

Putting the horse before the cart
– Fitting a new project into established design and writing pedagogy

W. Riddell†, S. Bakrania†, K., Bhatia†, J. Courtney, K. Dahm†, R. Harvey‡, L. Weiss††

College of Engineering†
College of Communication‡
College of Liberal Arts and Sciences††

Rowan University

Project-based learning has been an important aspect of the Rowan University College of Engineering curriculum since its inception in 1996¹. In the fall of the sophomore year, engineering students take a multidisciplinary, integrated, project-based course that is designed to teach both design and technical writing. Recently, significant changes were made to the course by introducing a more systematic approach to design instruction than used previously, and by adopting a stronger “write-to-learn” component to both formal and informal writing assignments built around a main project that had been run for several years before.

These changes have been shown to result in measurable improvements in team’s design performances, course evaluations, and subsequent design reports². However, an additional benefit of the approach was realized in the fall 2008 semester, when a long standing design project was replaced with a new project. In earlier offerings, developing a new project meant completely rewriting assignments, and a risk that the scope of the project would be inappropriate. By the fall 2008, aspects of the course such as scope of the project, design lectures and writing assignments had evolved to support clearly stated objectives for both design and technical writing. The result of these changes was that it was relatively straightforward to define a reasonable scope for the design challenge, and the new writing assignments required only minimal changes in the details. This paper briefly discusses the instructional framework and course objectives for both design instruction and technical writing, compares and contrasts the old and new projects and gives examples from writing assignments and grading rubrics that demonstrate how the instructional framework facilitated developing the new project and corresponding instructional materials.

Introduction

Since its inception, the College of Engineering at Rowan University has emphasized project based learning (PBL)¹. Proponents argue that PBL is effective at reinforcing topics learned in traditional coursework, developing the so-called professional skills, and improving retention of students³. However, PBL can be a difficult environment to teach in³, and the professional skills thought to be developed through PBL are challenging to assess^{3,4}. Furthermore, the development of suitable projects and running of these projects can place significant demands on faculty and

staff time. As a result, there is a risk of letting a project become the main focus of a course, overrunning the educational objectives of the course.

Continued Development of Sophomore Engineering Clinic

All Sophomore engineering students take a two course sequence of project based learning courses, Sophomore Engineering Clinic I and II (SEC I and SEC II). These courses are part of a larger, eight semester sequence of clinic courses. Sophomore engineering clinic I and II are specifically charged with teaching design and communication. Technical writing and parametric design are covered in SEC I, while public speaking and “big picture” design are covered in SEC II.

By fall 2004, SEC I had been developed into a highly integrated course, team taught by faculty from the College of Communication and the College of Engineering. Class meetings included two 75 minute writing classes, led by a Communication faculty, and one 160 minute design lab, led by five Engineering faculty. In the design lab, students worked in teams of 4 to 5 students on a project called the “Hoistinator.” The objective was to design and build a crane arm that would be attached to a faculty-supplied I-beam, as shown in Figure 1. Although the exact objective equation was changed from year to year, it was significantly based on a strength-to-cost ratio. At the end of the semester, teams built and tested their cranes, with the performance being a significant part of the final course grade. In the writing classes, students developed their skills as technical writers. Reports documenting the progress and the final design were important deliverables for the class. Based on integration between design and writing, students working on multidisciplinary teams, creation of satisfactory design solutions, and student enthusiasm, the course was considered successful. While this approach is becoming more widely adopted, at the time, the integrated, project based course was fairly unique. This version of the course is documented by Constans, et al.⁵.

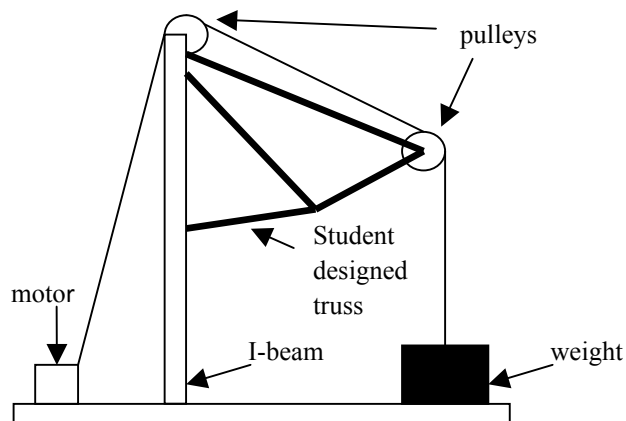


Figure 1. A schematic of a crane. The motor, I-beam and weights are provided; students design and build the truss structure.

Philosophical Changes

In summer 2005, faculty met to assess the course. Despite some obvious successes to the project, significant problems were observed in the way that teams went about designing. For example, many important decisions were being made without the support of calculations. These observations led to the faculty reconsidering the way that design was being taught. As a result, four tenets for teaching design were explicitly stated. These tenets are listed in Table 1, but are discussed in detail by Riddell, et al.⁶. The tenets, combined with literature on teaching technical writing and design, helped the faculty to develop an instructional framework⁷ and refine the course objectives, which are listed in Table 2, along with more detailed indicators.

Table 1. Tenets for Teaching Design

Building is not the same as designing.
Students can be both creative and analytical. However, they have a hard time harnessing these skills at appropriate times during the design process.
Language should play a role in design education beyond representing final designs.
Design can be taught.

Table 2. Objectives and Indicators for SEC I

Objective	Indicator
<i>Students will demonstrate rhetorical awareness</i>	Present technical information to different audiences
	Analyze the audience and account for competing and/or overlapping needs of different readers
	Select the best way to address audience and context needs for a given communication task.
<i>Students will write in the various engineering genres and follow appropriate conventions</i>	Write effectively in engineering genres such as progress reports and final reports
	Use conventions of academic writing in engineering (such as IEEE citations)
	Use engineering databases in library and internet resources
<i>Students will demonstrate specific communication abilities needed for engineering communication</i>	Skill with technical writing tasks such as description
	Understanding of importance of data presentation, data usability, and ethics
	Produce effective writing in a short time period
	Write collaboratively with team members
<i>Students will demonstrate effective design processes</i>	Generate multiple engineering design solutions using convergent and divergent design processes
	Apply sound engineering principles to choose the best solution, and see it through to completion
	Use parametric design to optimize an artifact or process

Organizational Changes

Several changes resulted from these discussions. Explicit design instruction was introduced into the course. An additional project was added to the course that allowed the students a more gradual introduction to parametric design⁸. In addition to being shortened, the Hoistinator

project was modified⁹. An additional constraint that the crane be constructed as a truss was added. This change meant that the sophomores could completely analyze their design. Writing assignments and grading rubrics were adjusted to directly reflect the objectives listed in Table 2.

The design process involved students brainstorming potential ideas for trusses. Each initial idea was then used to define a family of truss shapes. A family would have the same number of nodes, joints and member connectivity, but different members of the same family would have different locations of specific joints. Student teams used MatLab algorithms to perform a truss analysis for families of trusses, using the locations of joints as parameters. While it is likely possible to write a computer program that will explicitly develop an optimal truss design for this project, the faculty did not expect, nor encourage, the sophomores to accomplish this. Instead, teams were taught an analysis procedure that required a different code for each family of trusses. Then, teams identified several families with a limited number of parameters and optimized a single family at a time. This approach required students to apply judgment when defining parameters.

These changes resulted in noticeable improvements in the design efforts². The improved instructional model was shown to have lasting effects on the students in the second semester of sophomore year², as well as in senior year projects for Chemical Engineering students¹⁰. However, in fall 2008, an additional benefit of the instructional framework was observed when a new project was introduced.

Introducing a New Design Project

In summer 2008, the faculty teaching SEC I decided to retire the Hoistinator project and develop a new project. Although it had been developed into a largely successful and smoothly running project, the Hoistinator had three main factors working against it. First, after several years, the project was at risk of becoming stale. Second, the physical behavior of the truss gave a significant advantage to Civil and Environmental Engineering and Mechanical Engineering students, who have taken statics by this point in their curriculum, over Chemical Engineering and Electrical and Computer Engineering students, who have not. Finally, the manufacture of the trusses (largely from aluminum sections) placed a great demand on the machine shop at the end of the semester, which conflicted with the needs of many upper level mechanical engineering courses. However, developing the Hoistinator project and corresponding writing assignments had taken the efforts of numerous faculty members over several years. Potentially repeating these efforts for a new project was a daunting task.

Prior to deciding to retire the Hoistinator project, the SEC team had identified the following principles to guide the selection of future projects⁷. These principles were essential in developing a new project.

Table 3. Guiding principles for design projects

Projects are team-based. Ideal projects are those that allow students from all disciplines to make significant contributions.
Good design projects will include and reinforce some technical content from the engineering curricula. However, projects should fit the pedagogical needs of teaching design and communication, and the technical content covered should depend on the project. Projects should not be counted on to cover any specific engineering content.
Projects should have objective measures for success and failure. The consequences for failure should be significant, as they would be in professional practice.
Students should be challenged by a progression of design projects that increase in complexity to enable them to gradually learn to handle complex design tasks.
Constraints and criteria should start out simple and be clearly defined by the faculty at the beginning of the sequence. The responsibility for determining the constraints and criteria should shift to the students as they progress through the curriculum.
Projects should be rooted in design, with nontrivial calculation used to inform the design process.

Overview of Wind Turbine Project

Keeping the principles listed above in mind, the faculty team developed a wind turbine design project. Details of this project will be discussed by Bakrania, et al.,¹¹ but an overview is given here. The coefficient of performance of a wind turbine, C_p , is the ratio of the energy captured by the turbine to the kinetic energy in the wind that passes through the area swept by the turbine. The objective function that each team was evaluated on was the average C_p at a low and a high wind speed.

A large fan, plastic sheeting, and a metal diffuser were used to generate a temporary wind tunnel that could produce laminar wind flow at two different speeds. A hub that could be quickly and easily attached to a faculty-supplied generator was designed, and a hub for each team was manufactured. Wooden dowels were also cut to the specifications and distributed to the teams. The hub and dowels are shown in Figure 2. Teams were supplied with luan or foam board for the manufacture of blades. A turbine that was constructed by the faculty as a demonstration is shown in Figure 3. Teams could determine the number of blades (in various combinations up to 12), the pitch of the blades, and the width of the blades. Both the pitch and width of the blades could vary with the distance from the hub.

In practice, optimizing a turbine is a tremendously complex task. For this project, a simple constraint was added to the project that allowed sophomore engineering students to analyze the turbines. The cross section of each blade was required to be rectangular. In other words, teams were not designing the airfoils along the blades. Teams were given data for lift and drag coefficients for a single cross section that was felt to be representative of a rectangle. As a result of this assumption, all 24 teams were able to develop a MatLab code to analyze the simplified turbine configurations – allowing nontrivial calculations to inform design decisions. As with the previous project, it is likely possible to write a single program to optimize the turbine for the given performance equation. Unlike in the Hoistinator project, a single MatLab code could be used to analyze all of the potential turbine designs teams could consider. However, the

combination of calculation time for each design, and the large number of parameters meant that the student teams needed to apply judgment when they decided which parameters to consider.

The scope of the turbine project was carefully chosen to be similar to that of the Hoistinator. Specific aspects of the two projects that are analogous are summarized in Table 4. However, certain aspects of the turbine project had distinct advantages over the Hoistinator. These are summarized in Table 5. These improvements were in direct response to the weaknesses of the Hoistinator that were described above.

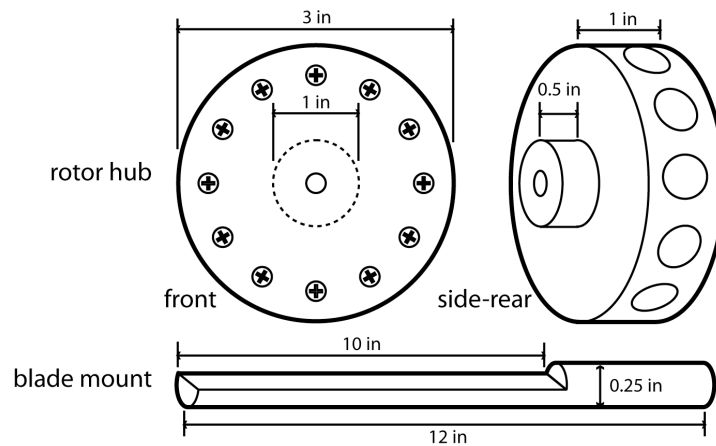


Figure 2. Standard hub and dowels supplied to student teams

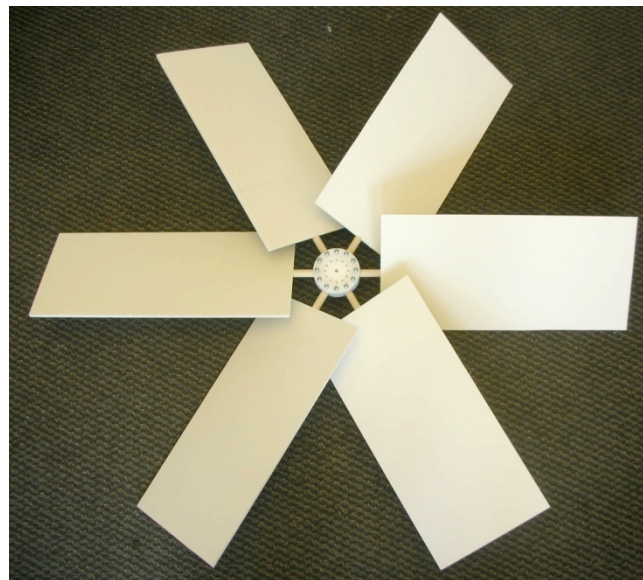


Figure 3. Demonstration turbine

Table 4. Aspects of design projects that are analogous

	Hoistinator	Turbine
Parametric Design Challenge with too many variables for sophomores to explicitly optimize	Number and location of joints Number of members Member connectivity Member size and material	Number of blades Width of blades Pitch angle of blades
Additional Constraint to Enable Analysis	2D Truss structures only No rigid connections 3D support not counted in cost of truss.	Rectangular cross section – no airfoil
Optimization Formula	Strength to Cost	Average of C_p at two wind speeds
Primary Analysis Tool	Matlab program	Matlab Program
Governing Physical Principles covered in Physics I	Equilibrium	Kinetics and momentum
Supplied Components	Frame Pulleys Weights	Pre-manufactured hub Wooden dowels Generator Wind tunnel

Table 5. Aspects of design projects where turbine was an improvement

	Hoistinator	Turbine
Explicit Analysis Procedures	<i>Covered in Statics:</i> Truss analysis	<i>Covered in SEC I lectures:</i> Blade element theory Blade momentum theory
Construction Materials	<i>More Expensive:</i> Aluminum and Plastic bars, Nuts and bolts	<i>Less Expensive:</i> Balsa Wood and Luan
Construction Technique	<i>Requires machine shop:</i> Cutting bars Drilling holes.	<i>Does not require machine shop:</i> Cutting Balsa wood or Luan, Gluing blades to dowels Attaching blades to dowels with set pins

Revised Assignments

The assignment sheets for this class are fairly detailed. In both fall 2007 and 2008, the assignment sheet for the final report was 4 pages long. The assignments include a brief introduction to the genre of final reports, due dates, objectives of the assignment, detailed descriptions of all the sections required for the final report, document specifications, and additional notes. Aside from the due dates, and changes such as replacing “truss” with “turbine” the only changes in the assignment sheet were in the descriptions of the report sections. The ten sections that are specified on the assignment sheet are listed in Table 6, along with an assessment of the extent of changes made. Many sections needed minor changes, for example, asking for different types of plots reflecting the different analyses that were performed. Only the section on design process required significant rewriting. This was required because the two projects required different design procedures. The Hoistinator required a different code for each

family considered, but each analysis was fairly quick. This meant that teams needed to evaluate which families of trusses to consider. The turbine required only a single code, but each analysis took longer to perform. This meant that teams needed to decide which parameters to evaluate. As a result, the expectations for the section on the design process were significantly different. The specifications for the Design Process section of the two different final reports are shown below.

Table 6. Specified Sections of Final Reports

Section	Extent of Changes
Letter of transmittal	None
Cover Page	None
Executive Summary	None
Acknowledgements	None
Introduction	None
Design Process	Significant
Final Design	Minor
Results and Discussion	Minor
Conclusions	Minor
Appendices	Minor

Design Process for Hoistinator

This section reviews the design process with an emphasis on the thought process and the data that inform your final design. Begin with the definition of the design problem. Then describe the process by which you chose and optimized your final design. At the beginning of this discussion, you should refer the reader to the final design section, and the figure showing your final design. In particular, identify the information that you had available to you when you chose the truss family you optimized and explain the basis for your decision. Include figures showing at least two other truss families that you considered; part of your discussion here should address the criteria that led you to eliminate these design possibilities. Explain the additional design work you undertook to further optimize your final design. Plots showing data from your parametric studies should be integrated into this discussion and their impact on your final design should be explained. Additionally, provide the relevant parameters for the plastic that were measured on the MTS machine. One or more sets of data that you used to predict load-deflection relationships and failure load for critical plastic members would be helpful. The raw data that are presented on the wiki might or might not be appropriate for making your prediction. It is possible that you will need to consider the relationships between multiple sets of data to extract the

pertinent information. Be sure to summarize and show all relevant data in figures or tables in the body of the report.

Design Process for the Turbine Project

This section reviews the design process with an emphasis on your parametric design strategy. Begin with the definition of the design problem. Then discuss the process by which you chose and optimized your final design. Refer the reader to the Final Design section and the figure showing your final design. In this discussion, address the following questions:

- How did you sample the design space to narrow in on the optimal parameters?
- How did you use your algorithm to vary the parameters?
- What additional constraints did you impose on your design space and why?
- How did you account for the interdependencies among parameters?
- How did you evaluate the performance of a given design instance?
- How did the prototype testing drive your final optimization?
- How was the algorithm structured to converge on an optimal solution?

Revised Rubrics

The rubric sheets were significantly revised in fall 2008. However, this was more a reflection of the constant evolution of course materials than a need to change based on a new project. Most significantly, in fall 2007, the grading rubric included 20 indicators that were organized around the course objectives. In fall 2008, the grading rubric included 37 indicators that were organized around the structure of the report. These changes were made because the faculty felt it would make it easier for students to evaluate their own reports before turning it in. However, the nine indicators (spread between two sections) that relate to design objectives in the fall 2008 report suggest that this rubric is widely applicable to any design project that might fit the instructional framework developed for SEC I.

Table 7. Design related indicators in final report rubric for fall 2008.

Defines the design problem, including goals, parameters, initial constraints, and criteria for evaluating effectiveness of the final design
Explains initial explorations of design space and development of parametric model
Identifies design decisions and constraints established by the team and their rationale
Describes how algorithm was constructed to analyze the parameters
Explains how given design instances were evaluated
Reviews rational for prototype testing and explains how results were used
Shows representative data as needed to illustrate key strategies and decisions
Shows results of a series of parametric studies that informed the final design
Discusses how results were interpreted

Summary and Conclusions

Fitting design projects and writing assignments into an established instructional framework is an essential aspect of teaching project-based courses. In addition to pedagogical benefits, which have been documented in the literature, an established instructional framework based on defined learning objectives enables introduction of new projects into existing courses.

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