Measuring Innovation and Creative Content in Course Content and Learning Effectiveness: A Case Study with QFD

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ABSTRACT

The theory of knowledge on concepts or CK design theory describes creativity as a design conceptualization independent of other design areas. It represents innovation, creation, and discovery within the design process framework. Engineering design requires creative skills. This article presents a “Quality Function Deployment” method for constructing “Engineering Design and Creativity” courses with appropriate pedagogical elements for second-year engineering students. The course structure has features of creativity, engineering design, and knowledge of prototype development. The results validate that the QFD course design methodology integrates the learning outcome with the assessment methodologies, learning processes, and knowledge elements. The course development methodology, as suggested, minimizes learning deficiencies. Measurement of course and student outcomes (COs and SOs) identifies the shortcomings and pedagogies supporting learning outcomes. For example, the students are deficient initially in defining an appropriate innovative project. Also, at the initial stage, the students face difficulty in team dynamics. To improve and design the course for diverse student backgrounds, we provide special sessions with expert faculty members and counseling to manage conflict of group interest. Data over three semesters are analyzed, and six learning stages are structured with rigorous follow-up to develop an innovative startup project.

KEYWORDS

Course Design, Flip Class, Learning Outcome, Learning Resources, Pedagogy, QFD, Student Center

1 INTRODUCTION

A creative idea is a concept or a proposition with out of box thinking and is a logical status for a design process. Without creative idea or concept, the design is a standard problem-solving or optimization method. Creative ideas explore unknown design that contains characteristics and features anticipated by both designer and end users. Creativity is not searched or explored but formation of a concept (Hatchuel and Weil, 2009). Design by reasoning is the logic of a creative process that conceives the idea of building unknown objects. Creativity is derived from systematic design, axiomatic design, creativity theories, and artificial intelligence. The concept-knowledge theory or C-K design theory advocates the theory of reasoning so far as design is concerned. The C-K design theory explains
that creativity is the conceptualization of design that is independent of any other design domain. It explains innovation, creation, and discovery within the framework of design processes. Creativity is an integral part of engineering design (Hubka, and Eder, 1996; Pahl and Beitz, 1996; Ullman, 2003). Hatchuel and Weil, 2009; suggest that design involves creativity. Innovation through creativity is important in technology, engineering, business and industry (Kelley and Littman, 2005; Mahle, 2007). These arguments set a policy that creativity, innovation and design should be an essential part of engineering education and an important student outcome (Vision 2030, National Transformation Plan of the Kingdom of Saudi Arabia).

Faculty of Engineering at the Islamic University, Madinah integrated the “Creativity and Engineering Design” course into its engineering curriculum. The course introduces the student engineering design, creative problem-solving techniques, teamwork, brainstorming, project planning, economic cost analysis, environmental impact, proposal, report writing, presentation skills, investigation and research for design and development. The engineering skill sets include reverse engineering, design of structural/mechanical/electrical/pneumatic systems, different testing and evaluation methods, manufacturing techniques in engineering, human factors in engineering design. Students are expected to design a civil/ electrical/ mechanical system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability in a team spirit and eventually present their design in front of an audience consisting of faculty and students.

The course is comprises with theory and laboratory work. It is a semester-long course involving 18 weeks of Lab and theory work. Depending on the innovative design product, the Lab work varies. Students use 3D printing facility, which is available to all undergraduate students. The Lab facilities are available to all the students. The students are financed for this project up to a limit of $ (USD) 200.00. Additional funds are made available, through a review process, to the students if a creativity and engineering design project is selected for competition.

The National Transformation Program (“NTP”) of the Kingdom of Saudi Arabia sets out an ambitious plan to reform education (www.vision 2030. gov. sa). The NTP is derived from Saudi Arabia’s “Vision 2030” strategic plan, which is a roadmap for the Kingdom of Saudi Arabia about its development, economic transformation with a diversified economy for the next 15 years. The success of the Vision 2030 requires the education system to generate employment of young Saudis. In the education sector, the transformation process will require to maintain a modern curriculum focused on rigorous standards in numerical competence, professional skills, literacy, and ethical standards. The vision 2030 advocates in taking advantage of the country’s demographic dividend by expanding entrepreneurship and enterprise opportunities for both male and female. The strategic educational objectives of the “vision 2030” and the national transformation program emanating from this initiative are likely to focus on (www.vision 2030. gov. sa):

i) best practices in recruitment, training, and development of educators in Saudi Arabia
ii) improvement of the learning environment and stimulate innovation through creativity
iii) improve curricula and teaching methods
iv) improve ethical values and core skills
v) develop strategically fit project financing methods and practice financial efficiency
vi) train students to understand the national development program and fit into skilled based market demands
vii) engage private sector involvement in the education sector.

The skills taught in a course needs to evolve continuously by keeping pace with the Kingdom of Saudi Arabia’s progress. The skills refer to higher levels of knowledge, agile skills/ knowledge, and the ability to adapt to the rapidly changing technological skills need in the Kingdom. The general engineering curriculum is highly applied in nature and as such the graduates of the engineering
program is expected to demonstrate employability when the economy is functional and become a productive workforce by further enhancing technical skills as lifelong learning. In the context of balanced scorecard philosophy (Kaplan and Norton, 1996), this is a leading indicator and is a self-sustaining strategy for continuous improved within the given set of constraints through input optimization and continual evolution.

1.1 Purpose and Research Questions:

Identify and explore the society’s requirements of education service quality and how the customer (student) needs to comply in designing an “engineering design and creativity course” within the engineering curriculum. The following research problems are listed to address these issues:

1) What are the industry requirements for creative courses?
2) How the curriculum of an institution satisfies the external stakeholders?
3) What innovation characteristics are associated with industry requirements?
4) Identify and prioritize the innovation characteristics to design the course.
5) Identify performance indicators (course learning and student outcomes) in creativity in engineering design courses.
6) Develop a methodology to create a core course within the curriculum using Quality Function Deployment (QFD) matching the 2030 strategy of the country.
7) Identify the critical elements of pedagogy in designing “creativity in engineering course.”

Creativity and innovation skills for engineering graduates are necessary for developed economies. Methodologies to solve problem needs creative insights to find appropriate solutions. Industries are looking for skilled engineers with various skillsets to introduce creativity and competitive advantage. Creative skills produce unique ideas, and innovation is the strategy to implement creativity problem-solving process. Later or vertical thinking introduces a new solution or a new idea, solution, product, or process. Creativity and innovation is the path to success for the business. Therefore, the country prioritizes developing a course with skills sets in innovation and creativity.

1.1 Background Information

According to the US education pattern, a sophomore is a second-year student of a four-year engineering curriculum. In the 2016 academic year, the recent course is combined into a single course of three credit hours from two courses of each two credits hours. The new course restructures 25% credit hours in the current course compared to the previous credit hours while maintaining the same course outcome and course content. The course is taught for over four semesters in the newly established engineering faculty.

The course activates the entry-level engineering student’s mind to explore engineering through innovation. Students’ creativity and innovative ideas help undertake a practical but straightforward engineering project. The steps to be followed by the students in this course is a roadmap towards innovation. Furthermore, the engineering design and creativity course will help students foresee the major they will finally choose.

To cultivate the creativity of the entry-level engineering students, the course participants ideally select a project of their own through several brainstorming sessions with the formation of a cohesive team. Then, the course instructors, including lab instructors, guide and coach them to incubate the students’ ideas. Therefore, the students are encouraged to come up with their idea. In an extreme situation, if any student group cannot identify an appropriate or feasible project, the faculty member steps in to customize a project that they are unclear about or guide them with a predefined task.

Usually, a small grant is made available to the students from the engineering school. A screening committee reviews the projects to screen the feasibility of a design project. Table 1a is the rubric to judge the quality of a project proposal. The students are present in front of the screening committee
before the project rolls on actually. The role of the Engineering Design and Creativity project screening committee is to create an atmosphere where students can comfortably accomplish the significant task in a given time frame of sixteen weeks. The final projects are assessed through a separate screening committee. The successful projects qualify for national-level competition. Disruptive technologies are putting enterprises to stay competitive (Christensen et al., 2015). Businesses and industries must develop better ideas to innovate their goods and services to sustain themselves in the marketplace. This creativity and innovation course works in an interdisciplinary team mode to find innovative ways to improve processes, products, and services. This course offers students a chance to become familiar with the innovation process. The Faculty of Engineering supports students in preparing design projects for national competitions. At least 10% of the projects have the potential to be patented. The innovative ideas are embedded in this course through the projects. Some examples of the projects are shown later in other sections of this paper. The engineering school is just under six years of operations, offering undergraduate degrees in engineering. Two new M.Sc programs are operating from 2019.

The organization of this research article first describes the rationale and outcome of this design course design. Next, we present the literature review on engineering course design with specific learning outcomes, followed by the quality engineering methodology applied to develop and improve the course design. Finally, this section shows the application of the methods in real-life course design at the faculty of engineering and the necessary resources to run the course. The data collection method and hypothesized course design issues are discussed next. Then, emphasis is given to the reasoning behind the learning methodology, course delivery method, and its management. After that, we comprehensively analyze the results derived from the data collected over semester-long durations. Finally, we present conclusions and recommendations for engineering design and creativity courses.

All students must design and fabricate a working model in the engineering design and creativity course. The project is semester-long. The students in class and evaluations present the project ideas are based on predefined rubrics as listed next. A “Screening Committee” at the early stage of the proposal writing provides feedback so that the students can comfortably accomplish the significant task in a semester-long time. Some of the potential projects will stage for the national competition. The course grading depends on the creative project and theoretical coursework. The course grading rubric is shown in the following section. Exams are two hours long, and theory-based questions do not contain multiple-choice questions or fill the blanks. Exams are a closed book and comprehensive. All assessments are summarized to map and measure the ABET students’ outcomes (www.abet.org). The course mapping captures learning outcomes through consolidated incremental learning outcomes.

### Table 1a. Assessment scheme, assessment tools, and macro-level rubrics

| Course Assessment Method | Percentage (%) | Due Date | Week |
|--------------------------|----------------|----------|------|
| Final Exam: Comprehensive | 100 | 6-May-19 | 16-18 |
| Midterm Exam 2: Chapters 6, 9, 10, 11 & 12 | 15 | 15-May-19 | 14-16 |
| Midterm Exam 1: Chapters 3, 4, 5, 7, Project Planning, Economic Cost Analysis, Environmental Impact, Proposal Writing, Final Report Writing, Presentation Skills | 15 | 8-May-19 | 6-10 |
| Project Proposal | 12 | 13-Apr-19 | 7-9 |
| Project Proposal | 12 | 10-Apr-19 | 6-8 |
| Project Proposal | 12 | 7-Apr-19 | 5-7 |
| Project Proposal | 12 | 4-Apr-19 | 4-6 |
| Project Proposal | 12 | 1-Apr-19 | 3-5 |
| Proposal Writing | 15 | 15-May-19 | 14-16 |
| Proposal Writing | 15 | 8-May-19 | 6-10 |
| Proposal Writing | 15 | 1-May-19 | 4-6 |
| Proposal Writing | 15 | 25-Mar-19 | 3-5 |
| Proposition | 15 | 15-May-19 | 14-16 |
| Proposition | 15 | 8-May-19 | 6-10 |
| Proposition | 15 | 1-May-19 | 4-6 |
| Proposition | 15 | 25-Mar-19 | 3-5 |
| Proposition | 15 | 15-May-19 | 14-16 |
| Proposition | 15 | 8-May-19 | 6-10 |
| Proposition | 15 | 1-May-19 | 4-6 |
| Proposition | 15 | 25-Mar-19 | 3-5 |
This gradual learning correlates to course outcome (Table 4.2). Usually, a variety of learning outcome instruments map the ABET student outcomes.

Table 1c illustrates the assessment tools over a semester of 18 weeks. These are summative assessments and formative assessments integrated within this assessment method. The figure lists the course outcomes denoted as CO1, CO2, CO3, ……, CO13.

Table 1b. Creativity and Design project presentation and model demonstration assessment rubric

| CONTENTS | (L)–Leader | (R)–Reporter | (M)–Member |
|----------|-------------|--------------|------------|
| INTRODUCTION | 10 | 10 | 10 | 10 |
| LITERATURE SURVEY | 10 | 10 | 10 | 10 |
| METHOD OF SOLUTION | 20 | 20 | 20 | 20 |
| RESULTS & CONCLUSIONS | 20 | 20 | 20 | 20 |
| TEAMWORK | 10 | 10 | 10 | 10 |
| PROCESS OF PRESENTATION | 10 | 10 | 10 | 10 |
| PART III | 20 | 20 | 20 | 20 |
| Total | 100 | 100 | 100 | 100 |

Name, Family Name of Jury Member: ____________________________

Date: ______________ Signature: ____________________________

Rubric: Final project presentation
Assessment: Individual presentation & individual work done in a project
1. Total presentation per group = 20 minutes
2. 15 minutes presentation & 5 minutes question-answer
3. Each member is to present
4. Each group needs to design/organize/plans/presentation as per the attached guidelines
5. Each group need to demonstrate the final project as planned and reported (Working Model)
2 LITERATURE REVIEW

Quality is a complex, dynamic and multifaceted concept in higher education (Rahorjo, et al, 2007). It defines what is lacking rather than highlight complacency by its contents. It reflects national, regional and global socio-economic, cultural and ethical visions.

2.1 Role of Quality Function Deployment in Course Design

We use the QFD to enhance and improve learning outcome and quality (Pittman et al., 1996; Lam and Zhao, 1998; Hauser and Clausing; 1998; Terninko, 1997). Originally it was used in the manufacturing industry to improve product design by Yoji Akao in Japan in 1966. It is a “method to transform qualitative user demands into quantitative parameters, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process” (Kao, 1990; Akao and Yoji, 1990). He also combined the quality conformance, quality control and QFD in value engineering. QFD is a systematic method to increase the value of a product and or service by a value function either by less expensive alternatives method, material, improvement of product or service functionality without compromising the performance of the product or service rather than physical attributes (Bier and Cornesky, 2001; Cornesky, 1997). A working definition will be the ratio of characteristics function to cost. The value can, therefore, be increased by either improving the function or reducing the cost. The concept is correlated with Taguchi, 1966. The value engineering is a primary principle where the basic functions of a product or service are upheld but not reduced as a result of carrying out value engineering improvements. Taguchi philosophy advocates that quality suffers from poor design of product or process, while quality improvement is accomplished by utilizing quality loss function, quality robustness and target oriented quality. Robustness signifies uniformity in the design process to meet the customer expectation. This concept is related to six-sigma and process is expected to be controlled tightly to avoid deviations from the target value. Our course design aims to minimize learning defects. The quality loss function is mathematically described as:

\[ L = D^2C \]  

Where, \( L \) = Loss ($); \( D^2 \) = Deviation (Square of distance from targeted value or quality); \( C \) = Cost of deviation at the specification limit (Heizer & Render, 2008).

The promise of QFD in learning and course design is multifaceted (Bier and Cornesky, 2001; Cornesky, 1997). This methodology characterizes features, attributes, or functions that enhance learning quality when used in the context as service improvement (Chou, 2004; Akao, 1990). It is helpful in answering questions as to how to deliver quality learning experience based on the needs of the students, society, or the voices of stakeholders (VOS). Even though the quality principles are compatible with the values of higher education, but often the culture must change to support these principles (Akao, 1990; Sahney et al, 2003). For the culture to change the educators need to embrace the future trends. Consequently, modifying teaching methods, redesigning the course structure, restructuring the faculty composition would be equivalent to revising the pedagogical qualities, manners of delivery and benchmark the practices (Denton et al, 2005; Aytac et al, 2005; Duffuaa et al, 2003; Franceschini and Terzago, 1998). The key purpose of QFD is to try to ensure that the eventual
design of a learning outcome meets the needs of the stakeholders. We define the relationship between student learning needs and find a college’s ability to support the learning process.

Our case study shows QFD philosophy in designing creativity course for an engineering curriculum. This extension of the QFD application will examine the views of educators, administrators, students, and other stakeholders to incorporate the voices of diverse stakeholders in designing the course structure. This is important as the school is responsible for educating the students for the local communities, pursuing higher studies and serves the community at large. The course design methodology includes rigorous control of instructional quality for a diverse spectrum of course instructors in order to maintain the consistent level of course outcome objectives by infusing necessary tools and techniques for achieving course outcome through various assessments in course design (Hwarng, 2001). This is validated with the QFD methodology with embedding quality in all aspects of course design beginning with a building phase and ending in a continuous improvement process. A pilot study is presented in order to illustrate the suitability and realistic utility of the methodology.

2.2 Quality Methodology Applications in Education

At the West Virginia University, Jaraiedi and Ritz (1994) applied QFD to improve the quality of education. Several course design requirements were proposed in order to fulfill the demands of student expectations. Wiklund and Wiklund (1999) applied QFD to adjust student learning at the Lulea University of Technology in Sweden. Multiple characteristics of a graduate course in quality technology were developed using QFD matrix. They extended the application with a conjoint analysis, a multivariate statistical method to identify the dominant factors that will improve student’s individual learning.

Hwarng and Teo (2001) designed a process and operations management course at the National University of Singapore with the help of QFD. They developed three cascading houses of Quality (HOQ) to link key operations management topics and process management. They used this methodology for staff research grant application in designing and delivery mechanism of course. Sahney et al. (2003, 2004) applied QFD to enrich the quality education in an Indian university. They used one QFD to link “student requirements” and “design characteristics” by identifying interrelationship between the design characteristics and student requirements with a minimum set of design characteristics for a course. Duffuaa et al. (2003) applied QFD to design a basic statistics course at the KFUPM, Saudi Arabia. They identified alternative course design to satisfy the learning outcome. Chou (2004) utilized QFD to assess the quality of nursing education in Taiwan. In Turkey, Aytac and Deniz (2005) addressed the curriculum design dilemma for the Kocaeli University Köseköy’s vocational school of higher education with QFD. They developed a method for assigning importance ratings of “student requirements” and identified several quality characteristics of courses based on the student expectations. Denton et al. (2005) proposed QFD to design course and curriculum in the areas of management information systems. Sagnak et al, (2017) suggested using QFD in business school to improve the quality of education in a business school. Recently, Rodriguez et al, (2018) identify quality characterizes of higher education with multivariate data analysis. They used principal components analysis to identify 25 quality indicators fall under “people empowerment” and “continuous quality improvement” while the second principal component consisted of 24 quality indicators that fall under “leadership committment” and “stakeholder satisfaction”. Weerasinghe and Fernando (2018) offer a conceptual framework for measuring student satisfaction levels in a national higher education system in a developing region where tertiary education is free. Five recommendations are provided for policymakers. The quality of the academic staff, university facilities, degree program, administrative staff, university location, and university image have been correlated significantly with student satisfaction levels. Thakkar, Deshmukh, and Shastree, (2006), explore the role of TQM and QFD in self-financed technical institutions in the light of new demands and challenges posed by customers, students, and society. They identify technical and students’ requirements for the modern educational set-up, the need for continuous improvement, cultural change and effective use of financial resources.
to improve the value addition at each level. Jaraiedi and Ritz, (1994), used QFD tool to explore the requirements of university students as the primary customers. The interviews of faculty members and administrators were used to define “the voice of the customer. They recommend the comprehensive instructor-training programme to self-help and mentor programmes by student groups.

3 RESEARCH METHODOLOGIES

KSA’s Vision 2030 is a 15-year economic plan introduced to diversify its economy from dependence on hydrocarbons to a knowledge-based economy. This vision sets the country’s goals and guidelines to achieve by 2030. The vision aspires to transform KSA into a dynamic society, thriving economy, and ambitious nation in the world (Khan and Khan, 2019). The government has allocated SAR 2.8 billion in venture capital incentives to support entrepreneurial activities. In addition, the government has established an SME agency to develop entrepreneurship and SMEs with financing, facilitate business, stimulate demand, help businesses, innovation, culture, and education. KSA ranks seventh in the world for social media engagement, with an average of seven accounts per person.

Furthermore, the government invests heavily worldwide through the Vision Fund and the entrepreneurial cells (Ahmad et al., 2018). Accordingly, the educational institutions are responding to integrate innovation and entrepreneurial in the program to train the students with design skills to compete in the global and local marketplace. This research aims to create a unique course structure to fit with the country’s strategic vision. Accordingly, the following research questions (RQ) address the creativity and innovation course design. This course design will strategically align with the country 2030 vision, where one of the emphasis is to create young entrepreneurs in the country.

RQ:1) How educational learning outcomes correlate with the design of innovation creativity, instructional model, using quality function deployment model (QFD)
RQ:2) Which are critical pedagogies in designing innovation and creativity factors?
RQ:3) What are Student learning characteristics associated with the innovation and creativity instructional requirements?
RQ:4) How to prioritize student learning characteristics, and how does a course design use the findings to identify infrastructure requirements?
RQ:5) Is there evidence that the course design requirements account for creativity and innovation course outcome?
RQ:6) Is there evidence that the learning tools and assessments account for creativity and innovation course outcomes?

Research Hypothesis

To answer the research questions, we construct the following hypothesizes (H:n) to respond to the questions. We gather and analyze data from QFD and course outcomes student outcomes mapping from the course portal to support the hypotheses.

H:1) The core competencies of a creativity and Innovation course are identifiable by QFD.
H:2) About 75% of the “CRF” are critical in designing creativity and innovation course.
H:3) Project-based learning and technological supports are critical to creating innovative learning experiences (or course outcomes)
H:4) Are graduate attributes (or student learning outcomes) identifiable with rank order?
H:5) Can creativity and innovative learning be mapped with the course and student learning outcomes?
H:6) Does the weighted average of the course requirements factor (CRF) contribute appropriately to the course design? We define $\mu_j$ as the weighted average of the CRF. We hypothesize that the weighted averages of the CRF are engineering characteristics and are correlated. Denote
the “null hypothesis” as $H_0: \mu_1 = \mu_2 = \mu_3 \ldots = \mu_n$. The “alternative hypothesis” is $H_1: \mu_1 \neq \mu_2 \neq \mu_3 \ldots \neq \mu_n$, and $j = 1, 2, \ldots, n$. One can reject the “null hypothesis” if the P-value is less than the stated significance level (0.05). If we don’t accept or reject the “null hypothesis,” we may infer that the CRF is critical because the rate at which the learning takes place in course design is significant. Fail to reject the null hypothesis means that at a significance level of 0.05, CRFs are just as important as other CRSs.

3.1 Algorithm of QFD

The following main modules constitute the research design methodology of this case study:

a) Deployment of Quality Function for data analysis is the first step. QFD methodology allows the arrangement of the views as well as the preferences of various constituencies such as ABET accreditation standards, expert educators with substantial experience in course design, incorporation of national professional regulation boards, needs and requirements of industry etc.

b) Course Planning is the next step where the voice of customers also called the “Customer requirement”. It is the end user’s requirements that are ranked and assessed with a focused group. The examples of end users are accreditation board, employers, professional societies, the ministry of higher education, etc.). In this step, the expected course outcome or expectations are identified through question-answer session or brainstorming sessions. Once the appropriate factors are determined, they are ranked and prioritized from most important to the lowest with suitable numeric scale.

c) Component Deployment is a step in a sequence. In this case, the step the customer needs are sub-classified as “Technical” or “Engineering” attributes. As an example, “AutoCAD design” may imply to have sufficient knowledge in “General Programming”; “knowledge of programming theory”, “knowledge of debugging”, “knowledge of Algorithm” and so on.

d) Instruction planning step categorizes the methods, technology, and resources that are essential to add value in enhancing the learning experience by imparting wide-ranging fundamental knowledge in accomplishing the learning outcome of the students (Figure 3.1a, b).

e) Quality Control is a procedure in this methodology to prescribe a minimum level of knowledge that is expected from students in acquiring a threshold level of knowledge in the course.

f) Correlation matrix in the QFD is a section of the design QFD tool at the top of the matrix that correlates the “Technical” and “Customer requirements”. To assess the impact of quality learning from QFD, a House of Quality (HoQ) tool can assist with the series of QFD, as cascading effect. The QFD is shown in Figure 3.2.

g) Analysis through QFD leads to perform Pareto analysis for course evaluation. In this step, we identify non-performing components of a course. A statistical analysis decides the limited number of course characteristics that produce the significant overall effect. In reality, the analysis estimates the benefit delivered by the course attributes and then identifies the most effective course attributes that deliver a total benefit reasonably close to the maximal possible one.

3.2 Data Collection

The QFD is populated with course characteristics under technical requirements. These are the entries in the top of the QFD. The customer requirements are the course outcome. These are entered in the left column and are correlated with the technical requirements at the top of QFD as a roof. The customer importance column shows the priority of the customer requirements. This feature is a benchmark metric to compare characteristics of the target course with somewhat similar courses offered in other engineering institutions.

The customer requirements are paired with the product characteristic depending to find if there is a strong, medium or weak relationship and are marked with a scale. The matched pair is left blank if
there is no relationship between them. Following this iterative procedure with the focused group, the QFD is populated with different inputs on the left column of the matrix and in a sequence, different inputs are entered below the horizontal row.

Once the course is designed with initial characteristics and the course has been offered, some variances and undesirable characteristics are expected to come up for various reasons. One way to identify these undesirable characteristics is to go through a systematic course review. A methodology of course review is shown in Figure 3.5. The QFD matrix analysis additionally will show the characteristics that are not significantly contributing in learning outcome through a Pareto Analysis (Figure 4.1) Pareto analysis finds few hitches that are accountable for the maximum loss of student interest. Confronting the roots causes in a combination of course review leads to improvement in instruction. Combining this analysis, we can arrive at the attributes or characteristics that non-conformity in learning the outcome. Hence, we would expect to come up with a better course structure. Identifying the defect in student learning and instructional methods further improvement of course content and instruction methods are possible from one semester to the next semester. Most of the data in QFD comes from the course review and database with a supporting course portal. The snapshot of one of the portal data and related information to supports QFD is shown in Figure 3.2.

Figure 1. Course portal data for QFD
3.3 Implementing the QFD

The QFD model is built by addressing the student needs via course requirements that identify the VOC. Focus groups classify the needs by categories to identify the needs as shown in Figure 3.2. These customer requirements for the course are categorized into professor-based needs, the course content requirements (Bier et al., 2001; Lam et al., 2008) and the educational facility requirements.

The “What’s”, or ‘Customer Requirements’, in the QFD, are the list of competitive factors which students find significant. On the left side of QFD, as shown in QFD Figure 3.2, is the customer attributes defined as (“WHATs”). For instance, the professor category is an item in the customer want list. Following factors are considered for the QFD after going through brainstorming sessions.

1) Explain the essentials of engineering design and creativity.
2) Demonstrate problem definition and solving in an engineering design project.
3) Operate as a team in an engineering design project.
4) Practice brainstorming and concept generation in an engineering design project.
5) Examine investigation and research for design and development.
6) Practice scheduling and project planning methods in an engineering design project.
7) Demonstrate economic cost and environmental impact in engineering design.
8) Demonstrate proposal writing and record keeping skills in an engineering design project.
9) Demonstrate report writing and presentation skills in an engineering design project.
10) Explain reverse engineering.
11) Examine the design of structural/mechanical/electrical/pneumatic systems.
12) Classify testing, evaluation and manufacturing techniques in engineering.
13) Explain human factors in engineering design.
14) Sufficient knowledge of instructor: Shows how well the course is designed from communication and opinion interchange with student point of view.
15) Industry experience of instructor: Does the instructor have some experience in working in industry or does he/she have only theoretical knowledge?
16) Local industry application: Shows whether received knowledge can be applied to local business;
17) Lecturing skills of instructor: Shows how well the course is delivered by lectures;
18) Interaction with students in various form: Shows how well the course is designed from communication and opinion interchange with the student point of view;
19) Financial support (Fund) to design project
20) An ability to apply knowledge of mathematics, science, and engineering
21) An ability to design and conduct experiments, as well as to analyze and interpret data
22) An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
23) An ability to function on multidisciplinary teams
24) An ability to identify, formulate, and solve engineering problems
25) An understanding of professional and ethical responsibility
26) An ability to communicate effectively
27) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
28) A recognition of the need for, and an ability to engage in life-long learning
29) A knowledge of contemporary issues
30) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Educational facilities category is subdivided into the room, computer labs, and library requirements. It explains how customers appreciate such facilities as classrooms, computer labs, and library:

- Internet access – explains the rate of the importance of available internet connection from computer labs;
- Lab availability at any time – whether computer labs are available at institute’s open hours;
- Books availability – whether needed for education books are available in the institute’s library;
  1) In QFD, there is a column called customer importance. The relative importance of “What’s” are measured on a 10-point scale.
  2) The technical attributes of the QFD which are placed at the top side. The “How’s”, or “design characteristics” of the technological factors, are the various ‘dimensions’ of the QFD which identified important customer requirements. These attributes show the excellence of an institution.
    - Flexible – how well the instructor can be flexible during the lecture delivery process;
    - Prepared for lectures – whether instructors are prepared for lectures and give enough attention to them;
    - Qualified – whether instructors are good enough qualified to conduct a special subject;
    - Pedagogical skills – how well instructors are prepared from a pedagogical point of view.
    - Course structure – how well courses are organized in order to achieve higher effectiveness:
    - Industry trips – does the course include some trips to different industries;
- **Group presentations** – whether the course envisages any teamwork and group presentations;
- **Feedback** – how well the feedback from students is organized.
- **Flexible computer labs’ working hours** – if computer labs are working on holidays and during working time;
- **Smart rooms** – how many rooms equipped with multimedia are available to deliver an interactive lecture.
- **Financial support (Fund) to design project** – adequate fund available to design project to buy necessary components for the project. Current fund form COE is about USD 150.

3) Inside of the QFD, there is a **relationship matrix**, which shows correlations between the WHATs and HOWs. There are 3 different signs that are placed in the QFD matrix in customer requirements and technical attribute areas. These symbols show the correlation between corresponding attributes, so they show the level of relationship between them from weak (3 points) to a strong one (9 points).

4) The triangular ‘roof’ of the ‘house’ captures about the correlations (positive or negative) between the various student requirements and attributed provided. It is a very subjective evaluation because it is based on opinion. For example, the correlation between “qualified” and “competent in IT” is a strong positive. If a professor is qualified, he/she also should be knowledgeable about information technologies (Table 4.2).

The technical assessments of the QFD are explained next.

5) The bottom box of the matrix is a technical assessment of the services provided. This contains the absolute importance of each service element. For example, the service element “**Demonstrate economic cost and environmental impact in engineering design**” is related with “PSR”, “**Final Project Report**”, “**Final Exam**” and “**Design Project Budget / Fund**” and the composite score is 144. This is also translated into a ranked relative importance. In addition, the degree of technical difficulty to achieve high levels of performance in each service element is indicated on a 1 to 5 scale.

6) Stakeholders’ assessment is the right side of the QFD. This section is for competitive benchmarking to be assessed by entering scores is a 5 point scale comparing other universities in the region offering the similar course. This house shows the position of our college of engineering (COE) as well as the position of the other universities.
3.4 Instructional Methods

There is no single teaching method to teach at the institute. All methods and teaching tools need to be combined efficiently by the instructor to achieve good learning outcomes. For example, the lecture is a good method to share the fundamentals of a certain theme. For a better perception and understanding of the material, lectures should be well organized, interesting and easy to follow. Lectures should provide enough information to understand the theme. In addition, lectures need to be accompanied with a visual aid such as attractive slides, figures, graphs, diagrams, examples, video/audio materials, etc. Homework (HW) is a useful tool for improvement and deepening knowledge of students. We deemphasized HW as assessment due to inadequate learning as the students failed to invest independent time in solving HW problems. Hence, based on the learning curve theory (Figure 3.3), as discussed in college council meeting, the COE emphasizes the assessments components that are individual and group-based with adequate transparent assessment tools. Initially, as the time progress in learning, the learning is slow as shown in Figure 3.3. Gradually, as the learning concept is reinforced with various assessment methods, the fast learning takes place during the mid-portion of the learning curve. Eventually, the learning concept is matured or perfected as the learning is further reinforces with different learning domain and evaluated through various tools. At this stage the learning is marginally incremental, saturation is reached. We adopt the principle of capturing the learning at the mid-range of the learning curve. One example of initiating the slow learning is to assign homework and reinforce the concept later through independent Quizzes.

The COE academic council argues that by the time the students appear for quizzes, for example, adequate learning has taken place through the problems solving sessions in class, HW, class discussions, peer feedback and timely summative information about how the students are progressing to reach a goal on the design project. Basic five steps are designed in these steps, which will be described later in the section of the paper.
Figure 4. Learning curve

Figure 5. Student outcome (Direct individual assessment) and corresponding separate ABET performance indicators developed at the COE

Figure 6. Student outcome (Presentations) and corresponding separate ABET performance indicators developed at the COE
During the group discussion, students share their opinions, experience, knowledge; ideas that lead as a result of the extended understanding of the problem. Group discussion is also helpful for open communication skills. The case study gives students an opportunity to face a real problem in organizations. Students learn how to deal with issues raised in a certain company. The case study helps to analyze the current situation within the company, develop different alternatives for solving the problem, justify their opinion, conduct research, investigate additional sources, and give recommendations to the company. During case study students, develop their analytical skills, critical thinking, and decision-making. Quizzes and tests check current knowledge of course material gotten during lectures and tutorials. Industry visit helps to see how an industry works and organized. But due to inadequate resources, this component of pedagogy is deficient. During industry visit, students may ask specialists and expert questions. In our course review, the experts and instructors participating in course review have expressed concern on this pedagogy needs as shown in Figure 3.7. After visiting an industry, it is useful for students to conceive engineering design ideas and formulate the design proposal while studying theoretical material in the classroom. Students’ presentations directed at developing oral skills of students, ability to present their findings before diverse audiences. Ability to demonstrate a well-organized and attractive presentation is very helpful for future career development. The COE pay attention in developing presentation skills. The students have a real opportunity to show their acquired design skills and knowledge. The proper combination of different methods can lead to the successful mastering of the creativity and design subject.

3.5 Course Requirement Factors Importance

Define the following notations and equations to compute the integrated course requirement attributes.

\[ C_i = \text{Course requirement attributes } i = 1, 2, \ldots, n; \text{ where, } n = \text{Number of course requirement attributes} \]

\[ R_{ij} = \text{Relationship matrix for course requirement attributes } i = 1, 2, \ldots, n; \text{ and Technical attribute } j = 1, 2, \ldots, m; \text{ where, } m = \text{Number of technical attributes to support course requirements.} \]

\[ I_i = \text{Course requirements importance for attribute } i = 1, 2, \ldots, n. \]

\[ ICR_{ij} = \text{Integrated course requirements attribute importance is computed as:} \]

\[ ICR_{ij} = C_i \sum_j R_{ij} \text{ For a given } i = 1, 2, \ldots, n. \]

To satisfy the course requirement and to attain a suitable course outcome the entire technical attributes should be incorporated in course design. However, for immediate attention, the Pareto diagram (Figure 3b) suggests the order in which the course attributes are to be integrated with course design.

3.6 Learning Activities and Domain

Percentages of learning activities and assessment tools from this analysis are shown in the Figure 3.6a, 3.6b, 3.6c, 3.6d, 3.6e, 3.6f, 3.6g. It is a combination of flip class, learner-centered approach, case-based teaching, industrial problem solving, etc. The main part of the class work is consisting of lectures. Case study occupies the second place among teaching methods. The rest of the activities are tutorials, quizzes, tests, students’ presentations, and industry project. For example, industry visit is 5% of total teaching tools.

After evaluating attributes the ratings are shown in the QFD matrix. We calculate for each column absolute ratings by replacing signs with numeric values and multiplied by corresponding customer importance rating. The highest ratings we remark again with cross signs and so define new key attributes.
RESULTS AND DISCUSSIONS

Figure 7. (a) Percentages of learning domain; (b) Percentages of learning level

Figure 8. Outcome assessment (As per ABET Criteria)

Figure 9. shows the learning performance based on course outcome

Figure 10. Learning and performance

**Reflection on Course Delivery:**

- [SO-3]:
  - abet_PI_1_3_18
  - abet_PI_1_3_19
  - abet_PI_3_17

SO-3: (stated as “an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability”) affecting: abet_PI_3_18 (“Examine different manufacturing techniques in engineering: consequence of Q2-4”); and

abet_PI_3_17 ("Evaluate the design of structural/pneumatics/mechanical/electrical systems", as a result of performance in Final Exam: Q8-Q13).

abet_PI_3_12 (“Generate design alternatives through creative techniques and evaluate design trade-offs”; and abet_PI_3_17 (”Examine the design of structural/pneumatics/mechanical/electrical systems”) Several CO outcomes: CO 10, CO 8, CO 12, CO 3 are affected from poor performance in Q2-4, Midterm Exam-1: Q8-Q18, Midterm Exam-2: Q13-Q25, Final Exam: Q8-Q19, Final Exam: Q8-Q18, Project Presentation: Part I. as per the results derived from “Evaltools”.

Recommendations: Learning experiences can enhance with more examples related to the subject with field trips. Field trips would be great opportunity to provide the students with necessary real life engineering manufacturing environment. Experts/entrepreneur/scientists/creative professionals may be invited to inspire students in few lecture sessions to foster creative ideas and how it may impact society at the beginning of the course or during orientation sessions.
Figure 3.6 g shows the assessment of performance indicators. For example, the “abet.PI.1_10” is a performance indicator (PI) that defines “Demonstrate reverse engineering”. This PI is related to student outcome SO_1 (as per ABET definition). The SO_1 is defined as “an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics”. It is measured by Final exam Q4d (FE Q4d) having weight as 5%. It is further linked to course outcome C10. The course outcome 10 is stated as “CO-10: Explain concepts of human factors/ergonomics in engineering design.”. The “abet.PI.1_10” score is 4.67 out of 5. This PI is also measured through Question Q8, Q10 and Q15 of Test 1 (T1) with a total marks or weight of 20%. In addition, Q4d of final exam (FE) with 5% weight measures the PI.

a) The course content should aim at developing various skills in students (Figure 3.4, 3.5, 3.7). Software usage, case studies, projects, quizzes, team exercises should be included in the contents of courses. Specifically, the target course should not only emphasize on theory but also rely more on current practice and improvement of software usage skills. The midterm exams and
final exams should not be the source of only grades for the student since the performance of the student on the exam does not always reveal factual knowledge on the design subject. Table 1b shows instrument to capture student learning outcome.

b) In figure 3.4, SO_3 refers to student outcome 3, which is ABET outcome, C. this ABET come related to course outcome 3, 8, 10 and 12. The performance indicators, defined for the course, ABET_PI_3_nn are set of specific learnings and are measured via various course assessment tools, such as specific questions in Quizzes, Final exam, Projects, etc., as shown in Figure 3.1, 3.4, 3.5. The review of course learning and performance take place at the college level, through a committee and instructors delivering the course. One of the recommendations is to initiate industry interactions with the course by a various mechanism as a part of course delivery techniques.

c) The library resources should be expanded in the near future, since insufficient resources create difficulty for students, especially during the examination period. There are no adequate reference and textbooks available.

d) The sufficient number of qualified professors, who have the excellent theoretical knowledge, good pedagogical skills, and industry experience to deliver the course.

e) Availability of course material and other supporting material through the portal technologies is important in the absence of adequate support from a library.

4. RESULTS AND ANALYSIS

We use ANOVA analysis (Table 1a) to test if the weighted average of CRF, which implies if these factors adequately, contribute to the course design in different proportions. We define $\mu_i$ as the weighted average of course requirement factors (CRF). Note that the weighted average of CRF is in relation to the engineering characteristics and are co-related. Let us consider that the null hypothesis $H_0: \mu_1 = \mu_2 = \mu_3 = \ldots = \mu_n$ and the alternate hypothesis $H_1$: not all $\mu_{j=1,2,\ldots,n}$ are equal. If the P-value is greater than the significance level (0.05); we may not reject the null hypothesis. From the ANOVA analysis if we reject the Null Hypothesis, then we may conclude that the CRF is indeed significant since the CRS will have a variable proportion of contributions in course design. It will signify that at a 0.05 significance level, the CRF’s are notably just as important among the other CRS.

Figure 13. Course attributes ranking
4.1 Pareto Analysis

Figure 4.1 is the Pareto analysis. Some important points are worth noting. The course learning is dominated by “Project report stages”, “Quizzes”, and the “Final Project. The % importance is between the range of 12% to 8%. In addition the “3D Printing” facility, availability of “Computer Lab” proper functioning of “Smart classroom” and “Course / Lab Instructor’s competencies” are significant and the importance rating is approximately in the range 6%.

If we look at the Pareto diagram in Figure 4.1, we notice that the first four customer wants are important from course design viewpoint. After four factors the variances stabilizes. If the course design and instructional methodologies address adequately the learning pedagogy, the course becomes effective in a curriculum. Incorporating information from the QFD, the characteristics of course design becomes easier and course learning factors contribute significantly. This improves the overall course design strategy.

4.2 Hypothesis Testing for CRFs

The hypotheses; at significance level $\alpha = 0.05$; we test for the “Course requirements factors” in an ANOVA are as follows:

- Null Hypothesis: $H_0: \mu_1 = \mu_2 = \mu_3 \ldots = \mu_n$
- Alternate Hypothesis: $H_a: \mu_1 \neq \mu_2 \neq \mu_3 \ldots \neq \mu_n$

Where $n =$ the number of course requirement factors.

The ANOVA results for course Requirement factors are summarized next.

| Source of Variation | SS  | df | MS   | F      | P-value | F critical |
|---------------------|-----|----|------|--------|---------|------------|
| Between Groups      | 221.7 | 21 | 10.56 | 1.933  | 0.008   | 1.572      |
| Within Groups       | 3485 | 638 | 5.462 |        |         |            |
| Total               | 3707 | 659 |      |        |         |            |

The ANOVA result (Table 4.1a) suggests that the null hypothesis can be rejected at a 0.05 significance level and hence all the course requirements factors are significant.

4.3 Hypothesis Testing for CRFs supporting technical factors

Null Hypothesis: $H_0: \mu_1 = \mu_2 = \mu_3 \ldots = \mu_m$
- Alternate Hypothesis: $H_a: \mu_1 \neq \mu_2 \neq \mu_3 \ldots \neq \mu_m$
- Where $m =$ the number of courses supporting technical factors.

The QFD data leads to a correlation between the CRFs (Table 4.2). For instance, the correlation between “Instructor qualified to deliver course” and “Flexible to accommodate slow learning” is 0.559. It implies that the ability of the instructor to be flexible enough to accommodate slow learner is significantly correlated with 0.0559 at a 0.05 level significance. Similarly the “Flexible computer labs’ working hours” and “Lab availability at any time” is highly correlated with 0.947. This refers to college’s flexible rule in facilitating the computer lab to students at any time of their presence on campus.

The ANOVA result (Table 4.1b) suggests that the null hypothesis can be marginally rejected at a 0.05 significance level. Some of the technology may have cross-correlation effect some of the factors may not be independent. But overall all the course supporting technical factors appear to be significant.
4.2 Research Implications

There are issues with the design methodologies; consequently, the severity of the problem may vary depending on the specific pedagogy and the cohort as the composition varies from one semester to another. The students battle with innovative project definitions and conceptualizing innovation ideas due to insufficient market research, business experience, and financial analysis background. Students have difficulty understanding business requirements and the abstraction involved when translating requirements into a prototype or a full-fledged model development. Insufficient infrastructure presents a considerable challenge. The students may not find all facilities in laboratories and workshops with the faculty, and they have to rely on outside sources and contractors. Due to financial difficulties lately, the students do not get full financial support, and they have to bear the expenses. The students are fresh into the program and have only preuniversity experience. The students are often less technically,
financial computing, and marketing feasibility oriented. As a result, the students are inadequately prepared for the technical demands of the innovative project.

Nevertheless, in 18 weeks of semester-long time, the students accomplished the national-level creative projects. Some project gets a startup funding proposal. These are outstanding accomplishments. Due to COVID-19 restrictions, the students cannot display the innovative project nationally and internationally for the last two years.

About 15% of Students fail to test the systems they develop efficiently. The reason is that the validation and verification of the implemented processes during the development cycle is ineffective, insufficient, and poorly executed. This paper tests and measures student learning within the context of the systems development group project, focusing on the issues identified above. The article further investigates the identification of the elements of diverse learning styles and the role of an instructor in facilitating the innovation and creative development of a project.

With intensifying competition among universities to recruit students, universities must develop quality education for all stakeholders, with students, employers, and guardians. To improve education quality, universities must understand the expectations of their stakeholders. The authors demonstrate how QFD techniques using statistical analysis can measure customer satisfaction in educational institutions.

Educational accreditation requires an institution to demonstrate how a curriculum and course is designed or evolved. The methodology, as explained, is an acceptable method to satisfy the requirements of curriculum and course building. It is important to note that this methodology has the inherent characteristic to bridge the quality gap or deficiencies. The diverse student population, scarcity in government funding, and competition among educational institutions require implementing total quality management (TQM). The QFD, as a part of TQM, translates strategies to achieve customer or student satisfaction. The paper shows how the voice of customer data in QFD is used as the input to formulate Quality Characteristics to satisfy the Demanded Qualities. It helps financial institutions to provide improved strategic plans to link future needs with the clients. Many teaching methods and techniques are listed as classroom instructions. The effectiveness of the practices and procedures are evaluated with the QFD method. The proposed methodology is a measurement method for assessing the effectiveness of educational objectives and course outcomes. In this research, we illustrate how QFD can help determine the effectiveness of pedagogy and evaluate the effectiveness of achieving academic goals.

According to these studies, any institution can identify the characteristics of QFD in educational institutions. Experts from the appropriate constituencies can act as panelists to determine classroom instructions characteristics and technical requirements.

4.3 Examples of Past Design and Creativity Projects

Figure 1a shows one of engineering design and creativity project by the first year engineering students. It is a bicycle with an atomizer fan to prevent dehydration in hot and arid climate.

Figure 1b is an advanced atomizer / misting fan with water sprayer. The fan gets power from a dynamo. Figure 1c is a 1000mAh power bike bicycle chain cell phone charger generator dynamo connected with USB to tap power. Dynamo works by the bicycle chin rather than bicycle wheel. Figure 1d is the USB port support to connect USB firmly for convenience. Figure 1e is a USB cable for connecting power source from the generator to atomizer fan.
Figure 14. (a) Atomizer bicycle

Figure 15. (b) Atomizer Fan (c) Dynamo (d) USB Port

Figure 16. USB
CONCLUSIONS

Consistent with Vision 2030, the outcome of the engineering design and creativity course at the faculty of engineering, Islamic University of Madinah is an incremental exemplary step taken as a strategic fit with the Kingdom’s NTP.

We show how a QFD methodology is applied to construct the “engineering design and creativity course” at the faculty of engineering. The average class is about 25 students per section and on average each semester 50 students are enrolled in two sections.

Project evaluation panel members constitute disciple experts who witnessed the working model of all the project presentations. They scored, provided expert technical comments and ranked the projects based on originality and practicality of the projects. The weighted average score of expert rankings and other project evaluation criteria were factored into the course grade.

The QFD identify that group discussions, case study, pop quizzes, tests, industry visit, industry project, and students’ presentations are very helpful and necessary in teaching the classes. These methods give adequate understanding and skills to the students. It is better than the course introduce adequate lab sessions with competent lab instructors. In lectures, the instructor introduces the students to the theory of the particular theme, while in labs students develop problem-solving skills in design and creativity. Group discussions are necessary for the expressing own ideas, thoughts of the students and at the same time listen to others. Case studies are very helpful for considering situations and problems with which the students could encounter and solve them using the acquired knowledge. In current course design, the group presentation and discussions develop the qualities for the teamwork and communications skills. Students’ presentations are the necessary tool for educating and developing skills to speak in the public forum. Quizzes and tests are helpful for determination of the levels of knowledge and understanding that students acquired from the classes. See Figure 3a. Unfortunately, industry visit is not conducted by instructors, due to inadequate facilities. It will give the students an opportunity to know how innovative ideas are evolved in industry.
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