

A Quality Assessment Method for Engineering Student Designs in Project-Based learning

by

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DEDICATION

To my father, Engr. Dr. E. C. Ejichukwu, who is my role model and my mother, Mrs. P. O. Ejichukwu, for her support.

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I want to express my gratitude to everyone who helped and guided me on my path and toward the completion of this project.

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FORWARD

Working as a teaching assistant at the Nnamdi Azikiwe University, Nigeria, allowed me to engage in teaching and project-based activities with undergraduate students. Pursuing a master's degree in the Industrial and Systems Engineering department at University of Michigan-Dearborn has provided an avenue for me to investigate ways to improve the quality of students designs in the engineering program. This thesis will provide a quality assessment tool that integrates concepts of quality in the design process. This tool will provide a means of formative feedback and self-evaluation by students in engineering education.

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ABSTRACT

This study utilized a qualitative approach to explore how the quality of first-year students' design projects can be improved using a Quality Function Deployment framework (QFD). It also investigated students' perceptions of an excellent design. In the first phase of the study, the QFD was utilized to develop a rubric for evaluating the quality of design projects completed by first-year engineering students. The rubric was designed to incorporate key components of the QFD, including context, input, process, output, and feedback, to ensure a comprehensive assessment of project quality. The rubric was then used by independent raters to assess a sample of first-year engineering student design projects, with feedback provided to refine the rubric.

In the second phase of the study, the refined rubric was used to assess a larger sample of first-year engineering student design projects. Thematic analysis was used to explore students' perceptions of excellence in their design projects through their self-reflection statements. The analysis revealed that students valued factors such as technical accuracy, passion, functionality, domain knowledge, and user experience in their designs. Students perceived their projects to be of higher quality when these factors were present. However, these identified themes do not directly translate to an excellent quality of design.

The findings of this study have significant implications for the design and evaluation of first-year engineering student design projects. By incorporating the designed QFD rubric for self-assessment in project-based learning, the quality of student designs can be improved. Additionally, understanding students' perceptions of excellence in their designs can inform pedagogical strategies aimed at developing students' design skills and competencies. The study concludes with recommendations for future research aimed at further investigating the use of the QFD in the assessment of first-year student design projects and exploring the transferability of the rubric to other disciplines. The study contributes to pedagogy of assessment in engineering education.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Engineering is the application of scientific principles to the design of products or services that satisfy user needs [1]. Through critical thinking, engineers can solve problems experienced by humans in their everyday life. Design and design thinking are both vital to creativity and innovation [2]. Good design practices prioritize safety, reliability, efficiency, and sustainability. The engineering design process is essential in the product development lifecycle. To effectively solve problems or satisfy users, an understanding of the fundamentals of engineering and design is required [3], [4]. The design process determines the design outcome and product quality. Quality begins in the design stage; hence emphasis is being placed on improving the design skills, knowledge, and the design process of undergraduate engineers.

To ensure that students develop the required engineering design abilities and gain sufficient design experience prior to graduation, universities have integrated Project-Based Learning (PBL) into courses being taught [5], [6]. PBL has proven to be an efficient method for teaching engineering principles and related concepts to students [7]. It promotes learning, integration of knowledge and the application of multiple levels of creativity in design [6]. Students are able to acquire real engineering design experiences while developing technical and communication skills [8]–[10]. Through PBL, the knowledge, information sharing among students and real-life competencies are improved.

Students view engineering as majorly focused on the problem-solving process [11]. Past studies have assessed and compared the learning outcome of project-based learning of first-year students. [12], [13] compared freshman and seniors' design processes. [3] compared the design process of students and expert practitioners. The results show the differences between the quality of the design process and design output of freshman, seniors, and experts. Seniors and experts had more design experience produced higher quality solutions than freshmen. Experts spent more time solving the problem, considered more alternative solutions, and made more transitions between design steps than the freshmen new to the design process.

An increase in educational achievement benefits the student. Students' design outputs in PBL showcase their understanding of the design process. Student work independently or in teams to prepare and present a manufactured product in a way that demonstrates their understanding of the engineering design and manufacturing process. Students' design activity seemed to become more engineering-specific towards the tail end of their engineering education [14]. They also tend to produce better designs as they progress in the engineering program [15]. [16] reveal that students are satisfied with the skills they acquire in PBL but suggests the improvement of methods that increase student confidence and autonomy for better preparation of the labor market.

1.2 STATEMENT OF THE PROBLEM

Past research has shown the design process and design knowledge of undergraduate engineering students [13], [17]. Students are observed to be majorly focused on the problem-solving aspect of a project, without much consideration for quality of design output. Quality starts with the design process. The knowledge and consideration for quality in design is key to students in all engineering disciplines.

Incoming university students enroll in an Introduction to Engineering and Engineering Design course. This design course provides a general introduction to the engineering profession, engineering design, and programming. Past studies have shown that first-year students produce designs with poor quality [12]. With increased emphasis on enhancing design and creativity, there is a need for an assessment tool that can provide formative feedback to students on the quality of their design output. Formative feedback will improve the student design output as they engage in the design process [18].

The goal of this study is to:

1. To evaluate the quality of student designs from project artifacts.
2. To develop a means of assessment that provide feedback on design quality and identify areas for improvement.
3. To provide a quality assessment method of student designs from project artifacts.
4. To improve the quality of future student design projects

1.3 PURPOSE OF THE STUDY

To provide formative feedback to first-year engineering students as they develop required design knowledge and skills, this study will aim to answer the following research questions:

RQ1: How can the quality of first-year students design be improved using a Quality Deployment Framework?

RQ2: What is the quality of first-year students design upon completion of an Introductory design course?

RQ3: What are perceptions of excellence by first-year engineering students in their design projects?

1.4 SCOPE

This study aims to develop a rubric based on the quality function deployment framework, test the reliability and validity of the rubric, apply this rubric in the assessment of student artifacts, and investigation of the perceptions of excellence in student designs. This will help educators further understand how first-year students consider quality in design. All artifacts analyzed will be those of only first-year engineering students in a section of the course taken in the fall of 2022.

1.5 SIGNIFICANCE OF THE STUDY

This study has the potential to improve first-year engineering student's design and contribute to the advancement of design education and design practice in the following ways.

1. Improving design output of student designers by providing a means to assess the quality of their design.
2. Promote design education and design outcomes, whereby students are better prepared to take on design tasks and produce quality work.
3. Enhancement engineering education. Students will be able to clearly identify key criteria for design quality, resulting in improved design experiences.
4. Further demonstrate the value of rubrics for formative assessment.
5. A benchmark for evaluation of design quality from written reports and a basis to compare student design outputs.

1.6 ASSUMPTIONS

The following assumptions are made in this study:

1. All students enrolled the introductory design course are all first-year engineering students with little or no prior knowledge of engineering design and the design process.

2. Students included all steps in their design process and all factors considered in taking design decisions in the artifacts.
3. The raters of student artifacts follow the instructions given during their training.

1.7 LIMITATIONS OF THIS STUDY

The limitations of this study include the following:

1. Small sample size. The results of the study will be based on the artifacts submitted by 8 student teams. The perception of excellence in design will be determined by thematic analysis of 34 students' self-reflection present in their portfolio.
2. Existing student artifacts will be used. These artifacts are written reports that can only provide a limited amount of information about the visual design of a project, which can make it difficult to assess the aesthetics, usability, and functionality of the design.
3. Lack of interactivity: written reports do not provide the opportunity for the evaluator to interact with the students and their design outcomes directly. This can make it challenging to evaluate the design's usability and functionality accurately.
4. Subjectivity: Design quality is subjective, there are different opinions about what constitutes good design. Therefore, the assessment of design quality from written reports may vary depending on the evaluator's perspective and experience.
5. The study did not compare or investigate how the scores from the rubric compare to the final grades of each student teams in the course for summative assessment. The purpose of this work is to be able to provide formative assessment to the student and the teacher to identify achievement and areas of improvement.
6. Time to access and analyze each team's document was a limitation. The sample was therefore limited to the fall 2022 student teams. This study did not consider the final grades of students that took the course. Another limitation in this study is that the changes in the quality of designs by first year students over time was not investigated.

1.8 DEFINITIONS

1. Project-Based Learning (PBL)

This is an educational strategy that places a strong emphasis on learning through the completion of projects that incorporate issues or situations from the real world. PBL requires groups of students to identify problems or questions, do research, and then come up with a solution or

response. Project planning, research, design, and development, testing and evaluation, and presentation or dissemination of findings are a few of the phases that commonly make up the strategy. PBL aims to foster critical thinking, teamwork, communication, and other crucial abilities that are beneficial in a range of academic and professional settings.

2. Design

This involves the drafting of a thorough plan or blueprint for the project is a crucial phase in the development of any system or product. This stage often entails the drafting of requirements, the construction of intricate design drawings or models, the choice of materials, and the manufacturing procedures that will be applied to bring the concept to life. The design phase is crucial because it lays the groundwork for the rest of the project and makes sure that the finished system or product will satisfy the requirements of its target audience. To make sure that the project is successful, it is also crucial to consider variables like cost, viability, and sustainability throughout the design phase.

3. Design Process

The design process consists of several stages that assist designers in developing and producing efficient solutions to a problem.

4. Artifacts

Student proposals (preliminary design review) slides, final presentation (critical design review) slides, final written reports, prototypes, models, diagrams, and other visual representations are examples of artifacts, as are other tangible or digital items produced during the design process. These artifacts can act as a physical reminder of the design procedure, enabling designers to monitor their advancement and make changes. Artifacts can also be used to solicit feedback from stakeholders like clients or team members and convey design concepts to them. The usage of artifacts is crucial to design thinking since they allow for the exploration of concepts and the visualization of potential solutions.

5. Self-Regulated Learning (SRL)

This is the process through which people take charge of their own learning by creating plans, establishing goals, keeping track of their advancement, and making necessary adjustments. Self-regulated learners can recognize their own advantages and disadvantages, form attainable goals,

and employ a range of learning techniques to get there. This method of instruction has been proven to be successful in raising academic achievement and encouraging lifelong learning abilities.

CHAPTER 2: REVIEW OF LITERATURE

2.1 INTRODUCTION

This section provides an overview of existing literature and synthesis of the reviewed literature on project-based learning, engineering design process and design quality.

2.2 PROCEDURE FOR REVIEW OF LITERATURE

Literature review is a significant because it establishes concepts, context, and background of the research. It also identifies existing gaps in literature and informs the research question and hypothesis. The procedure for conducting this review is as follows.

2.2.1 Inclusion Criteria

Studies from the application of PBL in engineering discipline were reviewed and a decision of inclusion or rejection was made. Attention was given to publications that presented the use of rubrics in assessing the engineering design process. Materials selected include only peer reviewed publications such as dissertations, journals, edited books, and research reports.

2.2.2 Search term and Databases

The research question was identified, and the search term were selected. The search term includes Quality, Assessment, Project based Learning, Design process and Quality Function deployment. General searches were made using Madigan library, ERIC, google scholar, research gate and other search engines. Relevant literatures were identified in different databases. A spreadsheet was used to keep track of 108 related search results. This was followed by an in-depth study of each relevant literature.

2.2.3 Method of Analysis

Qualitative analysis of the gathered publications was carried out. Design articles were read to determine relevance and connection of paper to the topic. The list was sorted based on journals and sources to ensure relevance and connection of paper to the topic. The information from the selected papers were then organized and synthesized to identify common research design, procedures, findings, themes, patterns, and gaps. these were compared and discussed. The literature review was written and then revised for clarity and accuracy.

2.3 PROJECT-BASED LEARNING IN HIGHER INSTITUTIONS

Project based learning has been the preferred pedagogical model for teaching design in engineering because it has proven to increase students' knowledge, design thinking, communication skills and abilities to work in teams [5], [19]. This is also in agreement with Accreditation Board for Engineering and Technology's general engineering criteria for engineering education [20]. Students perform complex and open-ended design tasks in PBL. PBL in higher institutions is closely related to self-regulated learning (SRL). PBL allows students to actively manage their own design process by developing plans to achieve their set goal. The relationship between Project based learning (PBL) and SRL as presented by [21] is shown in the figure below.

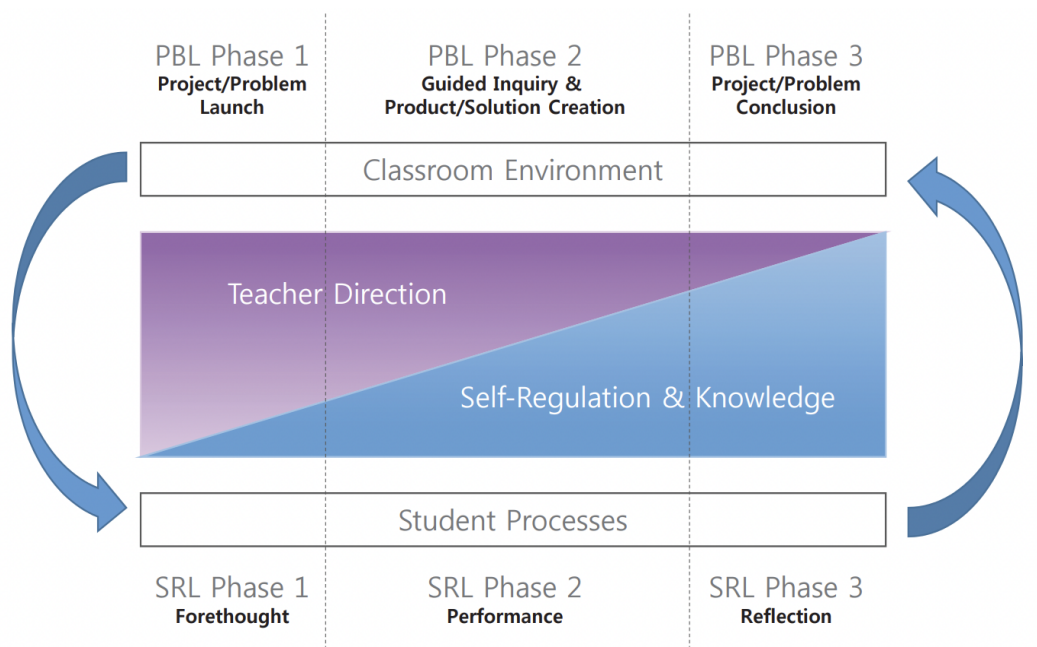


Figure 2-1: Relationship between Self-regulated learning and Project Based Learning.

Source [21]

Students gain understanding and gather information from relevant sources on the problem to be solved. They take responsibility for their learning process by working together to conduct research, apply logic and devise solutions to complex problems [21]. Some rely on previous knowledge to create design solutions.

In phase 1 (Project launch/Forethought), tasks are assigned, and ideas are generated. In phase 2 (Guided Inquiry, solution creation and performance), modelling, feasibility analysis and evaluation of design solution is carried out. The use of white boards (that enable visible thinking

by students), reflection prompts, and formative assessment methods can further assist students in phase 2. In phase 3, (project conclusion/reflection), reasons for decision making are considered and communicated. Team and self-reflections on new knowledge are also carried out on effective strategies that led to the success of the project.

2.4 ENGINEERING DESIGN PROCESS

Engineering design refers to the process of creating new product, system or process that meets set technical and functional requirements [1]. The engineering design process is systematic and iterative [22]. Toy design activities can be used to enhance students understanding of the design process through the hands-on approach [23].



Figure 2-2: The Engineering design Process.

Engineering design process involves the identification of a user's need, definition of the problem, gathering relevant information, idea generation, modelling, feasibility analysis, evaluation, decision making, communication and prototyping [17]. Quality starts with the design process. To improve student design output, students should consider quality in their design process.

2.5 UNDERGRADUATE STUDENT DESIGN

The relative quality of engineering student designs increases as students' progress in the program [24]. According to [21], students in PBL are faced with the lack of motivation, lack of ability to

take responsibility for learning, poor behavior, and negative attitudes. Past research has investigated attitudes of freshman in engineering and have suggested ways to improve the design process [12]–[14], [17]. [25] examined the relationship between student designer activities and project outcomes using multivariate linear regression analysis. The findings demonstrated that, when judged by qualified engineers, client satisfaction and design quality differed significantly.

[26] investigated how junior-level engineering students presented their design justifications on open ended projects. The paper examined their writing skill, assessed their written rationales, and assessed the changes in its quality over a 10-week period. The study found that their ability to express design decisions backed by engineering principles via writing increased over time.

[27] utilized qualitative analysis involving verbal descriptions and semi-structured interviews to investigate the relationship between domain knowledge, meta-representational knowledge, and reasoning process of engineering students in modelling. The results support the use of prompts or regulatory guidelines in PBL

2.6 DESIGN QUALITY

The design quality metrics include technical requirements, feasibility, creativity, simplicity, need satisfaction, and overall impression of the design solution. The client satisfaction metrics were the quality and overall feasibility of design outcome. Students utilize design languages or representations such as texts, graphical representations, shapes, features, mathematical or analytical models, numbers to convey design ideas.

2.7 DESIGN ASSESSMENT METHODS IN PROJECT BASED LEARNING

Assessments targeted at improving student learning is crucial to engineering education. Students benefit from feedback in the form of assessment, which can also point them in the direction of progress [28]. When there is a large variety of "right" solutions, it becomes challenging to evaluate student designs. Student design outputs have been assessed through various means. [29] suggests the use of checklist or scale to assess design process reports, and the use of open or closed ended questions, video of design teams and student portfolios to assess individual or team design process knowledge.

The framework provided by [30] for evaluation of the creative problem-solving stages and overall creativity is characterized into the functional purpose of the evaluation (formative or summative) and the paradigm of the evaluation (artificial or naturalistic). The measure of design innovation

developed by [31] is based on expert judgments of design concepts', value and functionality derived from a set of importance-weighted design requirements.

[32] proposed a systematic method for assessing design creativity and design quality. This method compares design appropriateness to design quality by assigning weights and ranking quality to a set of designs. This hierarchy is formed by identifying all relevant factors that influence the final quality and then ranking based on the relevance of each category to the specific design output. The specific quality metrics listed are performance, functionality, reliability, durability, and perceived quality.

The method of assessing the creativity of new product designers proposed by [33] is based on defining effort as the time taken through the design process and creativity as a design value. [34] developed the Design Competency Assessment (DesCA) framework that identifies distinct levels of design competency and helps instructors, design learners in the design process, institutes as well as employers assess and/or recognize competency.

[35] developed a method for assessing student project design reports. [36] applied the Consensual Assessment Technique in assessing the quality of each design stage as well as the overall creativity of the entire design process. Results show that varying interpretations of idea generation greatly impacted which stages were most related to each other and overall creativity. [37] proposed self-assessment report rubrics for assessing learning outcomes. Venable et al., (2016) proposed an evaluation framework and design evaluation method that guides researchers in choosing an appropriate strategy for the evaluation of the design artifacts and design theories that form the design output.

With increased emphasis on enhancing design and creativity, it is necessary to develop a means of assessment of students' understanding and consideration of quality in the design process. Commonly used methods of assessing design quality in project-based learning include:

1. Peer Assessment: This method of assessment directly involves students in the evaluation process. In this method of assessment, factors like social or inter-personal beliefs can interfere with the results if the peer assessment is done anonymously [38]. Students assess each other using set criteria. Although student performance can improve, adequate feedback on the quality of the design process may not always be received [39].

2. Self-Assessment: This involves the evaluation of one's own performance, and the reflection of one's strength and weaknesses using set criteria. Self-assessment is done to enhance personal growth. To develop independent and reflective engineering students, self-evaluation must become a norm [40]. [41] suggest that using rubrics to help students absorb the standards and better evaluate themselves and others. Self-assessment report rubrics are suggested for assessing learning outcomes [37].
3. Expert Review: An expert is a qualified and knowledgeable person with specialized knowledge in an area. The expert performs an assessment and provides feedback on the strength and weaknesses of a designed product or a designed process. The expert also identifies areas of improvements [42]. Most times, assessment of project deliverables often rely on expert judgment which has a potential for bias. This type of assessment is based on the final designs.
4. Testing: Testing allows designers evaluate the effectiveness and usability of designs. Designers can test their work to assess its efficacy and usefulness. Usability testing evaluates the use of a design. Performance testing evaluates design reliability under varying conditions. Feedback can be gotten from testing.
5. Surveys or Questionnaires: These are open or closed ended questions used to gather feedback from users about a process or a product. In most PBL courses utilize surveys to gather feedback on student performance at the end of a course [5]

[43] emphasizes the need for transparency and appropriateness of self-evaluation process. To encourage self-assessment, provide formative feedback on the design process, and improve design output of first-year engineering students as they engage in PBL, rubrics is preferred. Rubrics have been applied in teaching engineering principles in higher institutions [44]. Rubrics will be further discussed in the section below.

2.8 RUBRICS FOR THE ASSESSMENT OF DESIGN QUALITY

Rubrics are assessment tools that help students gain complex competencies [45]. The implementation of rubrics in the classroom is a valuable tool that supports and improves student learning (Brookhart, 2013). Students in higher education value the use of rubrics [46]. Rubrics directly assess performance based on set pre-established criteria [47]. Rubrics consist of checklists and rating scales which can either be analytical or holistic [48]. Educational assessment through

rubrics can direct and inspire learning, hence it is crucial for summative or formative purposes (Kennedy & Shiel, 2022). Students can track their progress over time [45].

Rubrics have been used to assess writing skill and written rationales [26]. Some positive effects of using rubrics for self-assessment include reduced student anxiety, increased motivation, increased transparency, improved self-efficacy and better feedback. [49] validated a technical writing rubric for assessing communication, linguistic and organizational aspects of technical reports in undergraduate engineering design courses to identify areas of improvement. According to [50], some factors that can influence the use of rubrics include (1) educational level, (2) length of use, (3) gender, (4) topic, (5) performance, (6) contextual factors and (7) language in the rubric.

[51] created a framework to assess the sustainable design of 40 capstone projects of seniors in civil and environmental engineering. [52] applied rubric-based evaluation to evaluate student work as shown in their presentations and written reports. [53] utilized rubrics to assess engineering students' application of sustainability principles in problem solving.

Educational assessment through rubrics can direct and inspire learning, hence it is crucial for summative or formative purposes (Kennedy & Shiel, 2022; Pang et al., 2022). Rubrics have been used to assess the quality of new products [21], [54]. For rubrics to be an effective quality assessment method, it should be designed to be specific, contain exemplars, scoring strategy, evaluative criteria, levels of quality, quality definitions, judgement complexity (for experts), users and uses, creators, quality process, accompanying feedback, presentation and explanation [55]. First-year students find grade descriptors, marking criteria and annotated exemplars very useful when seeking precise guidance and an idea of expected standards [56].

2.9 FRAMEWORKS FOR THE ASSESSMENT OF DESIGN QUALITY

Quality begins in the design phase. Quality management is focused on customer satisfaction and an overall process improvement. To ensure the quality of design output, design requirements must reflect the needs of the users. The following are common frameworks that can be used in the assessment of design quality.

1. Design Structure Matrix (DSM): This is used to illustrate the interdependencies and interaction among various components of a design task [57]. It is a square matrix of zeros (0) and ones (1). It can be used to determine possible design flaws. DSM was applied to ensure sustainability of design [58].

2. Failure Modes and Effects Analysis (FMEA): This is a proactive technique for identifying and reducing possible causes of design failure on a system, process, or product [59]. FMEA can be utilized at several stages of the design and production process, from idea creation to manufacturing, and it can assist to lower costs, enhance quality, and raise customer satisfaction. The FMEA process often involves experts that identify probable failure modes and evaluate their impact and severity.
3. Quality Function Deployment (QFD): The QFD framework is focused on meeting customer needs [54].
4. Design For Six Sigma (DFSS): DFSS is a structured approach to design that makes use of statistical analysis and quality tools. It is useful in managing and enhancing the design process [60]. DFSS consists of five phases: Define, Measure, Analyze, Design, and Verify. DFSS can be used in a variety of industries.
5. Heuristic Evaluation: This involves comparing a list of usability guidelines, or heuristics, to assess its usability. This is done early in the design process to spot usability problems [61]. It is frequently used in developing engineering design process knowledge and skills [62].

2.10 QUALITY FUNCTION DEPLOYMENT FRAMEWORK

Quality Function Deployment (QFD) framework is the framework selected for assessing quality in this study. QFD focuses on transforming customers' needs into design requirements to ensure that the product design meets these needs or requirements. It uses the house of quality (HOQ), voice of the customer (VOC), technical correlation, design development, verification and validation, implementation to develop a solution. [63] applied the quality function deployment model to prevent poor design decisions that cause later changes in design and reduced productivity.

The quality function deployment model defines function and performance requirements when making design choices in the design process [64]. Customer needs are prioritized and connected to technical requirements using the house of quality [65]. The quality of final design has a strong positive correlation with system-level idea generation and refinement activities [25]. To improve student designs, QFD can be applied to the design process steps performed by students.

The application of QFD framework in assessing design quality from the design output, requires identifying the assessment's objectives, selecting an evaluation approach for selected properties and creation of the evaluation method. As it relates to this study, a rubric based on the QFD can be used to fulfill all four key aspects of design assessment. The rubric can provide formative feedback to students as they engage in design tasks.

The steps for involved in QFD are:

1. Gathering information on client needs from market research, questionnaires, or focus groups.
2. Determine the technical specifications required to meet the customer's needs based on those needs.
3. Using the house of quality to link technical requirements to customer needs and ranking needs in order of significance to customer.
4. Examining the connections between the technological needs to make sure they support and are compatible with one another.
5. Design a new product or process using the information gathered in the above steps.

2.11 ASSESSMENT OF DESIGN QUALITY FROM DESIGN ARTIFACTS

Design artifacts are tangible items created during the design process. Artifacts are a representation of the design process and can be used to communicate ideas, collaborate with others, test or refine a design [4]. Artifacts include sketches, diagrams, prototypes, models, and specifications. Students utilize each of these in different stages of the design process to explore ideas and generate multiple concepts diagrams and sketches can be found in written reports [29]. First year students commonly use quick and rough sketches to iterate and refine their ideas.

Diagrams are used to visualize the flow of a system or process. Specifications are used to define technical requirements and characteristics of functionality, performance, and standards or regulations to be met. Prototypes and models are advanced design artifacts used to test and refine the design. Prototypes can range from physical test samples to fully functional products. Written reports document the design process and the decisions made throughout that process. They include detailed descriptions of design requirements, design constraints, design options, and design decisions. Written reports facilitate collaboration and feedback [5].

Designers demonstrate how well they balanced both complementary and conflicting design criteria in their written reports. Written documents contain detailed open-ended responses that showcase students' knowledge skill and attitudes. These reports can be assessed to determine the design process and design quality [4], [24], [29]. Although artifacts may have poor documentation, incomplete or incorrect drawings, incomplete technical specifications, lack of detailed information, inaccurate details, design errors, error in design calculation, lack of clarity and legibility, artifacts provide elaborate information on how well students convert specified user requirements and product design specifications into relevant technical requirements in their design [66]. This information can be used to determine the quality of the final design output.

Design science research has focused on creating and assessing artifacts [67]. Factors assessed in design documentation include fit for purpose, completeness, relevance, clarity, timeliness, accuracy, conformity, concise, coherent, and consistent [66]. [4] identifies the need to develop a means of assessing design quality from design language represented through verbal or textual statements, graphical representations, shape grammars, features, mathematical or analytical models, or numbers. [68] placed further emphasis was on developing strategies for formative assessment of self, peer, and project deliverables to increase engineering entrepreneurship knowledge and skill among students.

2.12 CONCLUSION

This chapter presents scholarship on the engineering design process and assessment methods. This study aims at developing a self-assessment tool for formative feedback on the quality of design using the quality function development framework. As a strategy for developing engineering skill and improving learning outcomes, self-assessment of project deliverables is encouraged. Learning and instruction is better when expectations and criteria are made clear through rubrics. Students' creativity is greatly impacted by varying interpretations of idea generation. They find grade descriptors useful when seeking an idea of the acceptable standard. Rubrics can be used to provide a guide to an acceptable standard on the quality of design process, design output, and for self-assessment.

As a research gap, there is need to develop assessment methods for design process knowledge from languages or design representations found in design artifacts. The quality function deployment model prioritizes customer needs and connecting them to technical requirements.

Overall, developing a QFD based rubric for self-assessment of design can enhance design skill and design output.

CHAPTER 3: METHODOLOGY

3.1 OVERVIEW

This chapter outlines the detailed description of the development of the quality function development rubric, the use of this rubric in the assessing the quality of first-year students project artifacts, and a thematic analysis of student self-reflection to identify their perspectives of excellence in design. The chapter presents the research design, research instrument, data collection methods and data analysis technique.

3.2 RESEARCH QUESTION AND HYPOTHESIS

The aim of this study is to develop a self-assessment tool for formative feedback on the quality of the design. This tool is built on the quality function deployment framework. The hypothesis of this study is that first year engineering students do not consider quality, so they produce poor designs. This study will aim to answer the following research questions:

RQ1: How can the quality of first-year students design be improved using a Quality Deployment Framework?

RQ2: What is the quality of first-year students design upon completion of an Introductory design course?

RQ3: What are perceptions of excellence by first-year engineering students in their design projects?

3.3 DESIGN OF STUDY

This is qualitative research. Qualitative research is particularly appropriate for this study because the study seeks to (1) gain in-depth insights into the quality of design output by first-year engineering students on completion of a design course (2) utilize thematic analysis to investigate their perceptions of excellence in design as it relates to design quality. A rubric was developed to guide students towards quality function deployment in the design process. The reliability and validity of the designed rubric was tested, and the rubric was revised.

3.4 PROCEDURE

The procedure taken in this study are as follows:

3.4.1 Population

Assessment of design quality involves selecting a sample population. The population selected in this study was first-year engineering students, at the start of their engineering program. Age, gender, race, or ethnicity, nationality or socioeconomic status was not considered here.

3.4.2 Context Description

The introduction to Engineering (ENG 100) is a course taught in the college of engineering at the University of Michigan, Dearborn to first-year engineering students. The goal of this course is to introduce students to (1) the different engineering disciplines and roles in the society, (2) the application of the engineering design process in design, building and testing a product, (3) understanding how teams work effectively in solving engineering problems irrespective of race, gender, global and cross-disciplinary perspectives. This course also aims to aid students develop required creativity and innovation, design and design thinking, critical thinking, analytical thinking, problem solving, decision making, and communication skills for successful transition into the College of Engineering and Computer Science (CECS).

The course integrates project-based learning. Students are required to apply the knowledge gained from the course to the project. Students gain understanding and gather information on the problem to be solved. Some rely on previous knowledge to create design solutions. To improve the design process and design output of first-year engineering students, this study will develop a quality function development rubric to provide a guide on acceptable standards and investigate students' perceptions of excellence in design.

Students were given two chances to hone their oral presentations. Each team member is expected to (1) demonstrate writing, speaking, and graphic skills through report and presentation, (2) Participate fully in team meetings, as well as in the planning, development, testing, and presentation of their specific design projects, (3) Participate in the Preliminary Design Review (PDR) and individual Critical Design Review (CDR) meetings and participate (4) Be respectful of and helpful to teammates.

3.4.3 Instructional Setting

The introduction to Engineering (ENG 100) is given in traditional classroom settings with face-to-face instruction. Practical design lab sessions, academic guidance, and tutoring to help students imbibe engineering concepts is incorporated into the course. This is done to support student achievement and encourage academic success. The instructional team is comprised of 1 faculty member, 6 laboratory assistants and 2 graduate student instructors. The students first complete lectures on engineering principles and laboratory training sessions on MATLAB sessions, use of Tinker CAD, ARDUINO. Team members begin brainstorming in the 7th week of the course. The project cycle continues for 6 weeks till the end of the course.

3.4.4 Sample Description

The selected sample for this study were first-year students that enrolled in the Introduction to Engineering and Engineering Design course (ENGR100), a Project Based Learning course at CECS, UM-DEARBORN in the fall of 2022. Students were expected to participate in a Toy-Design project and submit their artifacts. Only those that completed the toy design project and submitted complete artifacts were included in the study. The artifacts to be assessed using the designed rubric was gotten from 34 first-year engineering student that worked in a total of 8 project teams. Each team had a minimum of three to five maximum team members.

3.4.5 Data Collection

At the end of each course, students submit artifacts where they have communicated in clear and concise terms, the details of their work [5]. Secondary data from artifacts of project deliverables such as student design portfolios, proposal, presentation, and final report documents were gathered for assessment using the rubric. The data for this project only included teams who selected and completed the toy design projects.

A total of 8 team project artifacts and 34 student portfolios comprising of project preliminary design review (PDR), final critical design review (CDR), final report, final project documentation was gathered.

3.5 DEFINITION OF PROJECT DELIVERABLES

To ascertain design thinking and creativity in first-year engineering students, their design process and outcomes as shown by their written reports must be evaluated. Students report their design

process and findings in their portfolio, proposal document, presentation document, and final report documents.

Table 3-1: Data Structure

Course	Course Summary	Project	Artifacts for Assessment
ENGR100	Introduction to engineering course that reinforces concepts such as programming, prototyping, and design process knowledge.	Toy-Design Project	Project preliminary design review (PDR), Final critical design review (CDR) Final Report, Final Project documentation

After students are given a design task to perform, they were expected to orally present a preliminary design review of the project they intend to perform. The preliminary design review document used in this presentation contains details about the project title, goals and objectives of the team, a summary of the budget, scope, design stages, and methods. This document is prepared after series of brainstorming by team members.

In the critical design review stage, teams made an oral presentation of their completed work to both faculty and other students. The critical design review document includes details such as a title, introduction, motivation, details of the solution, experimental results demonstrating tests carried out, solutions, conclusions, and recommendation for future work. The Final Report is a written document that contains the project name, description of the project to be executed, scope, scheduled milestones, budget, milestones, and successes. It would also include the challenges faced, lessons learned and the project performance.

The students also submitted a final project documentation (portfolio) at the end of the course. This contained self-reflection and self-assessment of their design experiences and design knowledge gained. Document analysis and content analysis will be carried out all document to identify themes or patterns. To protect student’s identity, the submitted student artifacts were de-identified and coded as follows.

Table 3-2: Grouping according to Student teams.

Artifacts	TEAM A	TEAM B	TEAM C	TEAM D	TEAM E	TEAM F	TEAM G	TEAM H
Proposal,	1,	5,	9,	12,	17,	22,	27,	31,
Presentation	2,	6,	10,	13,	18,	23,	28,	32,
Final Report,	3,	7,	11	14,	19,	24,	29,	33,
Portfolio	4	8		15, 16	20, 21	25, 26	30	34

Each team had a minimum of 3 members and a maximum of 5. It is to note that there was no consideration in selecting members of a team.

3.5.1 PROJECT OVERVIEW

The first-year engineering course required students to design a toy for kids. The students must first identify the need and purpose of the design. Then gather information and generate possible ideas. Then an idea is selected from multiple generated ideas. Sketches and CAD drawings are used to model the selected design and prototype of their toy. They are required to build and test the feasibility of their design.

3.5.2 PROJECT DESIGN STAGES

The major design activities whereby student teams were expected to document and submit written reports were the project preliminary design review (PDR), final critical design review (CDR), final report, final project documentation (student portfolio). A final written report was to be submitted at the end of the course for grading. These documents from 8 student teams and portfolio of 34 students will be assessed for quality function deployment attributes. Figure 3 below presents an overview of the project design stages.

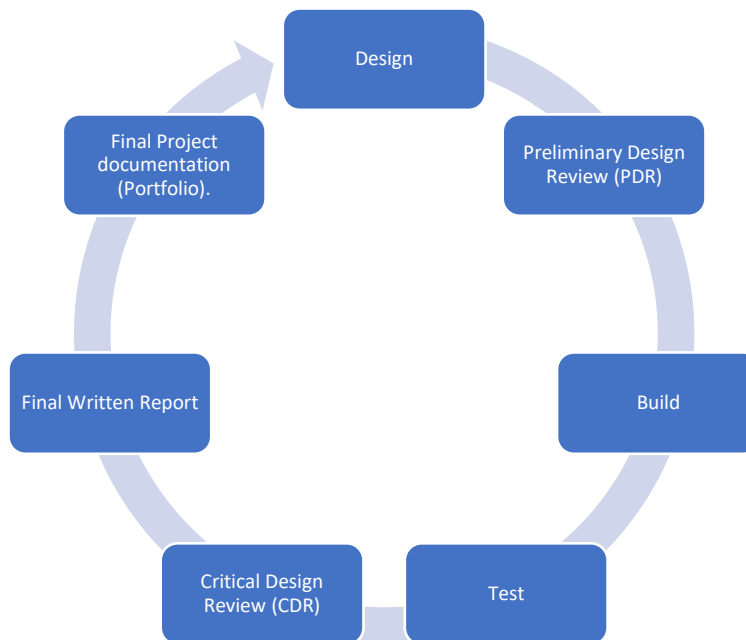


Figure 3-1: Flow Schematic of The Three Major Design Stages in Project Based Learning.

3.5.3 PROJECT TIMELINE

The project timeline from the beginning and completion of the project is shown below.

Table 3-3: Project Timeline

QFD Framework		DESIGN PROCESS/ ACTIVITY		WEEKS									
				7	8	9	10	11	12	13	14		
1	Product Definition	1	Identification of need										
		2	Problem definition										
2	Product Development	3	Gathering Information										
		4	Generating ideas/ Brainstorming										
3	Process Development	5	Modelling										
		6	Feasibility Evaluation										
		7	Decision Making										
4	Process Quality Control	8	Communication										
		9	Prototyping										

3.6 RESEARCH INSTRUMENT

The research instrument for this study is a rubric built on the quality deployment framework. This rubric will be used to assess design output from written reports.

3.6.1 RUBRIC DESIGN

Rubrics increase transparency, reduce anxiety, provide feedback, and improve self-confidence [50]. Early in their academic careers, students must be able to evaluate the quality of their own work. Holistic and analytic rubrics helped teachers and students better comprehend the standard, gave them the chance to evaluate themselves and one another, and allowed teachers to give constructive criticism [45].

3.6.2 RUBRIC DESIGN STEPS

The design of the rubric followed steps present in [47] for the development of a holistic rubric.

1. An examination of the learning objectives: this was done to ensure that they the designed rubric aligns with the course objectives.
2. Identification of quality attributes: expected quality attributes of students' work were identified. This includes idea generation, functionality, performance [33].
3. Brainstorming to determine how to describe the different levels of performance for each required design attributes listed above.

4. Thorough descriptions of each of the 5 levels of performance were described. Descriptors for what showcased excellent work and poor work were written.
5. Description for all intermediate levels were also set.
6. Samples of student work that represent different quality of designs were collected.
7. The rubric was presented to other colleagues for assessment and reflection. The use of exemplars and/or rater training could enhance the accuracy of performance assessment scoring rubrics [43].
8. When validating the rubric, a more thorough validity framework could help ensure valid assessment [41]. The framework used was the QFD.

The rubric was designed based on the quality function deployment framework. This framework was selected based on the course learning outcomes. This framework is categorized into three stages namely: product definition, product development, process development and process quality control. The product definition stage involves the collection of the voice of the customer and translating this into product specifications. Competitive analysis, and initial design concepts are developed in this phase. The Product Development involves translating the customers need into technical requirements, identifying and defining the key product characteristics and specification of the intended design. In this phase, the relationship between key product characteristics and technical requirements are determined.

3.6.3 SECTIONS OF THE DESIGNED RUBRIC

Consistency and transparency are required in the assessment of design tasks performed by students. It is to note that writing skills of the student may influence the final score received on the report. As students engage in design tasks, there is the need for an effective method of assessing design quality that can provide formative feedback irrespective of their writing skill. Rubrics contain clear goals, learning outcomes, relevant dimensions, and measurability of student outcomes. Rubrics describe the expected competence or standard. This support and improves student learning by allowing students understand how their work is being assessed [69].

The rubric further breaks down these key aspects of the quality function deployment framework into specific design stages. The design stages according to [3] are namely: identify the need, problem definition, gathering information, generating ideas, modeling, feasibility analysis,

evaluation, decision, communication, and prototyping. The section in the designed rubric are as follows.

3.6.3.1 PRODUCT DEFINITION

Definition of the product is an important step that determines subsequent activities. This involves identifying the customer needs, analyzing competitions, and establishing product or process objectives. Identification of a need clearly entails understanding the customer's voice. In problem definition, criteria and constraints are stated, and specification, functions or uses may be developed.

3.6.3.2 PRODUCT DEVELOPMENT

Activities in this stage relate to the actual design and development of the product. This includes generating ideas, developing concepts, and refining the design. In this stage, emphasis is placed on optimizing the function, performance, reliability, and safety of the product. In Gathering Information, identifies elements of evidence of any prior knowledge, searching for and gathering information needed to solve the problem and the review of literature.

3.6.3.3 PROCESS DEVELOPMENT

The process development entails identifying the process needed to produce the product, determining the critical process parameters, the relationship between critical process parameters and key product characteristics. The critical process characteristics are identified and the process flows, designed manufacturing & assembly process are developed in this phase of the quality deployment framework. In generating ideas design step, evidence of brainstorming, evaluating external information is investigated for the extent to which it is a unique or novel design.

Activities in this section ensure the product can be produced effectively. This includes modelling, feasibility evaluation and decision making. In modeling, evidence of the application of existing knowledge and principles is checked. Details on how to build the solution (or parts of the solution) to the problem should be clearly stated. Applies to initial concepts and final design. Each element of the solution should be made to fit into the larger design. All considerations of material properties needed to build solution can be listed here.

The Feasibility Analysis step assesses all planned solution to the problem (parts of the problem) on how well this solution work. It examines how well the solution meets problem definition, criteria, constraints, and estimation of the costs. In the evaluation design step, alternative solutions are

checked against criteria and how well each selection is justified, the specification of design tradeoffs among alternative solutions and oriented continuous improvement.

The decision aspect of the rubric assesses the process followed in the selection of one idea or solution to the problem (or parts of the problem), type of material, process, and design element to use from among those considered.

3.6.3.4 PROCESS QUALITY CONTROL

In this stage, activities such as communication, prototyping and evaluation ensure that the product meets desired quality standards. The plan for quality control is set, process controls are implemented, and continuous improvement is made to meet customers need and expectations. Communicating of the design in writing can be in the form of sketches, diagrams, lists, reports. A logical explanation for design choices made, tasks, milestones and a documentation of progress is required.

3.7 RUBRIC DESCRIPTION

The development of the rubric focused on the evaluation and revision of the rubric by both instructional faculty, graduate teaching assistant in the ENG100 course and an expert. The methodology used was the Delphi technique [70], [71] to gather opinions which was synthesized to identify distinct design process tasks and project outcomes. A consensus on the design steps and how it relates to the quality function deployment framework was reached.

Construct validity refers to the degree with which the definition of a concept and criteria matches the actual measurement [72]. After initial design of the rubric, the rubric was revised after getting feedback from the raters to ensure construct validity. After the design of the rubric, the evaluators of the rubric reviewed it to ensure that course goals were adequately represented in the rubric. The instructional faculty and graduate teaching assistant that tutor laboratory sessions and grade students' assignments and reports in this course were required to provide feedback and suggestions. This was done to ensure that the content of the rubric can be easily understood by students and performance levels described by the rubric were common student performances.

To ensure good construct validity [72], these different levels are formulated in words to serve as descriptors and indicators that support the use of the assessment criteria in the rubric. This complete rubric is shown in the appendix. The intent in designing this rubric is for it to assist and guide students in the design process and improve their design output. The criteria in the rubric

were derived from the quality function deployment framework. The rubric categorizes and describes these design steps into five different levels of design output quality that can be achieved by students in project-based learning. The quality score guide for each design output levels is given on a 5-point Likert scale as 1 (Poor), 2 (Weak), 3 (Good), 4 (Very Good), 5 (Excellent).

Table 3-4: Score guide for the QRD rubric.

Score	Rating	Definition
1	Poor	Below the required criteria. The design has counter-productive characteristics that may have negative outcomes or consequences.
2	Weak	Poorly satisfies customer design requirements. Meets only a few design criteria.
3	Good	Meets several of the major design criteria or acceptable equivalents. Demonstrated sufficient design consideration for the desired outcome.
4	Very Good	Generally, meets all design criteria with some additional considerations. The team demonstrates better-than-average level thinking and decision-making.
5	Excellent	Significantly exceeds design criteria for a successful working prototype. Meets all major/essential / core criteria or acceptable equivalents and met three or more additional criteria.

According to [47], a rating of 5 indicates thorough understanding and response to all required task, 4 indicates sufficient understanding and response to most required parts of the task, 3 indicates some understanding and response to many required parts of the task, 2 indicates limited understanding and lack of required parts of a task. 1 indicates no understanding of task.

As an example, the five assessment levels related to the design step of identifying a need, which falls under the product definition phase of the quality function deployment framework is shown in the table below.

Table 3-5: Designed Rubric

QUALITY FUNCTION DEVELOPMENT FRAMEWORK		Rating Scale						
		Design Step	1 (Poor)	2 (Weak)	3 (Good)	4 (Very Good)	5 (Excellent)	
A	<p>Product Definition This involves the collection of the voice of the customer, translating this into product specifications. Competitive analysis, and Initial design concept.</p>	1	<p>Identify need. Identifying basic needs (purpose, reason for design)</p> <p>Understanding the customer's needs.</p>	Student is uncertain or does not understand the customer's needs.	Student identifies only the need stated in the problem with little or no detail.	Student identifies some customer needs that may have not been mentioned.	Student identifies all customer needs that may have not been mentioned and groups them (i.e. weight, cost, texture, feel).	Student exhaustively identifies and redefines the needs, groups them and ranks all according to hierarchy.

Clear criteria were established for each level of the rubric.

3.8 PILOT STUDY

The second phase of validation of the rubric involved applying the rubric to score the gathered student artifacts. A small pilot study was done to determine the reliability of the rubric. To measure the reliability and validity of the designed rubric, a performance test was conducted. A graduate teaching assistant, an expert, and a novice were recruited, trained, and required to independently score the same artifact in a supervised scoring session. Each rater was trained on the use of the rubric and then given the same set of student documents to rate using the help of the rubric.

To achieve acceptable levels of reliability of the rubric, the process of selecting raters for assessing design quality from written report using the rubric include:

1. Definition of rater criteria: The rubric is designed to be used by undergraduate students engaging in the design process. The aim of using the rubric is to serve as a guide during the design process and to improve the design outcome. One of the raters had to be a novice designer (a first-year engineering student). The scores of the novice rater will be compared to the scores of a graduate student instructor and a quality expert. This is to ensure interrater reliability of the rubric as means to improve student design performances.

2. Identify potential raters: raters who fall in the relevant categories of a novice, an instructor or a grader, and an expert were selected. The educational, professional backgrounds and relevant experience of each rater were reviewed to ensure compliance. Since the rubric was designed to be used for self-assessment by students and for formative assessment of the design output by instructors, two raters were selected to represent these categories. The novice rater was a first-year engineering student, and the second rater was a graduate student who has experience as an instructor and with grading of similar but past students' artifacts. A third rater was selected because of his years of industry experience in design and quality assessment to represent the rating of an expert applying the rubric to assess students work.
3. Train raters: this is an important step in the validity and reliability of the rubric. Training sessions were conducted to ensure that the raters understood the rubric and the criteria for evaluating the designs. All three raters were trained for two hours each on how to independently apply the designed rubric to assess the same student artifacts which includes their preliminary design review, critical design review and the final report document. They were given an overview of the toy-design project, an explanation of the quality function deployment framework, an explanation of each design step and the description of the five different performance levels. The scoring guide was elaborated using examples of student artifacts. The raters individually scored the artifacts and presented their scores in a tabular form.
4. Establish inter-rater reliability of rubric criteria: this is done to ensure consistent evaluations. The inter-rater reliability of the three raters scores were checked. This was done to ensure that they apply the rubric and provide accurate assessment. The raters were also asked to provide feedback on the ease of use of the rubric and their experience using the rubric.

At the end of the independent scoring exercise, the raters were asked to provide feedback on the ease of use of the rubric. Some questions the raters were asked include (1) describe your experience using the rubric (2) Were there any confusing sections? (3) Are there changes you will recommend? (4) How useful will this rubric be to assist students in the design process? (5) Will the rubric be useful for self-assessment during a design process?

The novice rater and expert gave satisfactory comments on the ease of use of the rubric. The graduate student instructor requested that the problem definition stage be reviewed to make performance level 2 more distinct from level 3. This feedback was integrated into the final rubric. All feedback were examined and there was no other conflicting feedback from the three raters.

3.9 DATA ANALYSIS

Major phases in this study include the development of the rubric, assessment of artifacts which are in written form using the designed rubric. This is then followed by a thematic analysis of the student's self-reflection of their design experiences present in their portfolio upon completion of the course. Two key elements quality of rubrics and assessments are their validity and reliability. Reliability refers to the degree of disparity in evaluation outcomes. The presence of descriptors makes a rubric reliable. When more than one assessor, or the same assessor, uses a rubric on the same item, the reliability decreases as the outcomes get more diverse.

The designed rubric developed was used by all three raters to examine all written texts in a sample artifact. To determine the inter-rater reliability of the rubric, the scores of the three raters were analyzed for consistency.

To answer research question 1, Cronbach alpha, and intra-class correlation of the scores and Inter-item correlation matrix were analyzed.

3.9.1 Cronbach's alpha:

This is a measure of internal consistency (intra-rater reliability) for non-categorical data [73]. It is a coefficient of reliability (or consistency) between multiple raters on ordered scales [74]. The sufficient range of alpha coefficients is from .70 to .92. This was calculated using SPSS. The two-way mixed was selected because there were three raters who scored the same set of artifacts. Both the absolute agreement and consistency were calculated and presented in chapter 4.

3.9.2 Intraclass correlation:

This is a widely used test of inter-rater reliability analysis. For the 95% confidence interval of the ICC estimate, values less than 0.5 are considered poor, between 0.5 and 0.75 are considered moderate, between 0.75 and 0.9 are considered good, and greater than 0.90 are exceptional [75]. Intraclass correlation of rater scores were calculated using SPSS.

3.9.3 Inter-item correlation matrix:

Inter-item correlation matrix is used to assess the degree of relationship or association between items of the same construct [76]. The positive values indicate a positive relationship between quality concepts being assessed by the rubric. An inter-item correlation typically between 0.2 and 0.4 suggest to reasonable homogeneity although with some level of variation, above 0.5 is considered acceptable and measures the same construct. However, values below 0.2 are considered to measure different construct. The inter-item correlation in this study was calculated using SPSS. To answer research question 2, descriptive statistics of the team scores were carried out.

3.9.4 Descriptive statistics:

The QFD framework applies systematic approach to identifying customer needs and expectation and translating it into technical product and process requirement. The designed rubric was applied to the student artifacts. The mean and standard deviation of the preliminary design review, critical design review and final report scores of the 8 student teams used to describe the study sample [77]. The standard deviation provides an estimate of the variation of scores around the mean. The mean and standard deviation of the rater scores of all 8 teams were compared against each other to determine the performance of each student team using the rubric. Detailed description of results of the sample is presented in chapter 4.

To answer research question 3, thematic analysis of student self-reflection was done to identify themes and patterns present in student portfolio.

3.9.5 Thematic analysis of student self-reflection:

Students' self-reflection of their design experiences was qualitatively analyzed to identify the perceptions of first-year engineering student design perceptions. Perceptions refer to the language used by students to describe project knowledge and understanding, synthesis, and innovation [78]. This is a qualitative study hence inductive thematic analysis as outlined by [79] was chosen because it is flexible and not aligned to any theoretical framework. Thematic analysis of the self-reflection section of the student design portfolio was done to identify what the key factors student consider that determine the quality of their design output. Identifying first-year engineering students' perceptions of excellence in design will help contribute to pedagogical implications for design educators.

To describe the content of student self-reflection, two graduate student instructors read through students' self-reflections, familiarized themselves with it, and assigned preliminary codes. These

codes were compared across different student self-reflections to clearly identify and group the themes and sub-themes present in the student portfolios.

CHAPTER 4: DATA ANALYSIS AND RESULTS

4.1 INTRODUCTION

This chapter presents the results of the study on developing a holistic rubric that will enable engineering students to self-assess the quality of design output. The results will be presented based on the research question.

4.2 DATA ANALYSIS AND RESULTS

The results of this study will be presented based on the research question.

4.2.1 RESEARCH QUESTION 1:

How can the quality of first-year students design be improved using the Quality Deployment Framework?

To answer this question, this study revealed the possibility of designing a rubric that can be used for self-assessment by engineering students as they engage in the design process.

The rubric was designed based on the quality function deployment framework which focuses on how well designs are made to meet customer requirement. The contents in the rubric will help guide student in the designs process. The rubric can be used for self-assessment of design output by students.

A small pilot study was done to determine the reliability of the rubric. To measure the reliability and validity of the designed rubric, a performance test was conducted. Each rater was trained on the use of the rubric and then given the same set of student documents to rate using the help of the rubric. To determine the validity of the designed rubric, the raters were trained to use the rubric to assess the student team artifacts provided. These scores were compared, and the reliability was calculated. The initial rubric scores of the raters are presented below.

Table 4-1: Initial scoring by raters.

	QUALITY FUNCTION DEPLOYMENT FRAMEWORK		Design Step	Rater 1 (Novice)	Rater 2 (Instructor)	Rater 3 (Expert)
A	Product Definition	1	Identify the need.	3	3	3
		2	Problem Definition	2	1	1
B	Product Development	3	Gathering information	1	4	2
		4	Generating Ideas	4	3	2
C	Process Development	5	Modeling	2	2	1
		6	Feasibility Evaluation	1	1	1
		7	Decision	3	3	2
D	Process Quality Control	8	Communication	3	2	2
		9	Prototyping	2	4	2

During the initial scoring phase, the raters critically reviewed the written documents to identify evidence for concepts of quality in the various design stages and tasks performed. The score to be assigned was based on the extent to which evidence was present as stated by the five distinct levels in the rubric for each criterion being considered. The artifacts of all the teams for all design stages were scored and these scores were analyzed to provide insights. The table showing their rating of the score's raters.

The rubric consists of several dimensions or criteria, each of which is scored based on specific descriptors. To improve the reliability of the rubric, the wording of the rubric descriptors was reviewed in line with one of the suggestions of the rater 2 when summarizing his experience using the rubric [71], [72]. All ambiguous wordings were revised to ensure consistency with overall construct. Finally, guidelines and examples were provided to raters. The rater scores after revising the rubric are shown below.

Table 4-2: Rater scoring after revision of the rubric

	QUALITY FUNCTION DEPLOYMENT FRAMEWORK	Design Step		Rater 1 (Novice)	Rater 2 (Instructor)	Rater 3 (Expert)
A	Product Definition	1	Identify the need.	3	3	3
		2	Problem Definition	2	1	1
B	Product Development	3	Gathering information	1	2	2
		4	Generating Ideas	3	3	2
C	Process Development	5	Modeling	2	2	1
		6	Feasibility Evaluation	1	1	1
		7	Decision	3	3	2
D	Process Quality Control	8	Communication	2	2	2
		9	Prototyping	2	2	2

There is an observed similarity between the novice, instructor ratings and the expert ratings. Their rating only. This indicate that the two raters have more consistent ratings which demonstrates construct validity. A possible explanation is that instructors have advanced level of understanding of concepts of quality in design. The inter-rater reliability of the rubric was established in this pilot study. The high level of internal consistency of the criteria suggests that the entire rubric served as a credible assessment tool for the assessment of quality from written reports. The calculation of the reliability of the rubric is presented below.

4.2.1.1 CRONBACH’S ALPHA:

The analysis of scores gotten from the three raters following the initial design of the rubric yielded a Cronbach alpha of 0.649 for the three raters. Although a reliability of 0.60 or higher can be considered as ‘moderate’ interrater reliability, this suggests that there may be some inconsistencies with the reliability. The rubric consists of several dimensions or criteria, each of which is scored based on specific descriptors. The inconsistencies may be due to ambiguity wording of the descriptors. To improve the reliability of the rubric, the wording of the rubric descriptors was

reviewed. This is in line with one of the suggestions of the rater 2 when summarizing his experience using the rubric. All ambiguous wordings were revised to ensure consistency with overall construct. Finally, guidelines and examples were provided to raters.

The raters scored another document and the Cronbach’s alpha was calculated. The reliability became 0.792. Approximately 0.80. The Cronbach alpha based on standardized items was 0.807 for the three raters. This indicates a relatively high level of internal consistency among the criteria in the rubric. This is at an acceptable level.

4.2.1.2 INTRACLASS CORRELATION COEFFICIENT

The ICC statistic evaluates how closely measurements done on the same item, by the same observer, or with the same instrument agree with one another. The intraclass correlation coefficients (ICC) for consistency and absolute agreement metrics are described in the table below. For the consistency and absolute agreement of average measures, the estimator is computed assuming the interaction effect is absent.

Table 4-3: Intraclass Coefficient before Rubric revision

		Intraclass correlation	95% confidence Interval		Value
			Lower Bound	Upper Bound	
Consistency	Average measures	.649	-.096	.914	2.851
Absolute Agreement	Average measures	.654	-.064	.915	2.851

From the table, for consistency, the ICC of average measure is .649. For absolute agreement, the ICC of average measure is .654. This implies that there is an acceptable moderate level of agreement between the raters. The lower bounds are below zero indicating some degree of uncertainty around the ICC value.

The intraclass coefficient after the review of the rubric is shown below.

Table 4-4: Intraclass Coefficient after Rubric revision

		Intraclass correlation	95% confidence Interval		Value
			Lower Bound	Upper Bound	
Consistency	Average measures	.792	.349	.949	4.8
Absolute Agreement	Average measures	.760	.315	.939	4.8

For the consistency and absolute agreement of average measures, the estimator is computed assuming the interaction effect is absent. From the table, for consistency, the ICC of average measure is .792. For absolute agreement, the ICC of average measure is .760. The lower bounds are both also above zero, indicating some level of agreement beyond chance. This implies that the level of agreement between the raters increased due to the revision of the rubric and some evidence beyond chance.

Nonetheless, it should be emphasized that the number of levels in the rubric has a significant impact on the raters' level of consensus. In certain articles, Cohen's kappa is used to calculate the degree to which consensus agreement rates deviate from the rate predicted by chance. With fewer levels, there is a higher likelihood of agreement. Good agreement beyond chance is represented by kappa values between 0.40 and 0.75.

4.2.1.3 INTER-ITEM CORRELATION MATRIX:

Inter-item correlation matrix is used to assess the degree of relationship or association between items of the same construct. This table displays the correlation between each item in the rubric with regards to the quality of the design output as assessed from the written reports.

Table 4-5: Inter-item Correlation Matrix

	Rater 1 (Novice)	Rater 2 (Instructor)	Rater 3 (Expert)
Rater 1 (Novice)	1.00	0.404	0.550
Rater 2 (Instructor)		1.00	0.794
Rater 3 (Expert)			1.00

The positive values indicate a positive relationship between quality concepts being assessed by the rubric. An inter-item correlation typically above 0.5 is considered acceptable and measures the same construct. However, values below 0.3 are considered to measure different construct. As seen from the table, all values are above 0.5 and is acceptable and the inter-item correlation between the rater scores. This implies that all items are measuring the same underlying construct of quality.

The reliability of the rater scores were compared for the same teams showed good reliability. The inter-rater validity testing of the rubric is also acceptable.

4.2.2 RESEARCH QUESTION 2:

What is the quality of first-year students design upon completion of an Introductory design course?

To answer this question, the student teams artifacts were scored using the designed rubric. The QFD framework applies systematic approach to identifying customer needs and expectation and translating it into technical product and process requirement. The designed rubric was applied to the student artifacts. The table below presents the mean and standard deviation of the preliminary design review, critical design review and final report scores of the 8 student teams used in the study sample. The standard deviation provides an estimate of the variation of scores around the mean.

Table 4-6: Mean scores and Standard Deviation of student teams across artifacts

	Preliminary Design Review (PDR)		Final Critical Design Review (CDR)		Final Report	
	MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV
A	2.25	1.0	2.63	0.74	3.0	0
B	2.13	0.99	3.0	0.92	2.37	0.74
C	2.13	0.64	2.25	0.88	3.12	0.35
D	2.8	0.64	3.0	0.76	3.37	0.74
E	3.3	0.51	3.13	0.83	3.25	0.46
F	2.3	0.51	2.50	1.06	2.37	0.52
G	2.25	0.71	2.63	0.51	2.50	0.76
H	2.63	0.51	2.88	0.35	2.50	0.53

In the preliminary design review (PDR) stage, team E had the highest mean score of 3.3, indicating that they provided an excellent proposal. On the other hand, team B had the lowest mean score of 2.13. From the scoring guide, this indicates a weak proposal. The standard deviation of the teams ranged from 0.51 to 1.0, indicating the scores were consistent. Team D had the highest mean of 3.0 and team F had the lowest mean of 2.5 in the presentation document. The standard deviation ranged from 0.35 to 1.06 across teams. This indicates more variability in the scores across teams using the rubric.

In the final report, team D had the highest mean of 3.37, and team C had the lowest mean of 3.12. The standard deviation of 0 to 0.74 indicates the scores were consistent across teams. The analysis of rated rubric scores revealed that although most designs meet several of the major design criteria or acceptable equivalents, team D performed highest and team B performed weakest. There was also more variability in the presentation scores than in other categories.

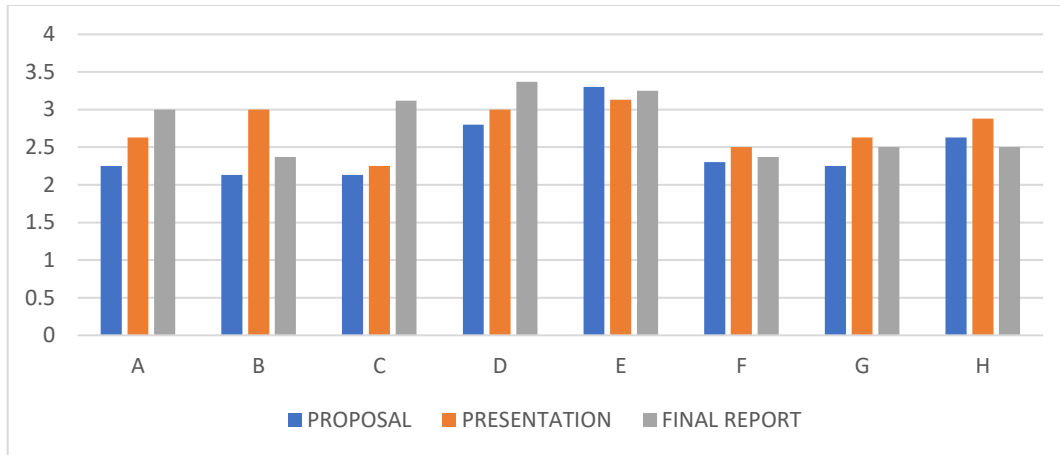


Figure 4-1: Mean scores across artifacts for each student team

The students demonstrated sufficient design consideration for the desired outcome. There was satisfactory evidence of evaluation and communication through sketches. Although some teams utilized computer aided designs in modelling, free hand sketches were prevalent in the reports.

4.2.3 RESEARCH QUESTION 3:

What are perceptions of excellence by first-year engineering students in their design projects?

Perceptions refer to the language used by students to describe project knowledge and understanding, synthesis, and innovation [78]. To answer this question, a thematic analysis of the self-reflection section of the student design portfolio was done to identify what the key factors student consider that determine the quality of their design output.

Two themes were identified in the analysis. The first theme was performance which was coded using functionality and technical accuracy. The second theme was individual factors with four codes namely: Enjoy teamwork, passion for learning engineering, gained new knowledge or skill, and domain knowledge or skill. This analysis was done using NVIVO and the codes and counts are presented below.

Table 4-7: Thematic analysis of student’s self-reflection.

Themes		Codes	Description	COUNT	PERCENT
Performance	1	Functionality	This term was used to code sentences that indicated that in-depth consideration for functionality in design imply quality.	27	79.4%
	2	Technical Accuracy	This was used to code sentences that indicate the use of the technical skill will result in quality design output.	23	67%
Individual factors	3	Enjoy Teamwork	This was used to code the sentences that indicate students’ active engagement in all design process with team members result in quality design output.	19	56%
	4	Passion for learning Engineering	– This was used to code sentences that indicate the application of design knowledge in the design process indicate quality design output.	22	64.7%
	5	New knowledge/Skill gained	This was used to code sentences that indicate the application of gained knowledge and skill will result in quality design output.	33	97%
	6	Domain Knowledge/Skill	This was used to code sentences that indicate previous technical skill will result in quality design output.	4	12%

Themes identified in the self-reflection are explained below.

4.2.3.1 INDIVIDUAL FACTORS:

This refers to the elements relating to an individual that might have tendencies to influence the quality of design output. Students in the sample population perceive the quality of the final design outcome to be largely dependent on the following individual factors:

- a. **Domain Knowledge:** 12% of the students already had previous knowledge about the design process. They believe that this could have had an impact on the quality of their design output. An excerpt of such sentence is shown below.

“The circuit design was simple as I already had some knowledge about circuits from high school. My previous knowledge helped me in my design.”

- b. **New Knowledge/ Skill Gained:** this PBL course was designed to introduce students to engineering. Students agree to have gained new knowledge from the course which they applied to design a quality product. 97% of the study sample agree to have gained new knowledge which they applied in their design.

“This class taught me foundations of engineering and how to implement them. I applied it to my design and satisfied the requirement.”

Another student said:

“I think that, as a whole, I have cultivated the mindset and creativity necessary for design thinking and innovation through the application of engineering skills.”

Generally, students relied on the new knowledge gained from the course and applied it to the toy design.

- c. **Passion to Learn Engineering:** From the analysis of the self-reflection, students link their passion for engineering to the design of quality product.

“I evolved as a student and as a human being. I gained confidence in pursuing a career in engineering. I could use the knowledge gained in the future. I am passionate about learning the hardware of the computer. How tiny parts interact to make up a device. My goal is to teach myself how to make hardware and be creative with technology.’

Another student said:

“Overall, I learnt the in-depth parts of the design process. My favorite part was learning circuit design. Even though I did a few of the optional assignments, I tried thinking critically through them.”

Rubrics encourage learning by offering formative feedback and clearly defining goals for each project job. They also make peer and self-assessment possible. Students’ efficacy in self-learning and confidence in participating in design projects can be improved.

- d. **Enjoy Teamwork:** Some students explained how the time spent brainstorming and working together with teammates resulted in high quality design output. Working in teams made students feel the sense of belonging, commitment, ownership, and corporation among team members indicate excellent design. For most students, this was their first experience

working on a team to achieve a goal. Most of them were excited about developing the ability to work alongside others irrespective of race or gender.

“I’ve gained a new perspective by working alongside other people. This helped in brainstorming ideas we applied to our design.’

4.2.3.2 PERFORMANCE FACTORS:

First-year student designers valued the functionality and technical accuracy of their design output. They reported feeling more confident once their designs worked despite feeling overwhelmed in the testing and evaluation phase. They narrated the challenges faced in testing and the design modifications they had to make.

- a. **Functionality:** 79.4% of the students laid huge emphasis on how satisfying the need indicate the designed product hugely indicate quality and perceptions of an excellent work. “I wanted the children to be able to assemble and disassemble the parts. Seeing as we had issues with the car being unstable, I reasoned making the frame to which the wheels attached would improve stability. I also thought to include most of the metal near the bottom of the car and added weights near the wheels to lower the center of gravity. The weights also helped the car have better traction on carpet.

Another student said:

“Making the body of the car was a bit difficult because we had to take all factors into consideration to make sure the car is light weight and able to move fast’. “The body of the car was assembled in many ways just to make sure that young children can play with it.

- b. **Technical Accuracy:** 67% of the students emphasized how they found the knowledge and skills gained from the course very useful in each step of the design process and in making their designs work.

“I revised my codes multiple times to ensure my toy design worked.”

PBL is designed to increase student knowledge on design and their understanding of the design process. For most first year engineering students, the ENG 100 course is where they get first design experience. They showed excitement in learning new concepts and skills they find useful.

4.3 CONCLUSION

This chapter presents the results and analysis of the assessment of quality from written reports, the results show that an assessment rubric built on the quality function deployment framework is

suitable for assessing design quality. This rubric can also provide formative feedback to students for self-assessment. Rather than the identified perceptions of an excellent design, the rubric descriptors indicate all necessary criteria for creating excellent designs and improving the quality in design.

The rubric was designed based on the quality function deployment framework. This framework was selected based on how it fits the course learning outcomes. The mean scores all student team's performance were above 2.0 (weak) but below 4.0 (very good). The students provided some evidence that indicate the quality of their work. Some teams focused only the stated design requirement. There is also an observed increase in the quality of design output as the students make progress from the proposal stage to the final presentation and in the artifacts.

The analysis of the scores gotten from the three raters revealed that the use of the rubric is reliable despite the level of experience or expertise of the rater. The rubric provides formative feedback. The novice rater which serves can use it for self-evaluation. The designed rubric will assist students in translating the voice of the customer into product and design specifications. Assessment from written reports will also help students improve their communication skill.

CHAPTER 5: DISCUSSION

5.1 INTRODUCTION

This chapter presents the conclusion drawn from the study and provides recommendation for future work. This study aimed to assess the quality of design output from written reports using a rubric based on the quality deployment framework. The research questions were answered through qualitative research design.

5.2 DISCUSSION OF FINDINGS

The goal of this study is to (1) to evaluate the quality of student designs from project artifacts, (2) to develop a means of assessment that provide feedback on design quality and identify areas for improvement, (3) to provide a quality assessment method of student designs from project artifacts, (4) to improve the quality of future student design projects.

Past research has emphasized the benefits of the use of rubrics in project-based learning and the need to improve first-year engineering student designs. The designed quality function deployment rubric indicates what students should include in a written report. This can guide students and provide an effective means of self-assessment and formative feedback to students as they engage in the design process. The different performance levels that clearly specify an acceptable design can further improve the quality of student designs.

Reliability and validity are required for an assessment tool to be valid. The reliability and validity of the designed rubric was carried out using a small pilot study. The score raring by the raters were analyzed and the result indicate acceptable reliability. To determine the construct validity, the feedback from the raters after the review of the descriptors indicate acceptable construct of quality. The novice rater when asked to provide feedback on the rubric agreed that this will further assist first-year students who have no previous design knowledge to produce quality designs as they engage in the design process.

Student artifacts were analyzed based on the designed quality function development rubric. Quality in the context of this study refers to how well final designs output meet required customer specifications. Seniors and experts produce better quality designs than freshman [12], [17]. The

ENG 100 course introduces the critical design thinking. Rating scores for the sample population range between 2(Weak) and 4(Very Good). This slightly agrees with previous research on the quality of first year student design output. A possible explanation is that 97% of the study sample had no prior knowledge or understanding of engineering or the design process. It is to also note that 5 out of the 8 design teams had scores equivalent to rating 3 (Good) or higher. In agreement with [80], they learnt the required skills such as MATLAB or ARDUINO, and ethical considerations in engineering. The designed rubric will serve as a self-assessment tool to students as they engage in design.

According to [78], first-year engineering students perceive excellence in design as presentation, communication, great design, synthesis, innovation, conceptualization, functionality, money, effort, and passion. The self-reflection of participants of this study were analyzed to identify student perceptions of quality in design. The results of the analysis of self-reflection in the student portfolio revealed first-year student perceptions of excellence in design projects. These perceptions are grouped into two broad themes namely design performance factors and individual factors. Design performance has sub themes of functionality and technical accuracy. Individual factors that influence the quality of final design output of first year engineering students include domain knowledge or skill, passion for engineering, enjoy teamwork, and new knowledge gained.

Teamwork is an important skill engineers should have. 56% of the students mentioned teamwork which involved multiple brainstorming sessions among team members as very useful in the design process and was relevant to the quality of final design output. 67% of students also perceived the quality of design output depends on technical accuracy. 12% of the students had previous domain knowledge or skill relevant to the design task. Overall, 97% of the study sample of first year engineering students considered the new knowledge or skill gained and 79.4% considered functionality as a huge determinant of the quality of their design output.

Despite majority of the student perspectives, analysis of rubric scores indicate that student actual perceptions do not directly translate to excellent designs. Good design practices prioritize safety, reliability, efficiency, and sustainability. First year students need to be able to self-access their design output. The designed rubric lists descriptors of a quality design process. The use of this rubric can be suggested to further improve student confidence in the design process as they apply the skill learned to higher level classes, and the production of excellent designs.

5.3 PEDAGOGICAL IMPLICATION

Engineering students feel a level of achievement and excitement in their ability to identify and solve design tasks in project-based learning. These identified perceptions do not equate to excellent design output. PBL requires commitment from both the educator and the student. [21] lists some challenges faced by students in PBL include lack of motivation, lack of ability to take responsibility for learning, poor behavior, and negative attitudes. To encourage learning in PBL, educators must provide support and self-assessment tools that consciously cultivate positive design behaviors, goals, beliefs, and strategies. Rubrics have been used as a strategy to promote self-evaluation and self-learning.

The knowledge and understanding of student perceptions of quality in design and a means to assess design output is relevant to engineering education. This finding of this study contributes to the field of design science research and engineering education. It addresses the concerns raised by [4] by providing a means to assess design quality from written reports. A rubric for rubrics for self-assessment and evaluation of design quality from written report was developed. By applying this rubric in quality evaluation of project-based learning, the results can be reported to a larger public and compared to those from other institutes or departments thanks to their use in other courses.

Rubrics serve as effective assessment tools for both students and educators [81]. Rubrics encourage learning by offering formative feedback and clearly defining goals for each project job. They also make peer and self-assessment possible. When students are aware of the criteria for evaluation, they can work better to meet it. Rubrics helps students co-construct their own knowledge by providing feedback [47], [82]. The designed rubric can serve as a tool to further instill quality principals, communication skills, life-long learning in engineering students. Students' efficacy in self-learning and confidence in participating in design projects can be improved.

5.4 CONCLUSION

This study focused on assessing the quality of first year engineering students design output from project artifacts using the quality function deployment framework. The quality function deployment framework focuses on improving quality of design output by capturing the voice of the customer and converting it into technical requirements. When evaluating reasoning, the solution and the explanation of the process should be considered. Students internal design thinking

and thought process is considered as constructs related evidence. Assessment of written reports will provide insights into problem solving, creativity, writing process, self-esteem, and attitudes of student's teams. Results and explanations found in the rubric can help reveal some of the student's reasoning.

Students gain understanding and gather information on the problem to be solved. Some rely on previous knowledge to create design solutions. The designed rubric provides a set of criteria and standards that can be used to assess and communicate expectations about performance on a project task. It also provides a consistent criterion for grading. It allows students examine the criteria and evaluate how their artifacts meet these criteria. It is a good way to integrate performance and feedback.

From the study, factors that can contribute to design quality include clarity of requirements, creativity, and the completeness of design documentation. Team reports that had fulfilled these criteria had higher scores. The designed rubric was found to be reliable and valid. The findings of this work indicate that a rubric is effective in assessing the quality of design output from written reports. The results are consistent with the findings from past research.

5.5 FUTURE WORK

The study presents a rubric for self-assessment of student design output. Early introduction of this tool to students engaged in a project-based course may improve student design output. Pre-test and post-test can be done to further validate the rubric for increase in design process knowledge. Long exposure to the rubric is required [50]. This rubric can be adjusted for more specific use cases to suit the target application and student population.

A larger or more diverse sample can be used to increase the generalizability of the findings in future work. The rubric can be further refined and validated through additional reliability and validity testing. The rubric is continuously applied to further investigate the changes in the quality of design output of a particular group of students over several semesters. The experiences of the teachers and students using the rubric in classroom in the diagnoses and assessment of students' competence can be studied. Investigation can be done to identify the effect of gender, prior academic performance, on how students used the designed rubric.

APPENDIX

DESIGN QUALITY ASSESSMENT RUBRIC BASED ON THE QUALITY FUNCTION DEPLOYMENT FRAMEWORK

		Rating Scale						
QUALITY FUNCTION DEPLOYMENT FRAMEWORK		Design Step	1 (Poor)	2 (Weak)	3 (Good)	4 (Very Good)	5 (Excellent)	
A	Product Definition This involves collection of the voice of the customer and translating this into product specifications.	1	Identify need. Identifying basic needs (purpose, reason for design) Understanding the customer's needs.	Student is uncertain or does not understand the customer's needs.	Student identifies only the need stated in the problem with little or no detail.	Student identifies some customer needs that may have not been mentioned.	Student identifies all customer needs that may have not been mentioned and groups them (i.e. weight, cost, texture, feel).	Student exhaustively identifies and redefines the needs, groups them and ranks all according to hierarchy.
	Competitive	2	Problem Definition This involves defining the problem,	Student is uncertain about the requirements or constraints	Student establishes only requirements or constraints stated in	Student brainstorms to identify the root cause of the problem that may	Student establishes all requirements or constraints for the root cause of the problem and	Student comprehensively establishes all requirements or

	analysis, and initial design concept is carried out here.		elaborating, or reframing the problem. Identifying design criteria and constraints, developing specifications, defining functions or uses.		the problem.	not have been mentioned.	groups them (i.e., functionality, aesthetics).	constraints for the root cause of the problem, groups them and ranks all according to hierarchy (i.e., functionality, aesthetics).
B	Product Development This involves translating the customers need into technical requirements.	3	Gathering Information Evidence of any prior knowledge. Searching and gathering	Student gathers superficial or incorrect information gathered. Lacking literature review	Student gathers basic, partial, or repetitive information. Poor literature review	Student gathers standard or well-known information gathered. Evidence of sufficient	Student is critical and extensive in gathering information from literature review and all relevant sources. Defines the relationship	Student provides evidence of extensive information gathering and literature review. Defines the relationship

	Identifying and defining the key product characteristics and specification of the intended design	<p>information needed to solve the problem.</p> <p>Reviewing literature</p>			<p>literature review.</p> <p>Defines the relationship between major product characteristics and technical requirements.</p>	between all key product characteristics and technical requirements.	between all key product characteristics, constraints and technical requirements.
		<p>4 Generating Ideas</p> <p>This involves generating alternate solutions, brainstorming, evaluating external information, coming up with an idea/set of</p>	<p>Students only generates one idea, or the idea generated is not relevant to the desired solution.</p> <p>Student does not consider principles of design in</p>	<p>Student generates few ideas but does not consider principles of design in generating these ideas.</p>	<p>Student generates several ideas and provides evidence of consideration and application of design principles in the generation of these ideas.</p>	<p>Student generates multiple ideas, showcases evidence of internalized knowledge through obvious use of design principles.</p>	<p>Student generates multiple ideas and presents an extensive consideration and application of design principles in the generation of ideas. There is evidence of</p>

			ideas for a solution. The result is a unique design (novelty) or an improvement on an already existing design.	generating the ideas.				internalized knowledge.
C	Process Development This involves identifying the process needed to produce the product. Critical process parameters are	5	Modeling Applying existing knowledge and principles. Detailing how to build the solution (or parts of the solution) from the initial concepts to	Student uses partial or free hand sketches, Sketches lack proper dimensions and isometric views. Sketches does not show the relationship between key product	Student uses simple free hand sketches. Sketches include proper dimensions and isometric views of the design. Sketches showcase the	Student presents sufficient use of CAD tools to show the relationship between key product characteristics and technical requirements. Lacking dimensions	Student presents detailed use of CAD tools to show the relationship between key product characteristics and technical requirements. Proper dimensions are included where necessary.	Student presents extensive use of CAD tools to show the relationship between key product characteristics and technical requirements. All dimensions and required

<p>determine the relationship between critical process parameters and key product characteristics.</p>	<p>the final design. Fitting the solution element(s) in the larger design. Considers material properties needed to build solution.</p>	<p>characteristics and technical requirements.</p>	<p>relationship between key product characteristics and technical requirements.</p>			<p>information is present.</p>
<p>Developing process flows, designed manufacturing & Assembly process, Identification of critical process characteristics.</p>	<p>6 Feasibility Analysis / Evaluation Assessing and passing judgment on how well a possible or planned solution to the problem (parts of</p>	<p>Student does not present use of key parameters to determine suitability of the solution to problem definition, criteria, constraints.</p>	<p>Student presents use of some key parameters to determine suitability of the solution to problem definition, criteria,</p>	<p>Student presents use of all key parameters to determine suitability of the solution to problem definition, criteria, constraints, little</p>	<p>Student presents use of all key parameters to determine suitability of the solution to problem definition, criteria, complete evidence of cost consideration</p>	<p>Student presents use of all key parameters to determine suitability of the solution to problem definition, criteria, constraints,</p>

	<p>the problem) will work. Specifying tradeoffs Examination on suitability of the solution to problem definition, criteria, constraints .</p> <p>Costs estimations and calculations.</p>	<p>Inaccurate or estimation no evidence of cost consideration for effectiveness.</p>	<p>constraints, little evidence of cost consideration or variable estimation</p>	<p>evidence of correct consideration and correct estimation.</p>	<p>and useful estimation</p>	<p>extensive evidence of cost consideration and evidence of valuable estimation.</p>
C	<p>7 Decision This step involves selecting best solution material, process, and design</p>	<p>Student shows no consideration for key requirement and constraints in selecting the</p>	<p>Student shows consideration for some key requirement and constraints in</p>	<p>Student shows consideration for all key requirement and constraints in selecting</p>	<p>Student shows consideration for all key requirements and constraints in selecting the material, process, and in</p>	<p>Student shows consideration for all key requirements and constraints in selecting</p>

	<p>element to use to the problem (or parts of the problem) from among those considered. Eliminating options Iterating and assessing the solution and the process followed.</p>	<p>material, process, and in the design of the solution. Document is scattered or confusing. There is no validation of the design solution.</p>	<p>selecting the material, process, and in the design of the solution. Document provides passive or minimal validation of the design solutions</p>	<p>the material, process, and in the design of the solution. Document is organized, and contains some validation of the design solutions</p>	<p>the design of the solution. Several considerations for customer's voice. Document is organized and logically presents all validation of the design solution. Design solution meets all requirement</p>	<p>the material, process, and in the design of the solution. There is evidence of consistent and Efficient consideration for the customer's voice. Document is comprehensive, organized, and logical. Designed solution exceeds all requirement</p>
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D	<p>Process Quality Control Set quality control plan. Implement process controls, Continuous improvement to meet customers need and expectation.</p>	9	<p>Communication Communicating elements of the design in writing (sketches, diagrams, lists, reports), or with oral reports to contractors and the community, Communicating all tasks and milestones Logical explanation, Documentation of progress</p>	<p>Document is disorganized or incoherent report and project documentation No Illustration, visuals, and graphics</p>	<p>Sketchy report and project documentation Poor Illustration, visuals, and graphics</p>	<p>Good report and project documentation Useful Illustration, visuals, and graphics</p>	<p>Organized report and project documentation Substantial Illustration, visuals, and graphics</p>	<p>Comprehensive report and project documentation Illustrative visuals and graphics</p>
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	<p>Prototyping involves creating a preliminary model or product sample. Testing is done to reveal all possible flaws in the design are identified. This results in a perfect finished prototype. Continuous improvements</p>	<p>Student presents an incomplete prototype that does not reflect design specifications. Sketchy attempts to test the design solution. Faulty prototype. Prototype does not work. Trial and error method in experimentation, Poor attempts to test the</p>	<p>Student presents a functioning but deficient prototype. There are multiple errors in the code or system deficiencies that show the design was not refined. Fair attempts to test the design solution. Partial justification for selected choice.</p>	<p>Student presents a functional prototype that meets most of the requirements but has minor issues. Good attempts to test the design solution. Adaptive experimentation, Fair justification for selected choice.</p>	<p>Student presents a functional prototype that meets all design criteria with no significant issues. . Reliable test of the design solution. Correct experimentation and justification for selected choice. Designed solution is oriented towards continuous improvement.</p>	<p>Student presents an accurate and aesthetically pleasing prototype that showcases extensive use of design criteria. Reliable and creative test of the design solution. Extensive justification for selected choice. Designed solution is oriented towards Continuous</p>
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			design solution. Random justification for selected choice.				improvement.
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Summary

Score	Rating	Definition
0 – 1	Poor	Below the required criteria. The design has counter-productive characteristics that may have negative outcomes or consequences.
2	Weak	Poorly satisfies customer design requirements. Meets only a few design criteria.
3	Good	Meets several of the major design criteria or acceptable equivalents. Demonstrated sufficient design consideration for the desired outcome.
4	Very Good	Generally, meets all design criteria with some additional considerations. The team demonstrates better-than-average level thinking and decision-making.
5	Excellent	Significantly exceeds design criteria for a successful working prototype. Meets all major/essential / core criteria or acceptable equivalents and met three or more additional criteria.

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