The Design Report: A Staged Approach

Rebecca K. Toghiani[1]

Abstract – Design reporting in the senior Process Design course is discussed in this paper. Class discussions allowed students to recognize the importance of each section of a design report, to identify who in the business/engineering organization might be most likely to read/review a particular section, and to identify specific elements that were critical to formulation of a particular section. With multiple projects completed over the course of a semester, it was possible to include only 3 to 4 sections in the first design report (selected by the instructor). Each subsequent report incorporated additional sections. The final project report included all sections typically found in an engineering design report. This staged approach to design reports has benefits realized by both the students and the instructor. The staged approach, where emphasis was placed on specific sections of the report, allows students to hone their skills in reporting/crafting each specific section. They also were able to incorporate feedback from previously submitted reports on relevant report sections. This approach also benefited the instructor through focused grading activities and reduced load as the instructor had to focus attention primarily on those sections new to the given project/report. Those sections that were not new to the specific report were typically of higher quality and required little critique as students had successfully incorporated feedback from the graded previous report. This approach could be implemented in any senior capstone design course or laboratory course where multiple projects/reports are performed over the course of a semester.

Keywords: Design reports; capstone design, communication skills, student teams, chemical engineering

INTRODUCTION

In Chemical Engineering, the senior capstone element is often a two semester design course sequence. The first semester focuses on the fundamentals of process design, including process economics, equipment sizing, and development of process flow diagrams (PFDs). Usually, multiple small design projects of three to four weeks duration are completed during this first course. The second semester is typically focused on a more comprehensive design project (i.e., a plant design). Establishing a balance between the technical aspects of a project (i.e., the 'design' element) and the communications aspects of a project (i.e., the 'reporting' element) is critical in providing undergraduates with the necessary skills to function effectively in the industrial sector. The instructor plays a key role in establishing the need for and providing the tools necessary for developing both the 'design' and the 'reporting' capabilities of their students.

Seniors entering the capstone design sequence typically have little or no experience in preparing design reports, even though many of them may have worked as engineers through internships or cooperative education. In industry, project design reports are actually very important as they form the repository of company intellectual property and the decision-making process that led to the development of a particular facility design. If a retrofitting project focused on capacity expansion is undertaken some ten to fifteen years in the future, having the necessary information available to reveal the decision-making process during the original design phase as well as the basis for equipment sizing calculations and source of data employed is extremely beneficial to the team tasked with the retrofit. Technical reports and memos also communicate design effort to supervisors and managers, those responsible for both technical and financial operations of the company. Thus, effective communication of the importance of a particular project, its technical viability as well as the economic bottom line associated with the project, must be an objective of these reports/memos.

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[1] Dave C. Swalm School of Chemical Engineering, Box 9595, Mississippi State University, Mississippi State, MS 39762; rebecca@che.msstate.edu

COURSE DESIGN PROJECTS

Over the course of the semester, three projects were assigned. Each project focused on a different engineering/design objective. The design projects along with the project objective are shown in Table 1. These projects were adapted from a design project collection [1] established and maintained by the authors of *Analysis, Synthesis, and Design of Chemical Processes* [2], used as the required text for both courses in the senior design sequence. A brief description of each project is provided as are elements of the lecture and the laboratory components of the course required to provide students with necessary information to successfully complete the projects. Lectures covering specific knowledge for a particular project were provided at project start.

Table 1. Assigned Design Projects

Project #/Title	Project Objective	Length of Project/Required Reporting
1/Comparing Process Alternatives	Comparison of two process alternatives - direct and indirect sequencing in a distillation train	3 weeks/Written Report
2/Debottlenecking Production Process	Identification of bottleneck in acetone production process/retrofit to accommodate 33 % increase in capacity	3 weeks/Written Report/Poster
3/Waste Minimization/Heat Integration	Waste minimization/alternative recovery methods for hydrogen/heat integration in a toluene hydrodealkylation process	4 weeks/Written Report/Poster and Presentation

Project 1/Comparing Process Alternatives

In this project, the focus was to compare two methods of sequencing separations in a distillation train. A lecture discussing heuristics for separations sequencing as well as specific examples of direct and indirect sequencing was provided. A companion laboratory section accompanies the Process Design course. In the laboratory, activities focused on thermodynamic property models and simulation of distillation columns using both shortcut and rigorous methods (design mode) were completed.

Project 2/Debottlenecking Production

In this project, an established design for a process is determined to be inadequate to meet the required production capacity. This type of project is one commonly encountered by recent graduates entering the workforce. Production capacity must be increased, and the engineer has to quickly identify which equipment item(s) or step(s) in a process limit(s) the overall process in meeting the new capacity. Lectures were included in the course on debottlenecking, process trouble shooting and design performance calculations for process equipment (the text used for the course has excellent resources for these topics). In the companion laboratory, activities focused on the simulation of existing equipment (a 'rating' simulation, as opposed to a 'design' simulation).

Project 3/Waste Minimization/Heat Integration

In this project, the concepts of waste minimization and heat integration were the focus. The hydrodealkylation of toluene to produce benzene is a process that sometimes possesses favorable economics and sometimes possesses unfavorable economics, depending primarily on the relative market values of benzene and toluene, as well as operating costs (primarily energy costs associated with separations).

To expose students to the concepts of waste minimization (both materials and energy), lectures were included - what waste minimization is and why is it important. Also discussed was the "Waste Reduction Algorithm" (WAR), developed to quantify waste reduction and environmental impact of a process [3-5]. Waste minimization efforts in the project were to focus on two streams: a gaseous effluent stream containing hydrogen and nitrogen and a liquid effluent stream of biphenyl. Reuse/recycle of hydrogen in the gaseous effluent stream (a hydrogen/nitrogen mixture) through use of gas permeation membranes for recovery of the hydrogen from the stream was suggested. Elimination of the biphenyl stream through the concept of 'recycle to extinction' for a product of an equilibrium reaction was also suggested. A lecture on the fundamentals of gas permeation membrane processes was included and discussion included how to effectively simulate such a process using process simulation software. Heat integration opportunities arise in this process because of the elevated temperatures used in the reactors. A chapter on pinch technology and heat integration is included in the text; also distributed with the text is a software package 'HENSAD' that allows heat exchanger networks and integration of energy in said networks to be evaluated. A number of lectures focused on the topics of heat integration and pinch technology, supporting this third design project.

STAGED DESIGN REPORTS FOR EFFECTIVE LEARNING

Having served as instructor for the process design course four different semesters, the greatest challenge was providing timely feedback to the students on their design efforts/design reports. This was particularly true when the course had a large enrollment and comprehensive design reports were required for each project. One objective of the design course is that, by the end of the semester, students have gained knowledge of the design process and can effectively design/analyze/synthesize a process to accomplish a specific task. However, a second objective is that students are also equipped to communicate the results of their design effort in an appropriate and comprehensive manner. To satisfy both objectives, a staged approach was undertaken in design report preparation. Shown in Table 2 are the required elements for a typical comprehensive design report. Also shown in Table 2 are the specific report elements required for each of the three written reports. For the first project, only three report elements are required, but in the mind of this instructor, these are critical to the design report, and therefore, are the elements that should be practiced and refined in subsequent reports. For the second project, three additional elements are required; however, two of these are the Table of Contents and References. For the third project, a complete design report is required, with all report elements included.

Table 2. Specific Report Elements for Three Design Projects

Report Element	Project 1 Comparison of Process Alternatives	Project 2 Debottlenecking Production	Project 3 Waste Minimization and Heat Integration
Letter of Transmittal			**X**
Title Page			**X**
Executive Summary	**X**	X	X
Table of Contents		**X**	X
Introduction			**X**
PFD and Process Description	**X**	X	X
Economic Summary			**X**
Discussion of Design Results		**X**	X
Conclusions and Recommendations			**X**
References		**X**	X
Appendices	**X**	X	X

When each design project was assigned, one lecture period was devoted to discussion of the specific report elements that were new to that particular report. This discussion supplemented text material provided on written reports [2]. Pertinent to the discussion was the audience to whom each section of the report is directed. For example, one often repeated statement is that the Executive Summary will be read by the person making the go/no-go decision on a project/process/renovation, but that person will probably not read other section of the report. The Process Description/PFD will be of great interest to the engineers and operators who actually are on-site during process operations as well as those who may be involved with troubleshooting operational problems. The Appendices, where design details are documented, may seem to be unnecessary; however, these are the specific details that will be critical to engineers tasked with redesign/retrofitting/upgrading a process in the future. For the first staged report, these were the three elements that design reports contained.

DESCRIPTION OF DESIGN PROJECT 1 ELEMENTS

Executive Summary

The Executive Summary must concisely identify the motivation for the project; in some cases, project motivation may arise from changing product markets, but may also arise from more restrictive regulatory guidelines/laws that must be adhered to. This section must contain sufficient detail regarding both the technical and economic viability of the project. Typically, this includes a very brief overview of proposed operating conditions/strategies and their outcome on key process variables. For a reaction system, these key process variables may be selectivity and yield of the desired compound; for a separation system, these key process variables may be purity and flow rate of the desired product stream. Additionally, the total cost of implementing a project (capital plus operating costs) should be provided as well as quantified return on investment. Students must be aware that this section is not a paragraph talking about what they did in calculations, what software they used for calculations, or where they provide qualitative descriptions of the process!

PFD and Process Description

The PFD and Process Description section is a well-defined section. The PFD (Process Flow Diagram) is a schematic of the chemical process where every item of process equipment is identified with a unique identifier (XX-###; XX symbolic of the type of unit, ### unique number). Also displayed on the PFD are process conditions (temperature and pressure) at various points in the process, utility requirements (bfw - boiler feed water; cw - cooling water; hps - high pressure steam; etc.). The process description is a verbal accounting of the entire process, where each and every stream is identified, and the units through which streams flow are identified. Key to the PFD and the Process Description is that the reader should be able to reproduce the Process Description from the PFD and be able to reproduce the PFD from the Process Description. This may seem redundant content, but both visual (PFD) and verbal (Process Description) descriptors are contained in the design report for completeness. One key aspect for the instructor is to critically review these two elements for consistency and point out any discrepancies, omissions or errors. The repetition of this section in all three design reports submitted over the course of the semester coupled with instructor feedback allowed students to refine their ability to accurately describe the process in verbal and visual formats.

Also included in this section of the report is a stream table that details temperature, pressure, vapor fraction of stream, total flow rate, and component flow rate (composition). An equipment summary is also required, where each equipment item is identified by unit number, equipment configuration (for example vertical or horizontal vessel, or specific type of heat exchanger), capacity (vessel volume or heat exchanger area), specifics to a particular equipment item (for example, number of trays in a distillation column, type of tray), and material of construction. Examples of stream tables/equipment summaries are provided in the text along with process descriptions for preliminary design projects (approximately 10 of these contained in the textbook). Thus, these tables typically require little grading as students use the text examples as a template.

Appendices

The appendices may seem an odd choice as a section to include in the first design report. Students often insert appendices to contain superfluous information when they cannot determine where this information is properly placed in the design report. Thus, student- developed appendices may not contain the critical information describing the design process/calculations/assumptions that may be needed when a process is being revamped some ten years hence. Guided structuring of the appendices enables students to produce a logical reporting of their base design calculations.

The importance of the appendices containing design calculations cannot be over-emphasized. During class discussion, the question was "if you are an engineer tasked with increasing capacity of a process, what information about the existing process would you like to have available?" Small teams brainstormed to generate a list of items/information they would want available. A master list was then generated from team responses.
Specific guidelines for what must appear in the appendices as well as the format of the appendices, was provided to the students in the design project assignment. These requirements were:

a) Detailed calculations for sizing the various equipment items (presented in a logical fashion, with pertinent information included and referenced as needed). Heuristics employed should be identified. Proper citations should be given for physical and thermodynamic property data that are used.
b) Cost summaries for each alternative including Capcost output, equipment operating conditions and how they were determined, a material balance table, cost tables, conclusions and recommendations.
c) Chemcad output.

In addition to the information provided in the design project assignment, a rubric for each design report was provided to the design teams. This allowed teams to review the rubric as they prepared their design reports. The rubric is based on a rubric available from the authors of the text [2] and was adapted for use in the Process Design course. This adapted rubric was much more specific as to particular items that should be included in each section and what constitutes the categories of 'not acceptable', 'below expectations', 'meets expectations', and 'exceeds expectations.' Not every category had the last classification. In particular, those categories that are specifically associated with report mechanics (grammar, page numbering, size of text, etc.) only had the first three classifications. Students were also provided with specifications for table and figure preparation.

DESCRIPTION OF DESIGN PROJECT 2 ELEMENTS

Table of Contents and References

Both of these sections are required in the second report, primarily so that formatting issues/omission issues can be identified and corrected for the third design report. Students often throw together the Table of Contents at the last minute. Common mistakes were: incorrect numbering of sections/subsections in report; incorrect numbering of pages; failure to include List of Tables and List of Figures; failure to number appendices correctly; failure to number the pages of appendices correctly; and failure to include titles for each of the appendices.

Learning to properly cite reference materials, be it a book, a journal article or a website, is very important to the practicing engineer. The use of a standard format (for example, the MLA format or the ACS format) for references should be introduced in the undergraduate curriculum prior to the senior year. Adherence to this standard format should be the focus of critiquing this element of the design report.

Discussion of Design Results

The Discussion of Design section is the primary focus of the second design project. This section is where the design team must lead the reader through the choices the team made in arriving at the new design, as well as alternatives that were considered. This section should not be a 'how to simulate the process'. Instead, for every decision in the design process, sufficient evidence to justify that decision should be presented. Thus, if one of the decisions made during design was the selection of an operating pressure for a separation, the report must provide information as to the range of operating pressures that was examined, as well as how the selected pressure was identified. If calculations were performed to aid in determining the range or selected pressure, these should be discussed. If two process alternatives were being considered, this section is where the design team must present a comparison of the processes, both technical and economic, and provide sufficient supporting data such so that the reader arrives at the same decision/conclusion as the design team.

Students are often tempted to state how they performed the calculations supporting their design decisions in this section. However, it is really the decision making process that led to the students identifying those particular calculations as being necessary and the results of those calculations that must be documented in the design report.

Thus, having this section as the focus of the second design report affords the students the opportunity to refine this section in their third design report, based on feedback and critique from the instructor.

DESIGN PROJECT 3 ELEMENTS

For the third design report, 4 additional sections are added: Letter of Transmittal, Introduction, Economic Summary, and Conclusions/Recommendations. The required content of these sections is detailed in the referenced text [2].

POSTER PRESENTATIONS

For the second and third design projects, student teams were also required to prepare posters presenting their design project/process. For the second project, evaluation of posters was performed by the student teams. This allowed students to see firsthand which elements of a poster worked well and which did not. For the third project, the instructor along with two external evaluators critiqued the posters and student presentations. The presentation could be equally divided amongst the team members for presentation to the external evaluators. However, the instructor required the students to draw straws and the individual choosing the shortest straw was required to give the entire presentation to the instructor. This approach held each member of the team accountable for the entire presentation; everyone on the team had to understand each and every aspect of the project in order to be able to effectively present the team's design effort. A set format was provided for the poster presentation with specific items required:

1. Title sheet (which includes group members' names)
2. Project Objective
3. Project Constraints
4. Waste Minimization Strategies/Alternatives Considered (can be more than 1 slide)
5. Recommended Design (PFD)
6. Major Cost Savings (compared to original process)
7. Overview of Economics
8. Ideas for Further Study

Other information could be included to help the audience to understand the approach taken by the team in completing the design project. A rubric for the presentations was also provided to the teams prior to the evaluation of poster presentations, so the teams were familiar with how they would be evaluated.

CONCLUSION

In any capstone design course where multiple projects/reports are required, this staged approach to design reports could be readily adapted. Using this approach allows students to hone their skills in reporting/crafting each specific section, where emphasis is placed on newer sections of the report and students have the opportunity to refine their ability to craft repeated sections of the report. This approach also benefits the instructor through focused grading activities and reduced load as the instructor must primarily critique those sections new to the given project/report. Those sections that were not new to the specific report were typically of higher quality and required little review as students had successfully incorporated feedback from the graded previous report. Students liked being able to focus their efforts on specific sections and not being required to prepare a full design report for each design project.

References

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Rebecca K. Toghiani

Dr. Rebecca K. Toghiani is an Associate Professor of Chemical Engineering at MSU and graduated from the University of Missouri-Columbia.. She received the 1996 Dow Outstanding New Faculty Award, the 2005 Outstanding Teaching Award from the ASEE Southeastern Section, and the 1997 J. J. Martin Award from the CHE Division of ASEE. A Grisham Master Teacher at MSU, she was an inaugural member of the Bagley College of Engineering Academy of Distinguished Teachers. She has also been recognized at MSU with the 2001 Outstanding Faculty Woman Award, a 2001 Hearin Professor of Engineering Award, and the 1999 College of Engineering Outstanding Engineering Educator Award.