal setting, and ethics.

Overall, the OSU MIME capstone course structure appears to be a typical capstone program. Its characteristics placed among the two most common responses in thirteen out of fifteen relevant survey questions in a national survey of capstone course attributes published in 2006³.

Introduction to the HoQ

The HoQ is a component of Quality Function Deployment (QFD), a management tool commonly used in industry to align product attributes to consumer needs. The HoQ can be employed in a variety of ways, with the basic HoQ explicitly relating often qualitative customer needs (referred to as customer requirements or CR's) to measurable specifications (referred to as engineering requirements or ER's). The HoQ uses a matrix format to show this connection, mapping each CR to one or more ER. The HoQ also shows a weighted value associated with each CR to indicate its

relative importance as well as lists a target value and testing procedure associated with each ER⁴. The HoQ used in the course is a simplified version of the traditional house⁴, with added elements for change penalty and evaluation score. Figure 1 shows an example of a partial HoQ as used by a student group in the capstone course. While CR's and ER's vary per group, the structure shown in figure 1 is used by all groups.

HoQ in the Curriculum

OSU MIME students are first introduced to the HoQ during a junior year design course. During the capstone course it is presented very early in the first term, and used extensively throughout the two term project, accounting for approximately 20 percent of the term one grade and 50 percent of the term two grade. While students, of course, benefit from prior knowledge of the house, it is not required and HoQ can be readily implemented in a capstone course without students having had prior instruction. The specific use of the HoQ in a capstone course, using OSU MIME as an example, will now be described.

Term One

The HoQ is constructed during the first term of the two-term OSU MIME course. HoQ is presented in the second lecture, is explained in detail, and example houses are discussed. Following team formation and

project assignment, students begin step one of HoQ creation, listing the customer requirements. Students generate CR's by meeting directly with the project sponsor. The CR's are to encompass everything required in the project and be written using the terminology and vocabulary of the project sponsor. Associated with each CR is a weighting number indicating relative importance. In the OSU MIME course, the sum of all CR weightings is set to be 250 in order for easy fit into the grading structure (1000 pnts. possible each term). By week 3 (of 10) of the term, students are required to have a complete list of CR's, with weightings, approved by the sponsor mentor, faculty advisor, and course instructor. Each of these individuals has the responsibility to withhold approval if the student's submission is not appropriate for the project or the course. The HoQ is presented at this time, and at the following two steps, as a section in a written project update report.

The second step in the HoQ creation is to map each CR to measureable technical specifications, the ER's. While generation of the CR's involved team interaction primarily the sponsor mentor, ER creation is more likely to focus on interaction with the faculty advisor and course instructor. In addition to being measurable and technically specific, each ER is also required to have an associated target value with allowable tolerance (see figure 1 for examples). By week 6, a complete list of ER's with targets and tolerances is required. Again, sponsor mentor, faculty advisor, and course instructor approvals are needed.

The final step, occurring at the end of term one, is the addition of testing procedures for each ER. These procedures will form a key component in the second term course grading. As in previous steps, the format is that the students write the testing procedures and submit them to sponsor mentor, faculty advisor, and course instructor for approval. A fully approved HoQ (CR's, weightings, ER's, targets, tolerances, and testing procedures) is required for students to be enrolled in the second term of the course.

During term one, students are free to make changes to the HoQ as they see fit as long as all approvals are subsequently obtained. For example, when generating ER's, students may realize a change is needed to a previously-approved CR. Students are permitted to

make the change, subject to approval by the sponsor mentor, faculty advisor, and course instructor when the ER's are evaluated. Thus each round of approvals includes evaluation of new content as well as consideration of changes to previously-existing content.

A key aspect of this process is that the *students* have written the project requirements, specified their relative importance, and provided means of determining if they have been met. Students are told "you have both written the exam and provided the answer key for term two." As described below, the HoQ provides the means of objectively evaluating the student team's design implementation in term two.

Term Two

Students are given the first half of term two (5 weeks) to complete their design implementation (e.g. prototype build) to the point of being able to begin testing. Grading their success in achieving this goal is performed using the HoQ during evaluation one. Each testing procedure created during term one is considered individually against the prototype's ability to be tested. If *all* ER's that map to a given CR can be fully tested, then the weighting points associated with that CR are awarded to the team. The sum of all such awarded points is the student's score for evaluation one. In the OSU course, this evaluation corresponds to a possible 250 (of a course total 1000) grade points. Note students are not required to *pass* the tests at this time, but must be able to *execute* the test, per their plan from term one.

Evaluation two occurs at the end of term two. This evaluation uses the same scoring method as evaluation one with the same 250 point value, however students must *pass* the tests listed in their testing plan, within the tolerance specified in the HoQ, to receive credit.

During term two, occasionally students desire to make changes to their HoQ. Given the role the HoQ plays in term-two grading, changes, particularly to testing procedures, tolerances, and weightings, must be carefully considered. Evaluation of HoQ change requests in term two is via a petition process. The petition must be initiated by the students and contain (i) what the requested change is, (ii) why it is being made, (iii) how it will affect the project, (iv) what fault or negligence rests with the student team, and (v) comments and signatures of the sponsor mentor and

Table 2: The petition process; instructor action based situation

Instructor Action	Reason	Grade Penalty
Approve	No fault/negligence of student team-- original scope/intent of project remains intact	No penalty
Approve with penalty	Fault/negligence of student team-- original scope/intent of project remains intact	10% grade deduction per week on corresponding CR
Reject	Scope of project will become inappropriate/original intent of project altered	-

faculty advisor.

The course instructor evaluates the petition and either approves, approves and imposes a penalty, or rejects the request (see table 2). The criteria for the decision are based on student negligence or fault and effect on project scope. The penalty, if imposed, is calculated as a 10% per week deduction of the associated weighting value. For example, if a petition for HoQ change is submitted in week 2 and a penalty imposed, the maximum possible score for the associated CR is reduced by 20%.

HoQ as a Design Assessment Tool

A challenge facing the engineering capstone course community is the objective assessment of the quality of students' design products. A common response to this challenge is to decrease or eliminate the assessment of the *product* by putting a large emphasis on assessing the design *process*¹. The approach presented here links evaluation of the process and product by directly involving the students in the creation of the primary design evaluation metric, the HoQ. Students that carefully consider each of the elements of the HoQ during its creation are rewarded with an effective, concise, guide to completing their project successfully. Since the HoQ is directly linked to project requirements, as agreed upon by all involved parties, it eliminates the ambiguity associated with many of the more common assessment tools.

The HoQ also allows for an increase in grader objectivity due to weighted binary evaluation of each CR. While other methods of assessing design product quality rely on more subjective evaluations by instructors or sponsors¹, the assessment that occurs during evaluation one and evaluation two consists of simple, yes/no scoring.

HoQ as Student-Created Course Requirement

Another issue that often appears in capstone courses is the students' lack of understanding and appreciation of the course objectives. In fact, according to a survey of accredited engineering programs reported in 2004, only 7% of the respondents "believed their students referenced the objectives of the course to monitor their own performance"². The HoQ approach presented here directly links, for example, a primary course objective (successful execution of the design process) to a student created document.

HoQ as a Tool to Evaluate Ingenuity

While the HoQ may be directly applied to objectively assess whether or not the design process has yielded a product that meets the customer's core needs, it requires more effort to assess the creativity or ingenuity of a design. If a creative solution is a requirement of the

customer (or possibly a requirement of the capstone course in general), this creativity CR can be built into the HoQ. The challenge then arises in creating a measurable ER and testing procedure that corresponds to this ER. There are several ways to address this challenge. Surveying is one approach that has been used at OSU to measure subjective ER's. Student groups present their designs to an appropriate sample group and administer a survey. Another way to address this issue is a sponsor survey¹ or an industry/alumni panel. In these methods the sponsor, and/or an industry/alumni panel, are asked to rank the design regarding the subjective ER's (such as creativity, potential success in the marketplace). With either method, the student team is striving for a response from the evaluators that meets the target value(s) of the ER(s) associated with the creativity or ingenuity CR.

Conclusion

This paper presented a method for using the HoQ as a primary project management tool and design evaluation metric for capstone senior project courses. Although presented in the context of the OSU MIME course, we feel that this method can be added to any capstone course format to improve effectiveness in evaluating student designs; directly involve students in defining design requirements; simplify and remove subjectivity in grading; provide a more authentic, real-world design experience; and increase project sponsor satisfaction.

Since implementing this approach at OSU MIME, student capstone course achievement and satisfaction have increased significantly based on course evaluations and instructor perception. Correspondingly, sponsor project submissions have increased in quality and number. Future work is warranted to quantitatively analyze course evaluations, final reports, and sponsor surveys to further define the effects of the HoQ on the OSU capstone course.

Sources:

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