Work-In-Progress: Teaching Quality Using Realistic Design and Implementation Projects

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***Abstract*— This work-in-progress innovative practice paper describes the updating of a class in Quality Control. Industrial Engineering 4516 Quality Assurance is an undergraduate course in statistical quality control and related techniques. The course has recently been overhauled, with updates to the lecture materials and the addition of application-based projects. The projects have two forms: a design project, in which students create a quality system for an imaginary medical device company, and an implementation project, in which students pick a problem and create a quality-based solution plan. The two approaches are alternated roughly every term. These approaches have been used for four semesters, with a total of more than 100 students. They have been assessed based on student feedback and faculty evaluation of the final products. In both cases, the projects themselves and the in-class exercises used to prepare the students for the projects were assessed by the students to be the most valuable parts of the class. The faculty assessment was positive; the projects are designed to integrate knowledge from the class, and successful completion of the projects is a strong indicator that students have learned the class material and are ready to use it in employment or further study.**

Keywords—Industrial Engineering, Quality, Active Learning, Design Based Learning, Project Based Learning, Instructional Design

I. Introduction and Background

This work-in-progress innovative practice paper describes new approaches used in a class in Quality Control. Two approaches were taken – a design-based approach, referred to hereafter as Design 1, and a project-based approach, hereafter referred to as Design 2. Both are based on the idea that an activity-based approach will result in both better engagement and learning to a higher level of application. Both are grounded in Project Based Learning (PjBL) ideas. There is strong evidence that this approach is useful in primary and secondary education. Most literature at the post-secondary level does not include controls or other aspects of good experimental design, and this paper is no exception [1]. However, it is hoped these approaches will engage students in this potentially dry material, and give them a basis for how and when to use the techniques learned [2].

Project-Based Learning has become an increasingly important instructional approach in engineering education, known for its ability to enhance student engagement and deepen understanding of complex concepts. PjBL provides a dynamic environment where students apply theoretical knowledge to real-world problems, thereby bridging the gap between academic learning and professional practice.

PjBL is grounded in experiential learning theories, particularly those advocated by John Dewey, which emphasize the importance of learning through experience. Dewey's work has influenced the integration of PjBL in education, where students learn by actively engaging in tasks that reflect real-world challenges. This approach has been supported by research in neuroscience and psychology, which underscores the interconnectedness of knowledge, thinking, and context, as well as the social nature of learning [3].

PjBL also aligns with the principles of problem-based learning (PBL) and inquiry-based learning, both of which promote active learning and critical thinking. These educational strategies encourage students to take ownership of their learning process, fostering a more profound and enduring understanding of the material [4].

The integration of PjBL into engineering curricula has been increasingly adopted by educational institutions worldwide. For example, Stevens Institute of Technology has incorporated PjBL across courses such as Mechanics of Solids and Mechanisms and Machine Dynamics. These courses utilize PjBL to connect theoretical knowledge with practical applications, enhancing students' ability to understand and retain fundamental engineering concepts. Students who participate in PjBL exhibit higher motivation, better retention rates, and improved academic performance, especially in the design components of their courses [5].

At the University of Botswana, PjBL has been introduced throughout the engineering curriculum to better equip students with the skills required for professional practice. The university emphasizes that PjBL should not be confined to capstone projects but should be embedded throughout the entire program to ensure that students develop essential “soft” skills such as problem-solving, teamwork, and lifelong learning, which are increasingly valued by employers [6].

PjBL presents certain challenges. One challenge is the shift in the instructor's role from a traditional lecturer to a facilitator of learning. This change requires instructors to balance providing guidance with allowing students the freedom to explore and solve problems independently [3], [5]. Assessing student performance in PjBL can be complex, particularly in group projects where individual contributions may be difficult to evaluate [6]. Substantial curriculum redesign is required to accommodate PjBL. This includes integrating PjBL into existing courses, providing the necessary resources, and ensuring that students are adequately prepared for the open-ended nature of project work [5].

II. Course Designs

The two versions of the course considered here share the same learning objectives, lecture content, and some active learning exercises. They differ in their approach to the end-of-term activity that is intended to teach and evaluate the students' mastery of the material as an integrated system.

The design project (in Course Design 1) is based on a fictitious medical device manufacturer, Gizmotronics. The students are given a general description of the firm and its major product early in the term. The regular homework is cast in the context of Gizmotronics. In lieu of a final exam, the students go through a three-step process to design a complete quality system for Gizmotronics. First, realistic problems are presented, and the students propose methods from the class to solve or control each one. Next, the students are asked to fully specify the design of the control systems that they proposed in the first part. Finally, these control systems are assessed using pseudo-data with the signatures of various problems (or lack thereof). The students do all work individually but are encouraged to study together as long as collaborative work is acknowledged.

The implementation project (in Course Design 2) is team-based. Teams of 4-6 students choose a system that might be improved by applying quality methods. Early in the term they pick a problem and write a proposal outlining the problem and their approach to solving it. The students have some latitude in choosing their approach. Typical approaches include a Plan-Do-Study-Act process improvement cycle, the use of a statistical quality control method, or an experimental approach such as collecting and analyzing data from the system of interest. As the term progresses, they apply the tools they are learning as appropriate to their problem. A mid-term progress report keeps them on track. Their final products include a formal report and a presentation to the class.

The common learning objectives of both courses are:

- Dimensions of Quality
- History of Quality, DMAIC, and the 7 quality tools
- Data collection and statistical representation; Hypothesis testing
- Shewhart Control Charts for Variables and Attributes
- Other control charts for special situations
- Control limits and rules for process monitoring
- Design of Experiments and Analysis of Variation (ANOVA)
- Acceptance Testing

Course Design 1 also has control system design as a learning objective, while Design 2 includes an objective of using a Define-Measure-Analyze-Improve-Control (DMAIC) process.

The courses share a set of recently-created lecture materials. The materials were created to replace a mix of original PowerPoint, extracts from published teaching materials, and hand-written notes used in earlier versions of the class. The materials are provided to the students, and provide a complete set of reference notes. The classes use two books as additional resources for the students, but neither version has a required textbook [7,8].

Both versions use a mix of traditional lectures and in-class exercises. The exercises are referred to as "recitations" when they take up an entire class, although there are no separate recitation sections. Both versions use short quizzes to evaluate students' learning of concepts. Both use individual and group homework to practice and evaluate the students' ability to execute the material. Both use running examples to help with continuity from the lectures, through the exercises, to the homework and final projects.

III. Course Design 1

In this course design, there is a regular rhythm of two lectures and one recitation per week. In the recitations, the students do active exercises to work problems based on the last few lectures. These exercises include physical (dice games), pen-and-pencil exercise (value stream mapping, manually charting real-time data), and use of tools such as Excel and Minitab. Most of the recitations are set in the context of Gizmotronics, the imaginary medical device company. The quality system for this company is mapped (by students) in Fig. 1. The company provides a unifying framework for the exercises, and context for the design project that concludes the course. The recitation exercises are graded for participation, not correct answers. Bonus points are sometimes given for particularly good work or for winning impromptu contests during the recitations. Short quizzes are given every other week. They alternate with weeks in which homework (also set Gizmotronics) is due. All of these elements add to the grading, with the weighting shown in Fig. 2.

The distinguishing feature of this version of the course is the design exercise. The recitation and homework problems apply the course learning to aspects of the problem in isolation. The final design problem requires a unified approach. The last two weeks of class are used for this effort. The exercise starts with an recitation where the company's quality control needs are

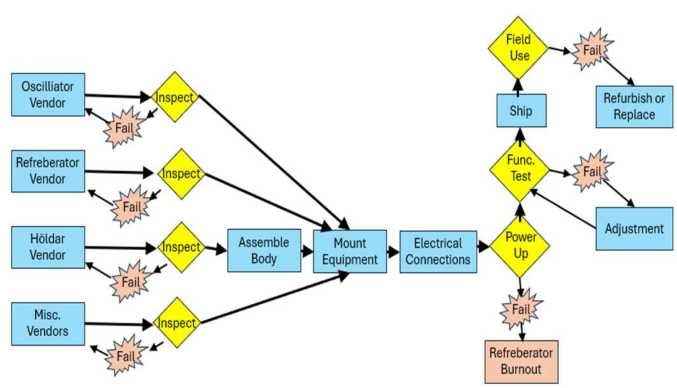

Fig. 1. Student-created map of the Gizmotronic quality system (edited for clarity)

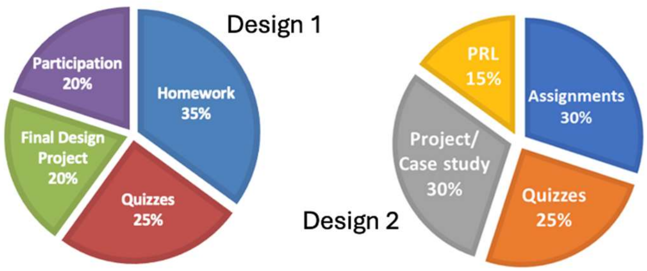

Fig. 2. Course Design Grading Schemes

defined. The students are asked to design an updated quality control system for the company. Seven separate areas of the company are described, with unique needs and problems. The problems are designed such that most of the course material will be needed to cover all of these areas. A typical set of problems include:

- Acceptance testing of incoming low-bid components
- Calibration using variable control charts
- Error monitoring using attribute control charts
- Dimensional tolerance measurement and control
- Analysis of large sets of process parameter data
- Correlation of test results with product characteristics
- Correlation of field failures with a large number of possible contributing factors

The students are first asked to decide what techniques are needed to cover each of the seven problem areas. They discuss in groups in a recitation, then (individually) do a short-deadline homework to document their ideas. In the next recitation these ideas are reviewed, and mentored corrections are applied where necessary. The students are allowed and indeed encouraged to be creative in their approaches, but they are steered away from approaches that will not work at all. After this discussion, the students are asked to create control systems for each problem, including factors such as how many samples will be collected, what chart or other tool should be used, and what rules will be used to detect and react to anomalous results. Again some in-class discussion is followed by work at home where students individually write up their designs. In the final component of the exercise, the students are given pseudo-data to run through their control systems. They write up the results, plotting what their chart or other tools did with each set of data, the defects or anomalies that they detected, and their proposed corrective actions, if any. In all cases students are asked to submit work in the form of written reports. The reports include explanations of methods used, discussions of results, and reflections on how the quality tools worked (or not) in each case.

IV. Course Design 2

In this course design, the students are taught quality control concepts based on lectures and in-class activities. In-class activities consist of inspection experiment, dice experiment, Excel, and Minitab applications. The assessment in this course is based on four categories and is distributed as shown in Fig. 2. Assignments are individual take-home homework which are direct applications of the taught knowledge. This gives the students time to access and use Excel and Minitab software. However, the first assignment was group work based on different case studies about DMAIC (Design-Measure-Check-Act) while the students got together to discuss the case study and present it to classmates. Then all are required to compare the various case studies presented in class individually.

Quizzes are in-class individual assessments to measure the theoretical background of the numerical application of quality aspects. PRL stands for Participation-Reflection-Learning Log which is a category used to assess the students' participation and understanding in class. Projects are group-based assessments where students form teams (4-6 students), pick their own ideas, apply their knowledge, and present their solutions. The project is based on three stages: proposal, progress, and final stage. In the proposal stage, students define the problem and project goals, develop a process map, and define the customer requirements. In the progress stage, students collect data either by themselves or online, perform data analysis, and propose solutions based on a literature review. Finally, students apply the solutions if it is applicable or provide an implementation plan if it is not applicable. They also provide a process control plan, conclusions, lessons learned, strengths and weaknesses, and proposed future work. All these stages are provided in professional technical engineering writing to enable the students to experience the professional world. The rubric of the stages gradually increases in rigor throughout the semester as the students gain more knowledge and become more comfortable with the instructor and the course itself as shown in Table 1.

TABLE I. Course Design 2 Project Grading Rubric

Part	Weight
Project Proposal	15%
Progress Report	20%
Final Report	35%
Final Presentation	30%

In Course Design 2, as the students have the freedom to pick their own quality problem, this freedom also provides ambiguity. Promoting the acceptance of ambiguity and uncertainty as regular elements of engineering design throughout the course project experience is crucial. The goal is not only to alleviate students' stress and frustration but also to enhance their professional skills in anticipating, managing, and even embracing uncertainty, preparing them for their future careers [9]. The students however get general structure to pick from three categories: 1) apply a Six-Sigma or DMAIC process to the proposed problem, 2) apply a statistical process control model or models to some process, or 3) conduct an experiment to identify and quantify potential cause-and-effect relationships between a performance measure and one or more independent variables. Then the students are asked to provide a proposal as mentioned above. After each stage the students receive appropriate feedback to support them to improve their next steps.

V. Results

At the end of the class a survey was distributed. The survey carried a small amount of participation credit. Student response was over 80%. Four classes, from Fall of 2022 to Spring of 2024, where surveyed. The classes had 22-32 responding students each, for a total of 110 surveys returned. Three of the classes were Design 1, and one was Design 2. The students were asked to rate if specific topics and learning modes were helpful to their learning, on a 1-5 scale. They could also comment on the strengths and weaknesses of the class with open text response questions.

Fig. 3 shows the comparison between average students' scores for various topics, ordered by score. With one exception there was no statistically significant difference between the responses for the 4 classes, so results were averaged across all classes. The colors indicate material that was unique to one of the class types. Blue shows Lean Six-Sigma material that was only giving in Class Design 2. It was preparation for the group project. The red material was only given in Class Design 1. The Design Project Recitations were the in-class part of the Design Project. The other unique topics were a matter of available space on the schedule and were not integral to the course architecture.

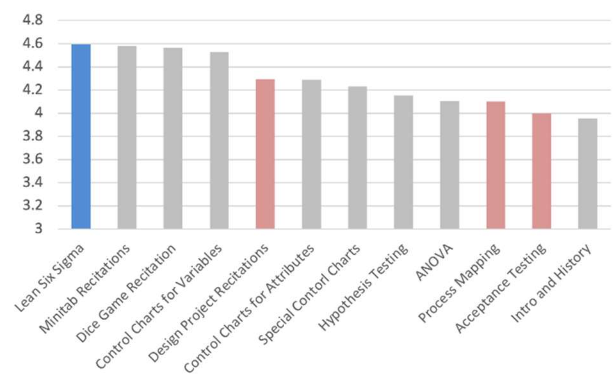

Fig. 3. Students' self-assessed learning by topic

There is a significant difference in student ratings between three groups of topics. The first four topics, which include the Lean introduction and the tools, demonstration, and lectures for Shewhart control charts for Variables, were rated most helpful by the students. This is the core material of the class, so this is a good thing! The second group included more specialized control charts, as well as the design project recitations which themselves covered may of the specialized charts as they were applied to the case study. The students found the material furthest from the core material (ANOVA, Mapping, Acceptance Testing, and Intro/History) to be the least helpful.

There was a significant difference between the topics unique to Design 1 and Design 2. The students felt the Lean Six-sigma material in Design 2 was more helpful than the design and miscellaneous other material taught in Design 1.

Examination of the open response answers reveals that students are interested more in learning the basic and introductory quality concepts, and as the topics get deeper the students tend to be more inactive and disappointed, especially when learning about ANOVA and other special topics. These topics were done later in the term and perhaps seemed a bit rushed. A quote from a student review "*More time if possible should be spent on ANOVA. The topic is very overwhelming when compared to the other modules and without every term being defined and explained and carefully walked through piece by piece, it is very difficult to follow*."

Fig. 4 shows students' ratings by teaching mode for both course designs. Again, common elements are averaged; the only distinguishing elements are the Design Project of Course Design 1 and the Group Project of Course Design 2. It can be seen that students found the recitations/in-class activities and the use of Excel and Minitab tools to be most helpful. There was a statistically significant drop the next level, containing homework, the design project, and group projects. Students are dissatisfied with lectures and quizzes. One quote from a student about lecture: "*I think that the class lecture slides could be a bit more engaging. Sometimes when there aren't class activities, it's hard to stay focused throughout a class of just lecture slides.*" A quote about the quizzes is "*I hate the way that the homework tests actual numbers and quizzes test concepts,*" which is unfortunate, as that was the intent. There was not a statistically significant difference in the student response to the two course designs.

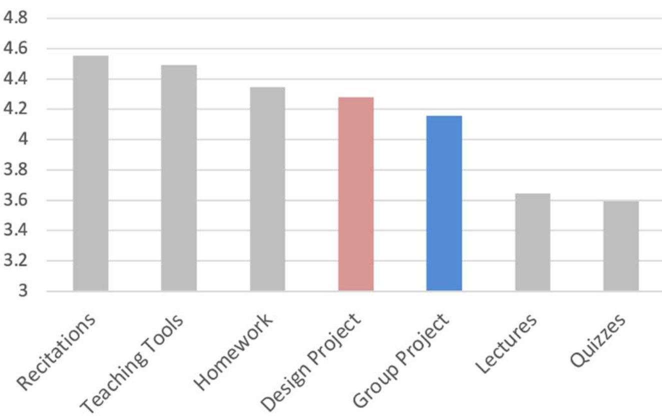

Fig. 4. Students' self-assessed learning by teaching mode

On the positive side, students particularly liked the recitation sections, with many positive comments along the lines of *"I really like the recitations, and I think that they are a great way to apply what we have learned and know how to actually use it ourselves!"* They also appreciated the structure: *"I really liked the … balance of two lecture days and one recitation day to apply what was learned. I also appreciate the alternation of quiz weeks and homework weeks."* They also understood and appreciated the integrating effect of the final project: *"Design [project] was great to revisit all the materials and use it in one large practical case."*

The grading rubrics used in the two course designs were different, an so grades are not a meaningful comparison. In general, students did well in both versions of the class. The key result was that almost all of the students demonstrated a mature ability to use the course materials to analyze realistic problems. ABET Student Outcomes were also assessed for both versions of the class, and both were solid. The ANOVA unit was an outlier in all modes of evaluation. The student grades had very high variation between sessions, and odd non-normal grading patterns. In one case the ANOVA grades negatively affected the course's ABET scores. This may have been due to the unit's position at the end of the class, when some students realized they could drop their lowest grade and thus skipped the unit, receiving a very poor grade on it.

VI. Conclusions and Further Work

The redesign of the Quality Assurance course was successful in both modes. Almost all students demonstrated the ability to both answer questions based on the course material, and use the material in an integrated fashion to solve realistic problems. The level of student satisfaction was mixed and further improvements are needed. The students were unimpressed with the updated lecture material, finding it dull compared to the more active parts of the course. On the other hand they found the active learning recitations and use of tools such as Excel and Minitab to be very helpful to their learning. They considered both versions of the unifying end-of-term project to be helpful, but not as much as the regular recitations. They preferred the central subject of the course (the design and use of Shewhart control charts) over other topics, and were particularly unimpressed with the lessons on ANOVA. These results were essentially independent of the Course Design.

The course continues to be offered in both modes. The schedules will be adjusted to include less introductory material, both by trimming introductory and history material, and coordinating with prerequisite courses such as Probability and Statistics to avoid unnecessary review. Time saved will be invested in improved teaching of ANOVA and Acceptance Testing, including active recitations for both topics.

As a proposed solution for the quizzes problem, next semester (which will run course Design 2) in-class activities will be conducted in the theoretical lectures. It will be a challenge to define active learning in the theoretical material where no Excel, Minitab or other experiments are done. The in-class activities will also include conceptual testing of the material in the form of mini-quizzes. The mini-quizzes will be part of the participation grade. This idea will be evaluated at the end of the semester as part of the student survey.

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