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Implementation of the House of Quality as a Tool to Assess Products of Design in a Capstone Design Course*

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While serving a vital role in the undergraduate curriculum, capstone design courses face a variety of challenges. These challenges include lack of student value & utilization of course objectives & assessment tools, sponsor retention & funding issues, and large instructional demands. Many of these challenges may be addressed by placing a larger and more genuine emphasis on assessing the product of the design project, not only the process by which the design occurs. Oregon State University's (OSU) Mechanical, Industrial, and Manufacturing Engineering capstone course currently organizes, manages, and evaluates capstone projects using the House of Quality (HoQ). In general, the HoQ is a tool used to relate project requirements to design performance specifications. Additionally, at OSU the HoQ serves as (i) a contract between students, sponsors, course instructors, and faculty advisers detailing exactly what is required from the design project, (ii) a guiding tool to allow students to self-monitor their progress throughout the course, and (iii) an objective means of evaluating the students' performance in terms of the product produced by their capstone design projects. This paper describes the OSU course, introduces the HoQ, and presents a time-line of the implementation of product assessment at OSU. Key changes are shown during the move from a purely process based assessment framework to the current state where 50% of total points in the design implementation term of the capstone course are awarded based on the student design team accomplishing design product metrics per sponsor defined design requirements. In addition, the authors report on the course instructor's perception regarding the effect of implementing the HoQ in the OSU capstone course. Finally, conclusions and implications of the work are presented.

Keywords: capstone design; product assessment; house of quality; quality function deployment

1. Introduction

Capstone courses serve an important role in engineering curricula across the country. These courses serve to address criteria outlined by the Accreditation Board for Engineering and Technology (ABET) and at a more fundamental level, serve to bridge the gap between the academic world that students have been operating in, and the industrial world in which many will soon enter [1]. An important goal for the capstone course is to provide students with the opportunity to apply tools learned in prior courses as they work to solve real-world, engineering problems. However, due to the complex nature of capstone courses, the effective offering of the capstone experience is far from simple. Challenges such as lack of sponsor support, high demand on instructors, and deficiencies in assessment devices are commonplace in many such courses [1–4]. The House of Quality (HoQ) has been implemented in the capstone course at the Oregon State University (OSU) School of Mechanical, Industrial, and Manufacturing Engineering (MIME) with the intent of addressing such challenges.

The purpose of this paper is to present a case study of what the authors feel is a novel implementation of an industry-developed design tool in the engineering capstone course setting. This paper will (i) discuss the roles and challenges associated with capstone courses both in general and specific to the OSU course, (ii) discuss the concept of transitioning from assessment of the process of design to the product of design, (iii) review the process of implementing the product assessment framework at OSU, (iv) introduce the House of Quality, (v) give an overview of the current OSU MIME course and the product assessment framework currently practiced, and finally (vi) discuss the course instructor's perception of the impact that the HoQ has had on the OSU course.

2. The role of the capstone course

While Accreditation Board of Engineering and Technology (ABET) accreditation is one of the primary roles served by the majority of capstone courses, the capstone course often serves many other roles in the engineering curriculum. One such role, one that is ubiquitous with the term 'capstone', is to offer an educational experience in which students can use content and concepts from prior courses to synthesize a solution to a genuine problem [1, 5]. This is useful both to ensure students graduating from a program have met minimum program requirements and to assess the educational

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experiences offered by the program prior to the capstone course [6].

Linking academia to industry is another essential task of the capstone course. This role is twofold in nature. First, capstone courses often strive to offer students authentic problems, similar to those problems that the students could encounter working in industry [7], while at the same time offering the instructional scaffolding and support that is found in the academic environment. Additionally, capstone courses serve to create and/or maintain relationships between the institution offering the course and the supporting industrial partners. When healthy, these relationships lead to job placement of graduates, sponsorship of department and university programs, clubs, etc., and continued support of capstone projects.

Unfortunately, pursuing the two roles mentioned above often presents conflicts for capstone course instructors. If a list of essential content covered in the undergraduate curriculum is to be addressed in the capstone course, a pre-conceived, well-planned, and consistent project (often the same for all student groups) is useful as these content areas can be built into the project statement. However, many authentic 'real-world' projects are not well planned, they do not have a 'check box' of engineering core principles that *must* be applied, and they vary in nature greatly from one to another. This is true especially in the field of mechanical and industrial engineering. This juxtaposition between roles can be difficult for capstone instructors as they must choose where to focus their class. Different disciplines lend themselves to a variety of approaches [8] but in general, Mechanical Engineering capstone courses tend to favor more open-ended projects often influenced heavily by industry. OSU MIME capstone course falls into this category. Students choose from a wide range of projects that each require a specific application of knowledge; be it thermodynamics and heat transfer for a micro channel radiator research project, kinematic design of linkages and dynamic modeling for a wave power generator, or control systems for a reconnaissance robotics project.

2.1 Common capstone course challenges

2.1.1 Sponsor support

While the distribution of capstone funding varies widely between institutions from no funding to large project budgets that exceed the $40,000 mark, 54 percent of the capstone instructors participating in a 2005 survey by Howe and Wilbarger reported project budgets at or below $500 [2]. Additionally, capstone instructors can find recruitment and retention of sponsors difficult, especially in programs that do not have an established sponsor base. Naturally, this challenge is magnified when capstone projects fail to provide useful products.

2.1.2 Instructor time

A recurring issue within the capstone community is the large amount of time required by instructors to implement the course [1]. The open-ended nature of capstone courses combined with an often lacking structure to guide student efforts on their design project can result in a sizable amount of instructor effort in managing student teams. Additional instructor time is spent recruiting and corresponding with sponsors in order to ensure a suitable number of projects that meet the needs of the capstone course regarding scope and nature are available to the students.

2.1.3 Standardizing the sponsored capstone experience

While this is not an issue for capstone courses offering the same project for all students/student groups, if a wide variety of projects are to be offered from multiple sources such as industry, private, and in-house sponsors, instructors must allocate a fair amount of time and energy into finding a way to make each project require a similar amount of student effort while at the same time assuring that the scope of the projects are indeed reasonable for the time allotted. As the diversity amongst projects offered by a single course widens, this task becomes more and more daunting.

2.1.4 Industry complaints with entry level engineers

It is a well-known fact that industry has numerous complaints regarding graduates of engineering programs. In an article featured in *Journal of Engineering Education*, Todd et al. outline several common complaints as reported by industry regarding entry level engineers. The authors then continue on to present the viewpoint that well-designed capstone courses can address these shortcomings in the undergraduate curriculum [9]. The list of weaknesses in entry level engineers below outlines key findings presented in the Todd et al. study [9] as relevant to this paper:

- A desire for complicated and 'high-tech' solutions
- To strong of a focus on analysis
- Little understanding of project engineering process
- Weak communication skills
- Underdeveloped teamwork skills
- No understanding of the quality process

When considering the contrasting roles of capstone courses presented in section 2.0 of this paper; the Todd study makes a strong case for offering capstone projects based on authentic, real-world design projects.

2.1.5 Frustrated students

The offering of authentic, real-world design challenges in capstone courses can often lead to ill-defined and open ended solution processes. Conversely, students entering capstone courses almost invariably have more experience, and thus are more comfortable, following rote solution processes that lead to one correct answer [10]. Curricular scaffolding by offering clear course objectives reinforced with straight-forward and authentic assessment practices is necessary to offer students the support they need in this often new and confusing problem space. Accomplishing this task is not easy however, as only seven percent of faculty surveyed in a US capstone assessment study felt that students understood and utilized course objectives to regulate their progress [3]. The survey, reported by Mckenzie et al., investigated assessment tools reported by capstone instructors. While the methods of assessment were found to vary between capstone programs, in general the scoring rubrics surveyed often "lacked clear performance criteria associated with the various levels of proficiency" [3]. In general, many capstone assessments seem to be subjective in nature and tend to focus on assessing the process followed by the student team while putting little if any weight on assessing the product(s) of the design process [1, 3, 4].

3. Challenges faced in the OSU MIME capstone course

The OSU MIME capstone course has been faced with many of the common capstone challenges listed above. Most notable, was the students' frequent failure to provide quality products to the sponsors of the capstone projects. This in turn led to frustration on behalf of both the sponsors and the course instructor. Sponsors were not receiving useful returns on their investments and the course instructor was spending a large amount of time managing student teams and recruiting new sponsors. The students' under-performance was facilitated by many factors. First, students could receive a perfect grade with a product that failed to meet any of the design specifications requested by the sponsor as 100 percent of the course grade came from design process evaluations such as oral progress reports, teamwork exercises, and written reports. If the product failed, the group could simply do a good job explaining *why* it failed and full credit was awarded. Students also felt confused and mislead. The completion of their senior capstone project, as embodied by a functional prototype, although expected, seemed to not be rewarded in a tangible way. Instead, all of the emphasis was put on following the correct processes, such as well constructed Gantt charts, good composition of presentations and reports, etc. While the task the students were given was authentic, the assessment of the task was not.

4. Changes made to the OSU MIME capstone course

Considering the above challenges and the potential benefit that could be derived by modifying assessment practices, the course instructor began exploring the concept of evaluating the products of the student design projects. Although it is a relatively straight-forward conclusion that increasing the portion of the course grade coming from product assessment will increase the quality of the product, there were other factors that were considered when making the transition to product assessment. First, simply requiring a product that met customer requirements would not have offered the support that many students needed to be successful under the new product assessment plan. A product assessment framework was needed that not only allowed for the objective assessment of products from a wide variety of authentic capstone design projects, but also afforded students the opportunity to self-monitor their progress as they moved forward in the design process. The House of Quality and two prototype-evaluation check points have been implemented at OSU to accomplish these objectives. Information regarding the HoQ as well as the framework implemented at OSU is presented in the following sections of this paper. Table 1 shows the timeline of implementation of the new product assessment framework, starting in 2004, the current instructor's first year teaching the course.

5. The house of quality

5.1 Introduction to the house of quality

Quality Function Deployment (QFD) is a management tool commonly used in industry to align product attributes (classified as 'Engineering Requirements' in this work) to consumer needs (Customer Requirements) [11]. At the heart of QFD is a matrix that explicitly relates these needs to attributes, this matrix is referred to as the House of Quality (HoQ). A simplified version of the HoQ can be seen in Table 2. The QFD methodology, developed in the 1960's, was first implemented in 1972 at Japan's Mitsubishi owned Kobe Shipyard [12]. Later in the 1970s Toyota used QFD to streamline their design process resulting in a 60 percent reduction in cost to bring a new car to market and

Table 1. A year by year account of changes in product assessment in the OSU MIME capstone course

Year	Change in product assessment
2004–05	Details of capstone deliverables are at the discretion of individual faculty advisors. No assessment of design product.
2005–06	All students must list project requirements. Assessment of meeting requirements is limited to a written discussion and constitutes 10% of the final report grade (4% of course grade). No penalty is incurred for not meeting requirements if a suitable explanation is provided.
2006–07	HoQ introduced (ERs and CRs in the matrix format). Two evaluations are instituted. In evaluation-1 the prototype must be built and be ready for testing. The evaluation-1 score is 25% of the course grade. In evaluation-2, the prototype *should* pass the ERs. Evaluation-2 occurs during a final, public, presentation at the end of the term and accounts for 10% of the course grade. However, as in the previous year, if ERs are not met, students can still receive full points if a suitable explanation is provided.
2007–08	The HoQ is expanded to include a testing plan for each ER. Evaluation-1 remains unchanged from 06–07. Evaluation-2 is also unchanged except that it now represents 15% of the course grade. Full credit may still be awarded to a design that falls short of ERs as long as adequate discussion follows.
2008–09	The HoQ is further expanded to include weighting for each ER. Evaluation-1, still comprising 25% of the course grade, remains a measure of the completeness of prototype construction and testability but is now scored via a simple summing of the corresponding weighting value for each testable ER and zero for each ER not testable. Evaluation-2, also now comprising 25% of the course grade, is conducted as a private oral exam. It is also scored via a simple summing of ER weightings, however tests must be passed. No credit is awarded for failing to meet ERs, regardless of explanation. However, a petition process is instituted to allow teams to make changes to their HoQ prior to evaluation-2.
2009–10	Weighting is shifted from ERs to CRs. In order to receive the weighting value of the CR in evaluation 1 / 2, the team must prove testability / pass tests for each associated ER.
2010–11	Pass/No pass (low technical effort) CRs are introduced. These CRs have no numerical weighting, but must be satisfied. They are associated with requirements that are necessary but have low technical difficulty (e.g. must paint prototype).

Table 2. An abbreviated HoQ as used in the OSU MIME capstone design course. An additional document detailing testing procedures, as noted in 'testing procedures' row, is also required

					Engineering Requirements						
Customer Requirements	**Weighting**	**Change Penalty**	**Evaluation 1 Score**	**Evaluation 2 Score**	Weight < 20 lbs	No sharp edges	No dimension > 12 in	AC of 110 V	AC of 60 Hz	Min. flow 10 in^3/min after 1 sec	Max flow 20 in^3/min
One person can easily carry across a room	20				X	X	X				
Powered by standard US residential wall outlet	60							X	X		
Flow rate of at least 10 in^3/min after 1 sec.	30									X	
Flow always ≤ 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

one-third reduction in development time, both while increasing product quality [11]. The QFD and the HoQ found their way into prominent US businesses such as Ford, AT&T, Bell Labs, and Hewlett-Packard [12] and in 1988, Hauser and Clausing authored the seminal US QFD paper, 'The House of Quality' [11]. The paper appeared in the Harvard Business Review and touted the widespread and effective use of the HoQ. Furthermore, it provided a clear description of the implementation process behind the tool. Since this introduction in the 1980s, the knowledge and use of the QFD approach has continued to spread. According to a survey reported in the Ullman design text, of 150 US companies surveyed, 69% use QFD, with 83% feeling that it increased customer satisfaction [13, 14].

Further proof of the wide scale acceptance of QFD is found by its presence in many of the widely read texts on design [13, 15–18]. All of these texts present QFD and HoQ as an effective means of defining the design problem as well as guiding designer resources. For further information on HoQ and QFD, many handbooks exist exploring the topic in greater detail. For example, Bossert outlines the benefits of QFD implementation in his book *Quality Function Deployment; A Practitioner's Approach*. According to Bossert, the QFD approach promotes focus of the designer's efforts on the customer's requirements, streamlines the design process by decreases midstream design changes, promotes communication and consensus between parties at stake, and promotes structured documentation of the design process [19]. Capstone courses could clearly benefit from such effects.

Although much literature exists on the positive attributes of the QFD approach, it is also important to note that not all aspects of the QFD approach are unanimously favored. Key issues include difficulty implementing the complex nature of the full QFD approach in cross-functional teams (there are four 'house' matrices in the full QFD model) [14] as well as difficulties in accurately representing the customer requirements for large and diverse markets. By selectively using small components of the full QFD model on projects with only one 'customer', OSU has not witnessed such difficulties.

5.2 HoQ for use in the capstone course

Given the established presence of HoQ in industry, coupled with the desire for capstone courses to provide real-world experiences to students, it should not be surprising that it can be an effective educational tool in the capstone setting. However, industrial HoQ implementations can be complicated, so as formerly mentioned, it is important to properly focus and refine the house for academic use. In the OSU MIME capstone course, the following common HoQ components are used: (i) A matrix mapping often qualitative customer needs (referred to as customer requirements or CRs) to one or more measurable specifications (referred to as engineering requirements or ERs), (ii) a weighting value associated with each CR to indicate relative importance and guide the students' use of resources, (iii) target values and tolerances for each ER (indicating design-to and limiting values respectively), and (iv) testing procedures associated with each ER, giving the students clear, objective, criteria that must be met. An abridged OSU MIME capstone HoQ, as created by a student team, can be seen in Table 2. As described above, this is a simplified version of the traditional house, emphasizing the needs of the course. Notice the matrix format connecting the qualitative CRs to the quantitative and testable ERs. Also note that the weightings associated with each CR. In an unabridged OSU capstone HoQ, the CR weightings would sum to 250 points. The change penalty and evaluation scores are course specific HoQ elements that have been added and will be described below.

6. The OSU MIME capstone course

6.1 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 and product evaluation criteria (CRs, weightings, ERs, targets & tolerances, and testing procedures), performing a literature review, considering alternative design concepts, and fully specifying a complete design solution. The second term 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, yielding approximately 40 projects completed each year. Since each project includes an implementation stage resulting in a final product (e.g. prototype build), funding is required. Project budgets vary from hundreds to tens-of-thousands of dollars. Project sources/sponsors are approximately two-thirds external (industry, individuals, non-profits, government agencies, etc) and one-third internal (faculty, university-affiliated programs, and administration) to OSU. Regardless of the source, each project has several commonalities: First, every project sponsor requires a deliverable, or product of the design process, at the end of the course. Second, 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. Third, each project is reviewed first by the course instructor at the macro level and later by an OSU MIME faculty advisor at the micro level to ensure the scope of the project is suitable. Additionally, the faculty advisor's role is to provide guidance and technical expertise as well as grade progress reports and the final report of their associated student team. The HoQ must include approval signatures from the sponsor mentor, faculty advisor, and course instructor. This ensures that the sponsor is receiving what they want, within reason, while the student groups are all held to reasonably the same standard regarding project difficulty.

Besides 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 represent the typical capstone course in the US. Its characteristics placed among the two most common responses in thirteen out of fifteen relevant survey questions in a US survey of capstone course attributes published in 2006 [2].

6.2 House of quality in the current OSU MIME curriculum

OSU MIME students are introduced to the HoQ during a junior-year design course. During the capstone course, the QFD approach is reviewed very early in the first term. While students naturally benefit from prior knowledge of the HoQ, it is not required and the HoQ, as used in the OSU course, can be readily implemented in a capstone course without students having had prior QFD instruction. The specific implementation of the HoQ in the current OSU MIME course will now be described.

6.2.1 Term one

The HoQ is constructed during the first term of the two-term OSU MIME course. It is presented in the second lecture, is explained in detail, and example HoQ's are discussed. Following team formation and project assignment, students begin the first step of HoQ creation; listing the customer requirements. Students generate CRs by meeting directly with the project sponsor mentor. In this way, the HoQ facilitates open and rich discussion between the student design teams and the sponsor mentors. The CRs are to encompass everything required in the project and should be written using the terminology and vocabulary of the project sponsor. A weighting number indicating relative importance is associated with most CRs. However, CRs that involve low technical difficulty (e.g. painting of prototype) receive a zero weight and are required to be met in order for course credit to be awarded. In the OSU MIME course, the sum of all CR weightings is 250, allowing for easy integration of point values during evaluation one and two in the second term of the course as explained below. By week 3 (of 10) of the term, students are required to have a complete list of CRs, 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 second step in the HoQ creation is to map each CR to measureable technical specifications, the engineering requirements. While generation of the CRs involved team interaction primarily with 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 Table 2 for examples). The target value is the 'design-to' value; the quantity students are to use in calculations, for example, to size components. The tolerance is the maximum deviation from the target value permitted. By week 6, a complete list of ERs with targets and tolerances is required. Again, sponsor mentor, faculty advisor, and course instructor approvals are needed. In this way, in addition to efforts made by the capstone instructor when selecting projects for the course, the level of technical difficulty required by each project can be somewhat standardized through this approval process. 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 of the prototype evaluations performed in the second term. As in previous steps, the students write the testing procedures and submit them to sponsor mentor, faculty advisor, and course instructor for approval. A fully approved HoQ (CRs, weightings, ERs, 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 ERs, 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 ERs are submitted. 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 teams' product of design in term two.

6.2.2 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. Evaluation of the students' success in achieving this goal is performed using the HoQ during an assessment termed 'evaluation one'. During evaluation one, students demonstrate to the course instructor the testability of their prototype per testing procedures outlined in the HoQ. For each testing procedure that is able to be completed, credit is given for the associated ER. If *all* ERs that map to a CR can be fully tested, then the weighting points associated with that CR are awarded to the team. Due to this assessment approach, the grading is objective as well as straight forward for the instructor, either the prototype is testable according to the specified testing procedures, or it is not. The sum of all such awarded points is the student team's score for evaluation one. 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 one assists students in overcoming the novice designer's expectation that a prototype will work exactly as expected upon completion the first time. In this way, evaluation one allows time for the iterative nature of the design process to be experienced by the student teams.

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, during evaluation two, students must *pass* the tests, within the tolerance specified in the HoQ, to receive credit. It should be noted that the combined point value from assessments of the design product using the HoQ equals 500 of 1000 total, with 250 points available at each of the two evaluations.

During term two, occasionally students desire to make changes to their HoQ. Given the large role the HoQ plays in term-two grading, changes (particularly to testing procedures, tolerances, and weightings) must be carefully considered. Evaluation of student team requests to change elements of their HoQ 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) why the change wasn't made earlier. Also required are comments and signatures of the sponsor mentor and faculty advisor.

The course instructor then evaluates the petition and either approves, approves and imposes a grade penalty, or rejects the request (see Table 3). The criteria for the decision are based on student negligence or fault and effect on project scope. The penalty, if imposed, is at the instructor's discretion but a guideline of a 10% per week deduction of the associated customer requirement weighting value is often used. For example, if a petition for HoQ change is submitted in week 2 and the standard penalty imposed, the maximum possible score in subsequent evaluations for the associated CR is reduced by 20%.

7. Perceived effects of implementation of the HoQ

The instructor teaching the OSU MIME capstone course has noticed several improvements since implementing the HoQ design product assessment framework. Such instructor perceived effects are discussed in this section. Although instructor perception is a common means of reporting capstone course success in the literature [1], caution should be exercised when interpreting the following discussion as more objective and quantitative research is needed to fully understand the impact that the

Table 3. The petition process; instructor action based on 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.	—

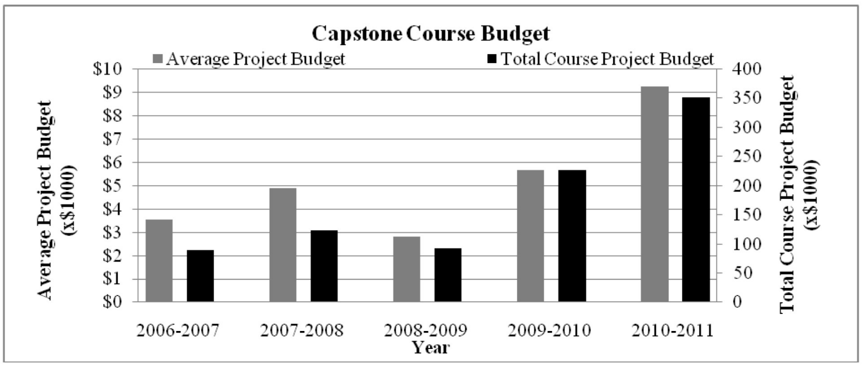

Fig. 1. Average project budgets and total capstone course project budgets over the product assessment implementation period in the OSU MIME.

Table 4. Issues faced in the OSU MIME capstone course with corresponding solutions afforded by the HoQ framework

Capstone Issue	HoQ solution
Difficult to assess quality of design products	Student team, project sponsor, and course instructor agree on the grade value of each project requirement, which is 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.
Managing teams and grading difficult and time consuming for course instructor.	HoQ provides straightforward, objective grading
Capstone experience/grading does not feel authentic to students.	Assessment based largely on students' ability to meet project requirements.
Low sponsor satisfaction.	Student course grade directly linked to meeting sponsor-approved project requirements.

HoQ assessment framework has had on the OSU MIME capstone course.

One indicator of the potential success of the HoQ framework is the relative effort required on the part of the course instructor to collect an appropriate number of projects for the course. In 2004–2005, assembling the project list required significant effort and time for the course instructor. In each subsequent year, project acquisition required less effort. By 2010–2011, project submissions exceeded class capacity and the instructor was able to spend time choosing the most suitable projects for the capstone course from the list of submissions. Along with an increase in submissions, came an overall increase in funding during the period of HoQ implementation. Figure 1 shows sponsor funding of the capstone course from the 2006–2007 academic year to the 2010–2011 academic year.

A second perception of the course instructor suggesting a positive impact of the HoQ framework is a decrease in instructor time spent pushing teams toward completion of projects. The instructor still dedicates a sizable amount of time to interacting with students. However, this time is now allocated in a predictable and structured way per the HoQ check points in term one and the prototype evaluations in term two. Further course issues addressed according to instructor perception at OSU through the implementation of product assessment and the HoQ can be seen in Table 4.

8. Conclusion and future work

The primary goal of this paper was to present a method for using the HoQ as a project management tool and design evaluation metric for senior capstone design courses. Although presented in the context of the OSU MIME course, it is the authors' opinion that this method may be implemented in a variety of engineering capstone course formats. At the fundamental level, the HoQ as presented in this work (i) directly involves students and sponsors in defining design requirements, (ii) affords students a large role in constructing and interacting with a management tool that will later be used to assess their performance, and (iii) provides instructors with an objective framework to assess a variety of different design projects. Effects of implementing the HoQ have been perceived by the course instructor as positive but further analysis of the OSU MIME capstone course is needed to fully characterize the impact that the HoQ has had. Such work is currently in progress.

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