Integrating Engineering Disciplines into a Common First Year Engineering Program

Gretchen Hein[1], Katie Torrey[1], James Hertel[1], Douglas Oppliger[1], Jason M. Keith[2], Glen Archer[3]
Department of Engineering Fundamentals[1]/Department of Chemical Engineering[2]/ Department of Electrical and Computer Engineering[3]
Michigan Technological University

Abstract

In the fall of 2000, Michigan Technological University started a common first year program for all engineering students. One of the goals of this program was to introduce first year students to the engineering majors available on campus. The Engineering Fundamentals faculty found it fairly simple to incorporate Mechanical and Civil Engineering problems into this program, but the other disciplines presented challenges in finding applications that matched the knowledge level of first year engineering students.

For the 2002-03 school year, the faculty worked on bringing Chemical, Biomedical, and Electrical Engineering assignments into the classroom that can be solved using tools taught in the first year program. The faculty relied greatly on the input and knowledge of the respective departmental faculty to develop illustrative problems. In Fundamentals of Engineering I (ENG1101), a Chemical Engineering problem introduced students to the concept of mass balances. This problem was used to illustrate how to properly set-up and document engineering problems, design and use spreadsheets, and observe the effect of changing process variables on an overall design. The students also learned technical writing skills by summarizing the project in a short report. Additionally, ENG1101 students were given a problem where they had to use unit conversions to solve a Biomedical Engineering problem. In Fundamentals of Engineering II (ENG1102), an Electrical Engineering project introduced the students to control logic design. Starting with a conceptual 3- D model of the mechanical design, the project required the team to develop a system configuration diagram, energy budget, functional specifications, and control logic program. The project stressed the design process within a multidisciplinary team. These activities and their development are outlined in this paper.

Introduction

Michigan Technological University (Michigan Tech) initiated a first year engineering program in the Fall of 2000, which is administered through the Engineering Fundamentals (EF) Department. As part of this program, all first year engineering students take Fundamentals of Engineering I (ENG1101) and Fundamentals of Engineering II (ENG1102). One goal of these courses is to introduce concepts from the various engineering disciplines. One particular aspect of this sequence is Engineering Explorations, which are two-hour long, active learning sessions where students are introduced to a given discipline[1]. Students pick Exploration topics depending on their interest in an engineering discipline. In addition to Explorations, exercises and projects are assigned in the courses to introduce concepts and design challenges from various engineering disciplines. Students work singly and in groups to solve problems that provide a context for discussion regarding the nature of "real engineering."

Over the past three years, most of the problem assignments have involved Civil and Mechanical Engineering. This integration has been relatively easy for several reasons. First of all, physics, which is usually taken during the first year, closely relates to these two disciplines. In ENG1101, students complete problems similar to labs they are doing in Development of Physics Skills I (PH1100) as part of their design project. Secondly, because most students have had high school physics, concepts relating to it can easily be brought into ENG1101/1102. Lastly, engineering examples from Mechanical and Civil Engineering are often easiest for first year students to conceptualize and understand.

The challenge for the EF faculty is to bring in good examples from the other engineering disciplines (Materials, Environmental, Chemical, Mining, Geological, Biomedical, Computer and Electrical Engineering). Increased integration with the different disciplines was strongly supported by faculty representatives from each engineering department. The departments wanted more examples from their individual disciplines incorporated into ENG1101/1102. To help with this, interested departmental faculty developed project ideas, which have been incorporated over the past academic year. These projects have focused on the disciplines of Chemical, Biomedical, and Electrical and Computer Engineering.

The idea to include a chemical mass balance problem in ENG1101 came when G. Hein heard how instructors at Virginia Tech were using an orange juice concentrate problem to introduce students to mass balances and spreadsheet analysis[2]. Previously, ENG1101 students were introduced to using spreadsheets as an engineering tool through the analysis of deflections in cantilever beams. After reading about the Virginia Tech project, discussions were held with J. Keith in Chemical Engineering at Michigan Tech. He conceived the idea of looking at a problem where students apply the problem solving method to a simple analysis. Then the analysis could be extended by using a spreadsheet to explore several different engineering scenarios.

The integration of this chemical engineering problem into ENG1101 was so successful, that the faculty asked if Biomedical Engineering would be interested in assisting with the development of a unit conversions assignment with an emphasis on biomedical engineering. Once again, through the active cooperation of another department, EF was successful in introducing another discipline into their courses.

Given the background of most first year engineering students, one of the hardest disciplines to introduce in a meaningful way is Electrical and Computer Engineering. To help with this, a meeting was held between the Department of Electrical and Computer Engineering (EE/CpE) and an EF faculty member. During this meeting, an electrical engineering professor suggested that an interesting design project would be for students to develop programs to operate a vending machine. This idea was then expanded, through close collaboration between the two departments, to include 3-D modeling along with programming. The basic idea for this ENG1102 design project was to have student teams design a physical machine (with little detail) and then use Matlab to simulate how the machine works. With the help of G. Archer (Electrical and Computer Engineering), the EF faculty were able to develop a semester long design project. During the first half of the semester, student teams used I-DEAS to create a 3-D model of a vending machine. In the latter half of the semester, they used Matlab to create a control program to simulate the operation of their machine.

The balance of this paper describes each of these integration efforts in more detail. Preliminary student reactions and faculty observations are also outlined.

Chemical Engineering Application Using Problem Solving and Spreadsheets

During the fourth week of ENG1101, students are introduced to the “Error Free” problem solving method, which is used to document their homework assignments[3]. Because most students have never used a logical method to solve problems, an example is worked in class which gives the instructors the opportunity to introduce additional concepts. In subsequent lectures, how to use spreadsheets is taught, which provides an opportunity to expand on the previously introduced concepts.

A problem introducing the concept of chemical material balances was piloted in 11 out of 13 sections of ENG1101 during the fall semester and in all four sections in the spring semester. A slightly modified problem from a sophomore level chemical engineering textbook was used to illustrate the Error Free problem solving method[4].

> “Strawberries contain about 85% water and the rest are solids. To make strawberry jam, sugar and crushed strawberries are mixed in a 55:45 ratio, and the mixture is heated to evaporate water until the jam contains one third water. How many pounds of strawberries are needed to make a pound of jam?”

It is important that the engineering analysis is completed after a discussion about the “reality” of this problem. Although the students are told beforehand that this problem is from a sophomore level chemical engineering text, an impromptu survey of “Is this a REAL engineering problem?” often results in a resounding “NO!” from the students. Several questions that were used by the EF faculty to change the students’ perspective on this problem included:

1. How many chemical engineers work in the food industry? Many students have the impression that most chemical engineers work in the chemical industry. This was a good opportunity to introduce students to the various industries where chemical engineers actually work. In reality only 23% of chemical engineers work in the chemical industry, while 11% work in the food/consumer products industry[5].
2. Are material and energy balances important for other engineering disciplines? Two examples the instructors used were: Environmental Engineers use material balances when they are designing treatment facilities; and Mechanical Engineers use material and energy balances

when they complete thermodynamic and fluid analyses.

3. Is the production of *one* pound of jam important? During this discussion, students can be introduced to the concept of lab scale, pilot scale and full-scale production. When giving examples of the lab scale, they often talk about experiments they are completing in chemistry lab. Very quickly, they realize that the lab scale is used as a first step to develop new products. The pilot scale is harder for them to comprehend, but students typically have no trouble coming up with examples of full-scale production.
4. Why would an engineer use a pilot scale? The reason for a pilot scale is not intuitive for students. The instructor points out that the pilot scale is used to determine if mass production is economical or even feasible. In many cases, it is only after the lab and pilot scales are successful that full-scale production is undertaken.

Before the Error Free problem solving method was applied, students were given some basic definitions of mass balance and ratio. It should be noted that these definitions were not meant to completely describe the concepts, but were given to the students so that they had enough information to solve the problem. The Error Free problem solving method uses a procedure where you clearly document the following information for the problem[3]:

1. Given
2. Find
3. Relationships
4. Solution

In the Given step of the problem solving method, students must list what they know about the problem. During this step, a picture of the problem similar to Figure 1 is drawn that includes information given in the problem statement. The first year students found this step challenging because they had to take information from the problem statement and figure out how it fit into the drawing. For the Find step, they used their picture to add variable names to the information they did not know. They were also required to state what they were trying to find. In this case, m_B, or the mass of berries needed to produce 1 lb of jam.

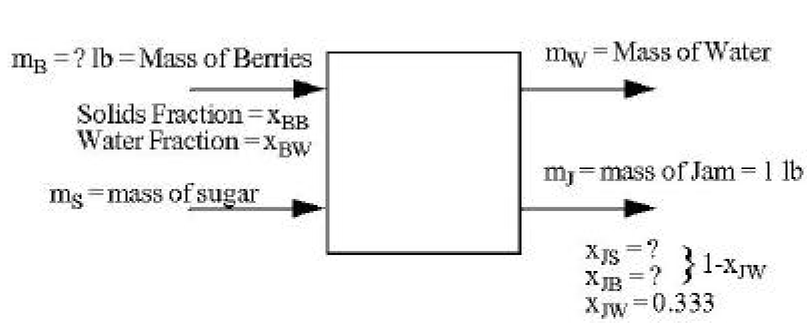

Figure 1: Chemical Engineering Mass Balance Problem

In the Relationships section, mass balance equations were used to derive a relationship between the given information and m_B. During this step, students learned the importance of algebra. They strongly resisted working with symbols and manipulating the equations. Most students wanted to solve the problem by plugging in the known values immediately, stating it was simpler to solve the problem that way.

The final step, the Solution section, was to take the equation they derived for the mass of berries, substitute in the numbers and units, and solve the problem. At this point, they saw that the solution was solved methodically, but they did not understand why this method was beneficial. The reason become more clear when the students were asked to solve this problem using a spreadsheet in the next class session.

During the next class period, students were introduced to using spreadsheets as an engineering tool. The material balance problem was revisited in a three part spreadsheet assignment. Appendix A contains the spreadsheet assignment description.

In the first part of the analysis, student teams completed a study of how much fruit and sugar were required to make 1 lb of jam for different kinds of fruit (strawberry, raspberry, apricot and apple). After the spreadsheet portion was completed, they had to answer questions that required them to consider the reason behind their answers.

In the second part of the analysis, students scaled up their jam production, to what could be considered pilot-scale production. They were asked to calculate the raw material costs of producing 500 lbs of each type of jam over 5 years. They were given the cost of the raw materials (fruit and sugar) and had to use this data and the mass balance equation to calculate the material costs. They then used their results to create a graph showing how the material costs changed over the 5 years. Finally, they were asked to discuss which jam cost the most to produce and why, how fluctuating prices affected the cost of the jam, and how the company could reduce their material costs.

Lastly, the students completed a pseudo profit margin analysis to see how much money their company would make when manufacturing strawberry jam. For this phase, the students were given the selling price for a jar of jam, the size of a jar of jam and the projected cost of strawberries. They were also told that the cost per pound of strawberries decreased by $0.10/lb. for every 500 lbs. of jam produced. From this information, the students created a graph showing the raw material cost and the profit per jar as a function of jam production. After creating the graph, the students addressed how selling price affected profit, what other production costs there were besides material costs, and how these costs affected profits.

The student teams had a week to complete this project. They summarized their results in a short report which was the first report many had completed at the college level. In the report, they addressed the points mentioned previously; they included figures and tables as required; and properly labeled and cited them in the text. In an appendix, they included a printout of their spreadsheet.

This mini-project accomplished many objectives.

1. Students began to use a problem solving method in engineering analysis. They also saw reasons why using a logical method benefited them. During class discussions regarding why clear and concise documentation of their work is important, many teams mentioned that this problem would be easier to grade. The instructors followed up on this comment when they told the students that this method also made it easier for their supervisor to understand their work.
2. The use of a chemical mass balance problem enabled the instructors to talk about chemical engineering in the first year engineering class. They also leaned the basic concept of a material balance. After the mass of berries had been calculated in the original problem, the students were asked to figure out how much sugar was needed. Most of the students could easily reapply the material balance to the problem, to solve for the amount of sugar.
3. Students were introduced to spreadsheets as an analysis tool. To illustrate how a spreadsheet can be used, students built upon the original mass balance problem by extending the problem to other jams. They also completed a pilot-scale cost analysis and a pseudo profit margin analysis.
4. The students summarized their work on jam production in a short engineering report that included figures and tables, references, and appendices.

Unit Conversions Using a Biomedical Engineering Application

Another topic covered in ENG1101 is unit conversions. This topic is presented at about the same time that the first year students are learning unit conversions in chemistry. In addition to describing how to complete unit conversions, the lecture also uses the Mars Climate Orbiter to illustrate the importance of completing unit conversions correctly[6]:

> "The 'root cause' of the loss of the spacecraft was the failed translation of English units into metric units in a segment of ground-based, navigation-related mission software, as NASA has previously announced," said Arthur Stephenson, chairman of the Mars Climate Orbiter Mission Failure Investigation Board. "The failure review board has identified other significant factors that allowed this error to be born, and then let it linger and propagate to the point where it resulted in a major error in our understanding of the spacecraft's path as it approached Mars."

After reminding the students what the purpose of the Mars Climate Orbiter was and what happened to it, a discussion was completed where the instructor and students explored the cost of the Mars Climate Orbiter failure in regard to financial loss, and the reputation of NASA, the Jet Propulsion Lab (JPL), and the engineers. Students are then shown how to document unit conversions and are asked to complete some simple unit conversions in class.

Traditionally, the homework for this class session simply required the student to complete basic unit conversions, independent of any kind of engineering problem. For the 2002-2003 academic year, D. Wright from the Department of Biomedical Engineering helped to develop a Biomedical Engineering problem that could be solved using unit conversions. The end result was a simplified analysis on transdermal patches[7]. A copy of this assignment is in Appendix B.

In addition to simply practicing unit conversions, this assignment introduced students to several Biomedical Engineering topics. Transdermal patches are introduced to the classes. Students learned what the patches are used for, how they work, and how this type of patch is designed by Biomedical Engineers. Some of the questions they answer using different units are:

- How much medication is released from the patch?
- How long will the patch last with a given chemical release rate?
- What volume of chemical is needed on the patch with a given density?
- How do different patches compares to one another?

Students found this problem more interesting and challenging than the approach used previously. Furthermore, the assignment introduced them to additional engineering terms, such as transdermal drug delivery and drug release rate, that they may not have encountered before.

Design Project with an Electrical and Computer Engineering Emphasis

One of the main objectives in ENG1102 is to have students work in teams to complete a design project with a focus on using computer tools. Since the introduction of the course, in spring 2001, the design project used mostly 3-D modeling to develop a "virtual" product such as playground equipment (spring/summer 2001) or furniture (fall/spring/summer 2002). The EF faculty recognized the need to expand the scope of the design project to include the use of more computer tools, including programming, and to expose students to a broader range of engineering disciplines. After several meetings between faculty in the EF and EE/CpE departments, a design project was developed to meet these needs.

The design project developed for the fall 2002 semester was titled "Building a Better Vending Machine". Minimally, vending machine design encompasses electrical, mechanical, computer, and human factors engineering. The design project as given to the students is included in Appendix C. The project is intended to be a cornerstone experience for ENG1102 and, as such, needs to address the **course objectives** listed here:

1. To develop an appreciation for all engineering disciplines
2. To develop proficiency in the use of computers to solve engineering and design problems
3. To develop computer programming skills
4. To improve spatial visualization skills
5. To improve teaming and communication skills

In addition, the design project needs to integrate as much of the varied ENG1102 **curriculum** as possible. The main components of this curriculum are listed here:

- 3-D solid modeling, assemblies and drafting using I-DEAS
- Programming techniques using Matlab (logic, loops, style, input/output, structure/functions)
- Reading engineering drawings using conventional and electronic (Maxview) drawings
- Engineering design process including creative problem solving and documentation
- Safety in design

To meet these needs, a series of project "deliverables" were assigned, completed by students, and reviewed by instructors through the first 12 weeks of the semester. Student teams were then able to revise the design documents so their final submission, a Project Binder, would be an example of their best work. These deliverables are described below, along with information on how each one fit into the course curriculum.

Preliminary Investigation - To begin the project, teams were able to inspect a partly disassembled, state-of-the-art vending machine to identify the major functional components (e.g. refrigeration unit, dispensing mechanisms, control logic boards, etc.). Each student then made a hand sketch a different part of the machine. This, combined with web research, was attached to a team memo summarizing what they learned about vending machine design. The assignment addressed the design process, working drawings, graphical communication, and documentation.

Project Proposal - Student teams were asked to create a vending machine concept that improved on the state-of-the-art. Following a creative problem solving session, each team developed a decision matrix to help select their best vending machine concept. A brief development proposal was written to describe the physical and functional concepts as well as the project plan (i.e., team roles, Gantt chart). This assignment introduced students to project planning and gave practice in written communication.

Physical Layout and Product Flow - Using I-DEAS, students modeled both internal and external features of their vending machine. Several views were created to show overall design appearance as well as some internal functions. Given the scope of the project, teams were not expected to provide mechanism detail. This deliverable addressed spatial visualization, design process, and graphical communication.

Controls Configuration Design - To document the overall electrical design concept, students created a configuration block diagram for their vending machine showing both power and signal flow. One goal of this deliverable was to get students to think about how the major components of the vending machine, electrical, electronic and mechanical, have to be linked to get them working together. Students used a computer drawing tool, such as VisioTech, to create their configuration diagram.

Energy Budget - Students were asked to consider the energy usage of their machine by researching the energy requirements of each component. They also had to compare the energy requirements of their machine to the requirements of a benchmark machine. Teams then used a spreadsheet to document the energy usage of each machine and proposed a plan for reducing the energy usage of their design. Concepts of voltage, current and power were discussed in the classroom to accompany the work on this deliverable.

Functional Specifications - This document described, in a specification format, how the vending machine worked. Teams were required to face issues such as how the machine interfaced with the user as well as how different components of the machine interfaced with each other. The assignment required the students take their configuration design to the "next level" of detail.

Because first year engineering students have very little experience with reading (much less writing) engineering specifications, teams were given a generic example to follow. The design process, written communication, and problem solving were some of the curriculum goals targeted in this deliverable.

Control Logic Flowchart - To prepare for the task of actually programming of the machine, students prepared a flowchart of how their intended program would work. This assignment forced teams to think about how the program could be broken down into small blocks (functions) that would work together.

Control Logic Program - Using Matlab, teams produced a program that used keyboard input and display screen output to simulate how their vending machine worked. Students turned in only a hard copy of the program, but were required to demonstrate the program to the class in the presentation described below.

Presentation - Teams created a multi-media presentation using Powerpoint slides for physical concept graphics and projecting their Matlab screen for logic demonstration. This was a great chance to practice team presentations in that several different tasks needed to be done during the allotted six minutes.

Project Book - This deliverable was the compilation of the entire design project. Students put all their previous deliverables (with corrections as needed) into a neatly organized binder along with appropriate introductory material for each section. For teams that had done a good job along the way, this binder took a minimum of time to complete. The focus of this deliverable was for teams to communicate all the work they had done in a neat and orderly manner.

One problem faced by all the first year engineering courses is how to make a project challenging for the well-prepared students while allowing the less-prepared students enough success to accomplish the learning objectives. One solution used in ENG1102 was to form diverse teams, each with varied levels of abilities. The other solution used in the vending machine design project was to provide detailed instructions for several of the deliverables. Referred to as "The B Template", these instructions give the weaker teams a strong start and, if they follow them closely and do quality work, will likely earn them a B for the project. Teams aspiring to get an A need to go beyond the template (i.e., more detail, creative features, convincing documentation, etc.).

With about 50 teams in the fall semester, no two vending machine concepts were the same; although teams that chose the B-template route came very close. The products chosen to vend ranged widely and included things from the following list: pop and candy, soft ice cream and slurpies, exam "scoop," printed jokes, custom burned CD's, videos, and of course (consider the age) mixed-drinks and beer. The mechanical design portion of the project was quite similar to previous design projects in terms of depth of concept, range of design detail and clarity of presentation. The control program simulation, however, appeared to be a much better real-world connection than previous programming projects. Every team was able to demonstrate vending machine logic using keyboard for simulated input and the screen for simulated output. Several teams added features such as inventory control, combined selections, fault handling routines, maintenance routine, comic responses. One team added a blackjack card program where the customer could play the vending machine for free items. In general, both the presentations and project books showed more variety and creativity than previous ENG1102 design projects.

Conclusions

With the input and collaboration of other engineering departments, the EF faculty were able to bring more examples of the engineering disciplines into a common first year program. Students were able to learn more about Chemical Engineering, Biomedical Engineering, and Electrical and Computer Engineering through the assignments and projects described in this paper. Since these projects have only been in place for one semester, there isn't an abundance of data to support their success. Course evaluations, given at the end of the semester, included questions designed to gage student learning resulting from these efforts. As this data becomes available the EF faculty plan to use it to improve these integration assignments and include others.

The EF faculty plan on continuing to work with other departments to bring more engineering applications into the classroom. The process of collaboration between the first year program and the other engineering departments is key to the success of this integration. In the 2003-2004 academic year, additional assignments from other departments plan to be added to the curriculum.

Acknowledgements

The authors appreciated the input from the other faculty in the Department of Engineering Fundamentals, Brett Hamlin, Norma Boersma, John Zarling and Sheryl Sorby. Without their input and assistance, these new projects would not have succeeded. We also appreciated the assistance of Debra Wright, Department of Biomedical Engineering. She was instrumental in helping us to develop the biomedical engineering application. Lastly, the idea of the vending machine logic problem came from Martha Sloan in the Department of Electrical and Computer Engineering. She provided the original concept for this design project.

References

1. Sorby, S., Monte, A.E., Hein, G.L. "Implementing a Common First Year Engineering Program at Michigan Tech", Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition.
2. Malzahn Kampe, J.C., Knott, T.W., "Exposing First-Year Students to Green Engineering", Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition.
3. Holtzapple, M.T., Reece, W.D., Foundations of Engineering, McGraw-Hill, 2000, pp. 61-89.
4. Felder, R.M., Rousseau, R.W., Elementary Principles of Chemical Processes, John Wiley & Sons, 2nd Ed., pp. 154.
5. American Institute of Chemical Engineers Web Site, 2000 - 2001 Initial Placement of Chemical Engineering Graduates, www.aiche.org/careerservices/trends/placement.htm.
6. Mars Climate Orbiter Web Site, MCO Failure Board Releases Report, http://mars.jpl.nasa.gov/msp98/news/mco991110.html, November 10, 1999

7. Dreyer, S.J., Peterson, T.A., “Customized Delivery Profile-A Comparison of a Novel Nicotine Transdermal System with Three Commercial Nicotine Transdermal Systems”, 3M Pharmaceuticals, www.3m.com/us/healthcare/ manufacturers/ dds/pdf/customized_delivery.pdf, November, 1998.

Biographical Information

GRETCHEN HEIN is a lecturer in the Department of Engineering Fundamentals at Michigan Technological University where she also earned her Ph.D. She received her BSME at Kettering University and her MSE at Purdue University. Prior to pursuing her masters degree, she worked as an engineer at General Motors Corporation. Gretchen teaches Fundamentals of Engineering I and II, and Engineering Applications in Science and Precalculus.

KATIE TORREY is a lecturer in the Department of Engineering Fundamentals at Michigan Technological University and also teaches classes for the Department of Chemical Engineering. She received her BS and MS degrees in Chemical Engineering from Michigan Technological University.

JAMES HERTEL comes to teaching following 25 years in business developing automated industrial machinery. He received the BSME from Marquette University and the MS from Lawrence Universityand an MSME from the University of Washington, Seattle. He is currently teaching Fundamentals of Engineering I & II, Statics and Mechanics of Materials and advises the Automotive Systems Enterprise.

DOUG OPPLIGER is a lecturer in the Department of Engineering Fundamentals at Michigan Technological University. He earned his BSCE from Michigan Tech and worked for several years in the Marine Construction Industry. He returned to school to pursue a career in teaching and received his Michigan Teaching Certificate in 1988. He has taught math and science courses at every level of middle and high school

JASON KEITH is an Assistant Professor of Chemical Engineering at Michigan Technological University. He received his Ph.D. from the University of Notre Dame. He teaches a new senior elective design course, Interdisciplinary Design, and a required junior level Transport / Unit Operations II course. At Notre Dame, Jason was active in the development of a new freshman engineering sequence EG111/EG112 Intro to Engineering Systems.

GLEN ARCHER is a lecturer in the Department of Electrical and Computer Engineering at Michigan Technological University . He received his BSEE from Texas Tech University and a MA in Information Systems Management from Webster University. He currently teaches Circuits and Instrumentation, and is working on his Ph.D. in Electrical Engineering.

Appendix A - Chemical Mass Balance Problem Spreadsheet Analysis, Part II

Spreadsheet Tables And Graphs

The purpose of this assignment is to give you practice in integrating text, tables, and graphs into a single technical document. Later this semester you will be expected to do this in a design project report. For today's assignment, you will be using the Strawberry Jam Mass Balance Problem, which you have already worked by hand, as a starting point to develop a spreadsheet and written report. The written report will discuss the results of your spreadsheet and answer the questions asked below.

Part 1. Comparison of Different Fruit Jams

You are a new food processing engineer and your job is to assist in the development of their new line of fruit jams. Your first assignment is to do a mass balance to determine how much fruit and sugar are needed to make each new product in the lab.

Directions: Develop a spreadsheet using the material balance equations derived in the previous homework to determine the amount of fruit and sugar needed to produce 1 lb_m of jam for the different fruit listed in Table 1.

Hints:

1. Use relative and absolute addressing for calculations so that you can copy your formulas easily.
2. Use absolute addressing for the amount of jam produced. You should only have to enter the amount of jam once in your spreadsheet, and the amount of fruit and sugar should adjust automatically for each jam type.
3. Test your solution for the strawberry jam to verify that your spreadsheet is doing the calculations correctly.

Table 1:Fruit Jam Information

	Strawberry	Blueberry	Raspberry	Apricot	Apple
Water Fraction in Fruit (B_W)	0.85	0.75	0.9	0.6	0.35
Water Fraction in Jam (J_W)	0.333	0.25	0.30	0.20	0.15
Sugar:Fruit Feed Ratio (R)	55:45	50:50	60:40	45:55	40:60

Questions:

1. Which fruit required the most sugar per lb_m of jam and speculate why?
2. How much water is evaporated during the jam production for each type of fruit?

Part 2. Effect of Raw Material Costs on Jam Prices

Your design team has developed five workable new products, and the company has decided to pilot their production. For the past 5 years, fruit prices have been increasing due to a prolonged drought and there is concern as to how this will affect the viability of this project. The average fruit prices over these five years are presented in Table 2. As an engineer familiar with this project, it is now your job to help analyze the raw material costs to determine how they may affect jam prices.

Directions: Develop a spreadsheet that calculates the raw material costs (fruit and sugar costs) per lb_m of jam for each type of jam analyzed in Part 1. On one graph, plot the raw material cost per lb_m of jam produced for all five products.

Hint: Use the fruit (B) and sugar (U) amounts calculated in Part 1 to determine the raw material costs for Part 2.

Table 2: Average Raw Material Costs Per Year

Year	$/$lb_m$ of fruit	$/$lb_m$ of sugar
1998	2.00	0.75
1999	2.50	0.75
2000	3.80	0.75
2001	4.20	0.75
2002	4.60	0.75

Questions:

1. Which jam has the highest material costs and why?
2. What would happen if sugar prices were fluctuating downward?
3. How could your company reduce the cost of jam by adjusting the formula (i.e: amount of each component)?

Part 3. Profit Margin Analysis on Large Scale Production

Due to the success of the strawberry jam pilot production, you will be moving to large scale production. All other products were not cost effective in the pilot program. Before you can go to large scale production, you need to complete a profit margin analysis of your raw material costs.

From the market survey of the pilot program, you are planning on selling a jar of strawberry jam for $4.00/jar. The cost of berries is linked to demand. In 2003, it is projected that strawberries will cost $5.20/$lb_m$ of strawberries for the first 500 lb_m of jam produced. As production increases, the cost of berries decreases. The cost per pound of strawberries is projected to decrease by $0.10 for every 500 lb_m of jam produced.

Directions: Develop a spreadsheet to calculate the raw material costs per jar and profit per jar for making different amounts of strawberry jam. Show the raw material cost per jar and profit per jar on a single chart.

Hints:
1. You are completing this analysis just for strawberry jam.
2. On your spreadsheet, jam production should vary from 500 lb_m to 12,000 lb_m in 500 lb_m incriments.
3. The strawberry cost is \$5.20/lb_m of strawberries if you produce 500 lb_m of jam. The strawberry cost is \$5.10/lb_m of strawberries if you produce 1000 lb_m of jam, and so on.
4. The sugar cost is a constant at \$0.75/lb_m of sugar.
5. One jar contains 8 oz. (0.5 lb_m) of strawberry jam. Therefore, if you manufacture 500 lb_m of jam, you will be making 1000 jars of jam.
6. Material cost/jar = (Total cost of strawberries and sugar)/(Total # jars of jam made)
7. Profit/jar = (Selling price/jar) - (Material cost/jar)

Questions:
1. What happens to your profit per jar if your projected selling price per jar is lower?
2. What other costs, besides raw material costs, will you incur while manufacturing your jam?
3. How do these other costs affect your profit per jar?

Report Guidelines

Your team must write a short, double-spaced report to summarize the results of this assignment. Your completed document should be structured as follows:

- Title page with a descriptive title and general information (names, date, course #, team #, etc.)
- Introductory paragraph with background information (problem statement, given, find, etc.)
- Sketch of the problem, either drawn in by hand or done electronically
- Short discussion of question in Parts 1 - 3 above
- Tables and graphs
- Tables and graphs introduced and discussed in the body of the document BEFORE they occur in the report
- Tables and graphs with descriptive titles, proper units, and labels
- Figures and text should be mutually supportive
- One printout of the numbers and another printout of the formulas of your team's completed spreadsheet in an appendix (at the end) of the report. (Two printouts total)

Appendix B - Unit Conversions

Many Biomedical Engineers deal with how medications are released into the body and bloodstream. One way drugs can be delivered is through the skin via a transdermal patch. These patches stick on the skin, and the medication inside of them diffuses through the skin and into the bloodstream. In order for the device to be effective, the medication must be delivered at a high enough rate into the bloodstream, and there must be enough medication in the patch. When the amount of medication in the patch drops below a certain level, the drug will stop diffusing into the bloodstream. Nicotine patches are an example of these devices.

The release rate of medication from a nicotine patch is related to various patch properties and can be simplified to Eq'n 1:

$$R = \frac{m}{A\,t} \qquad \text{Eq'n. 1}$$

Where,

R = release rate ($\mu g/cm^2hr$)
m = total mass of medication released (μg)
A = surface area of the patch (cm^2)
t = length of time that the patch is active (hr)

The nicotine patch you are evaluating has a surface area of 15 cm^2, and initially contains 0.12 g of medication. The patch is ineffective when it contains less than 0.05 g of medication. The release rate is 30 $\mu g/cm^2hr$. Typically, patches last anywhere from 1-7 days.

Note: These numbers are relative. Actual values are dependent upon the manufacturer and the drug being released. The values are based on an abstract regarding 3M's nicotine patches (Dreyer, S.J., T.A. Peterson, "Customized Delivery Profile - A Comparison of a Novel Nicotine Transdermal System with Three Commercial Transdermal Systems", 3M Pharmaceuticals, St. Paul, MN 55144.).

Questions:

Answer the following questions. Be sure to show all of your work and use the Line-Mole method to document any unit conversions.

1. How much medication (g and μg) is released from the patch?
2. How long (hr and days) will the patch last?
3. If the density of the drug is 20 g/mL, what volume (mL and in^3) of medication needs to be injected onto the patch?
4. Convert the release rate to lb_m/in^2s.
5. What should the units of m, A, and t be to balance Equation 1?
6. A competitor's patch has an area of 1 in^2, a release rate of 60 $\mu g/cm^2hr$, and the same mass of medication. Compare the two. How long would each patch last (days)? Which would enter the bloodstream faster?

Appendix C - ENG1102 Design Project - Building a Better Vending Machine

General Description of Project:

Every day, millions of people buy products from vending machines with little thought of what goes in to designing such a machine. As an engineer, however, your job is to quickly learn the "state of the art" and create design improvements for the next generation of products. This design project will have you and your team working to design several major components of a vending machine, and making at least one advancement in current technology. To be successful in this project, you will need to develop design concepts related to the function of the vending machine; i.e., both the mechanical and control systems.

Several deliverables will be turned in as part of this project. These are presented in the following list along with their due dates. Further descriptions of each of these deliverables are found after the list.

Deliverables:	Format		Due Date
Pre-Project			
1. Prelim Investigation	memo + enclosures	indiv./team	4.3
2. Project Proposal	memo + enclosures	team	5.3
Design Package			
1. Physical Layout and Product Flow	I-DEAS	indiv./team	7.2
2. Controls Configuration Design	VISIO Tech printout	team	7.2
3. Energy Budget	memo + encl.	team	8.1
4. Functional Specifications	memo + encl.	indiv.	9.1
5. Control Logic Flowchart	VISIO or P&P	indiv./team	10.3
6. Control Logic Program	Matlab	indiv./team	12.1
Final Deliverable			
1. Presentation of software & demonstration to class		team	12.2
2. Project Book	Organized Binder	team	13.1

Project Description:

Your job is to design the control logic for a vending machine. In order to accomplish this, you will first need to learn how current vending machines operate. Although you are not asked to do detail design of the mechanical or electrical systems, you will need to understand what systems are needed in a vending machine and how they need to be controlled.

The control logic will need to reference the various physical components in the machine; i.e., release mechanisms, product flow, money receptor, change maker, selection input, etc. You will need to document the physical machine concept so that these references are clear.

As with any new design, your objectives need to include improvement over other vending machines. This can be related to lower cost (simplicity), added functionality, reliability, convenience, etc. Your control logic should embody at least one improvement over current vending designs.

Control logic typically needs to interface with all the different systems in the machine. You do not need to design these interfaces, however, you do need to clearly document what inputs and outputs connect the control logic to the various components within the vending machine. In addition, the power consumption for the vending machine must be calculated based on the requirements for each sub-system.

Deliverable Descriptions

1. Prelim Investigation

Your team needs to view the inside mechanisms of one or more vending machines to understand their basic operation. Each individual on the team needs to sketch a different part or area of the design in order to document the basic functionality. These sketches will then be attached to a team memo which describes the basic systems and operation of the vending machine.

2. Project Proposal

Based upon your investigation and first-hand knowledge of vending machines, your team will brainstorm possible design improvements. At least 10 improvement ideas must be listed. The five "best ideas" will be evaluated in a decision matrix to find the one (or two) improvements that best match your design criteria; i.e., cost, marketability, reliability, entertainment value, etc.

Your team will then submit a proposal for the control system portion of the vending machine design:

Format - memo to 1102 instructor
Executive statement - what is this memo about and why is it written
Background - list the project objectives & target market(s)
- cite portions of your investigation

Proposal - describe the basic function of your recommended design. Reference your attached Evaluation Matrix.
- state how the new control logic would be developed and demonstrated

Staffing - state the project leader and various roles of the team members
Timing - state the completion date and reference an attached Gantt chart.
Closing - request approval to proceed with the project.

3. Physical Layout and Product Flow

Each member of your team will model a component or assembly related to the vending machine operation using I-DEAS. One of these must show the product storage and flow. One other must be a product release mechanism. Other models may be used to show systems or components controlled by the logic. An overall physical assembly needs to be created and shown in a variety of configurations; i.e., product held, product released, product at dispensing location, etc.

Printouts of the various models may be done from either Master Modeler or Master Drafting. Notes and labels should be used to indicate component names and features as referenced in your control logic.

4. Configuration Design

Using VisioTech, create a diagram which shows all the systems and major control components in the vending machine. Signal connections (logic inputs and outputs) between the logic controller and the components need to be shown and labeled consistent with your physical models.

5. Energy Budget

To examine the electrical energy requirements of your machine, your team will prepare an energy budget. By referencing your Configuration Design, the individual voltages, currents, and power requirements are estimated and summarized in a spreadsheet. Several reference documents will be available via the web which will help you establish realistic estimates.

Once your energy budget is established, you will need to: 1) compare your energy consumption to a benchmark design (2000 Maytag Glass Front Vendor) and 2) propose a means to reduce your energy consumption by 20% (including a projected cost saving).

6. Functional Specifications

Describe the intended operation of the vending machine based on references to the physical models and configuration design.

Format - Outline structure with numbered headings.
- attach to memo of transmission

Setup - does the logic need to be initialized when the machine is loaded or power is applied?

Normal sequences - what happens when a customer wants to get a product? i.e., taking money, dispensing product, making change,...

Fault sequences - what happens when something goes wrong?

Diagnostics - does the logic allow you to troubleshoot problems?

Other features - any other auxiliary functions

7. Control Logic Flowchart

Using VISIO Tech, or similar software, create a flowchart that shows how your vending machine will accept input and produce output. This is the prelude to your actual control logic program and it is expected that your program will be structured based on this flowchart.

Required logic and functions:

- Prompt messages to the customer
- Count money as customer enters from keyboard (n= nickel, d= dime, q= quarter, p= paper dollar)
- Execute product selection by actuating the proper release mechanism (screen message)
- Make change (print number of nickels, dimes and quarters)
- Update product inventory and eliminate choice when out.

Additional routines and functionality should be added based on your design improvements.

8. Control Logic Program

Using Matlab, your team will write the code to control your vending machine. The code should be written in a format like the one shown in class (i.e., proper header information, indenting, commenting, etc.). You will turn in both a printout and an electronic copy of your code. When the program runs, it should show messages to the vending machine user prompting them through the purchase of a product. (e.g. "Insert money into the machine"). It should also show messages saying what mechanical actions are taking place within the machine. (e.g. "actuate mechanism 3 to release can of soda"). Your program will reference the devices shown in your physical layout and configuration design drawings.

9. Presentation of software
Your team will give a short demonstration of how your software works to control your vending machine. You will use the classroom projection system to explain to your classmates, the neat features you have designed into your machine and show how they work. The presentation must be less than 8 minutes - including a brief question and answer period.

10. Project Book
This will be the collection of all project documentation (all previous deliverables - corrected as needed). It should have front-matter such as a cover page, letter of transmittal, table of contents, etc. as well as back-matter such as a reference list, appendices, etc. All of the material will be organized neatly in a 3 ring binder with tabs to delineate each section.

Project books (sometimes called Job Books) are used by engineers to document the various phases of the design; from concept through details. This discipline is essential to allow other engineers to understand the design and troubleshoot or modify it as needed. If good documentation is produced as you work through the steps of the design, the Project Book requires minimum time to assemble.

Grading

The first deliverables will be part of your team homework grade. This will give us a chance to get some feedback on these components so you can update them as needed. The final presentation and Project Book will be used to determine your team's project grade.

Deliverables:	Format	Team HW Points
1. Prelim Investigation	Memo & Sketches	10
2. Project Proposal	Proposal	10
3. Physical Layout and Product Flow	I-DEAS Assembly Dwgs	10
4. Controls Configuration Design	VisioTech Dwg	10
5. Energy Budget	Memo & Spreadsheet	10
6. Functional Specifications	Memo & Specifications	10
7. Control Logic Flowchart	VISIO or P&P	10
8. Control Logic Program	Matlab	15
Final Deliverables		**Project Points**
1. Presentation of software	demonstration to class	40
2. Project Book	Organized Binder	60