Recipe for Complexity: A Freshman Learning Experience

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Abstract

We live in a world in which we are starting to understand the complexities of the systems we "engineer." Our understanding of the complexities of engineered systems is rapidly increasing because science has given us a better understanding of the complexities of life itself. The freshman learning experience discussed in this paper is an attempt to introduce engineering freshmen to representative concepts presented in classical simple engineering systems and to expose them to an understanding of complex system concepts through critical thinking and experiential learning.

Introduction

According to the president and a member of the National Academy of Engineers (NAE), William Wulf and George Fisher, "many of the students who make it to graduation enter the workforce ill-equipped for the complex interactions, across many disciplines, of real-world engineered systems."[1] Unfortunately, the traditional engineering curriculum is a series of courses that teach simple systems. There is no emphasis on the true complexity of these systems—how they interact with other systems. "Engineers normally will not spend their lifetimes solving purely technical problems. Most engineering problems span a wide range of both technical and non-technical areas. The non-technical include environmental, political, economic, social, regulatory and corporate factors that are usually interrelated in a complex fashion."[2] There is a need to engage students in a new way of thinking about the problems that they will encounter in their careers. To change the trend in thinking, it is necessary to change the way that courses are taught throughout the engineering curriculum.

A course for first semester honors engineering students was designed to address this needed change from a simple systems approach to a more complex systems approach. This course was designed to emphasize both the simplicity and complexity of the problems that they will encounter as engineers. The Shewhart Cycle was used as a tool for continuous learning and improvement in the design of this course.[3] The Shewhart Cycle consists of four continuous steps: Plan, Do, Check, Act, and then repeat as necessary. If we discovered that the students did not learn what was intended in the check portion of the cycle, we would move through the cycle again under slightly different conditions. The syllabus reflects the Shewhart Cycle, because it leaves room for change by keeping the subjects somewhat vague, such as "Pit and Pit'um Laboratory" or Complex Systems (see the class web page at http://www.me.sc.edu/courses/U101E/). This allowed room in the course for some flexibility depending on what teaching methods worked well for the students.

The "story" of how this course exposed students to simple and complex system concepts and how they applied these concepts in an experiential learning project will be presented. A final "stew cooking" metaphorical experience that demonstrated the complexities involved in almost every facet of their lives will also be discussed. Because of the unique way that the course was designed, the "story" of this course will include student comments and learning outcomes throughout the following sections.

Methodology and Course Design

The freshman learning experience discussed in this paper took place in a College of Engineering section of University 101, "The Student in the University." This course recently received recognition from *U.S. News and World Reports* as the number one program for first-year students in the country.[4] The "university" part of this course introduces and exposes the students to living and learning opportunities such as sex education, alcohol and drug abuse education, the library, and the career center. This class was made up of ten freshman engineering honors students (four females and six males.) The students were divided into learning teams by a University of South Carolina Counseling Center staff member, Tracy Powers, who used the Keirsey Temperament Sorter as a team formation tool. All students took the Keirsey temperament test on the Internet and were asked to bring their results to class.[5] During class Tracy presented the different personalities and the qualities of these personalities.[6] Then, she divided the class into three teams based on their personality types so that each team would have people of different personality types. Each team came up with names for their teams, which included The Smarties, The Smart A's, and Team Thing. We then sought to develop, implement, and assess a learning experience that included simple system concepts, complex system concepts, and experiential learning about these simple and complex systems.

Tools:

To incorporate tools that the students will use in engineering school and in their career, we presented the class with tools to model simple systems. Computational tools and information technology were presented in the "Pit and Pit'um Laboratory." Problem solving tools were presented using problems from higher level engineering courses and simple systems were modeled using a projectile motion problem.

The "Pit and Pit'um Laboratory" took place in the computer lab during three class sessions. These lab sessions were used to introduce the students to computer software including Microsoft Word, Microsoft PowerPoint, Microsoft Excel, Microsoft Outlook, MathCad, and Instant Messenger. During the first lab session, the class was to work together in their teams and develop a PowerPoint slide show, which incorporated many of these software tools. Each team was also required to determine the meaning of "Pit and Pit'um" for their slide show.

> The three teams searched on the internet and two of the three teams determined that "Pit and Pit'um" in Gullah, the language of Coastal South Carolina, means "put and put in."[7] One group clarified it even more by saying: *"when using a computer you continuously put in info."*

In later lab sessions, the class reviewed a MathCad tutorial and practiced using the help menus. During these "Pit and Pit'um Laboratory" sessions, a projectile motion problem was introduced so that the students could begin thinking about a way to use computer software to solve a simple system exercise.

Problem solving tools were presented for the students to understand the importance of organization and repetition in solving problems. Using the tools, students reviewed and set up problem solutions. In a class discussion, students considered concepts such as Keep It Simple Stupid (K.I.S.S.), influence of design on the final product, and some commonly used problem-solving methods used in industry such as flowcharting.

With this overview of problem solving and some knowledge of the software available, the class was instructed to work in teams to solve a projectile motion problem. The basics of this problem were quickly introduced and the students started to work. They were required to use MathCad to determine the distance that a projectile will travel with a specific initial velocity and varying angles. This assignment was to be started in class and finished on their own time. This was an application of the tools that had been presented to them previously.

Class Readings:

Class readings were incorporated to help the students realize the complexity of problems and of life. The class was first required to read Gause and Weinburg's *Are Your Lights On?*.[8] They were also required to read Margulis and Sagan's *What is Life?*.[9]

Are Your Lights On? is a book that mainly addresses problem solving. It gives the reader a useful tool for approaching problems, not a recipe. Approaching problems, whether small or large, can be viewed in a way to determine the actual root of the problem that will lead to a solution. This book was discussed critically during a class session.

> The class believed that this book was an insult to their intelligence, because it is written in a large font with cartoon illustrations throughout. The class felt that this book did not provide any new information. They felt that it was of no use to them. However, throughout the experiential learning in the course they realized it was a great tool to understand the complexities in solving simple everyday problems.

What is Life? proved to be a more challenging book for the class to read. A report from a workshop organized by the Big-Ten-Plus Mechanical Department Heads in January of 2002 emphasizes the importance of including "new material on atomic and molecular physics, quantitative biology, comprehensive (organic) chemistry, micro fabrication, and modern computing" in a mechanical engineering curricula.[10] By having the students read *What is Life?*, we were attempting to introduce the students to the complexities of life, of living systems and engineered systems that interact with living systems. Because of its length, content, and the presentation of ideas, we thought it would be best to hold class discussions about the book two chapters at a time. This way we could observe student comments and reactions to the book as they read it, and not just when they finished it. After reading the first two chapters, most of the class agreed that they did not need to be reading this book. "Why do engineers need to read a book about biology?"

> One student, Lindsey, loved this book from the beginning. She wants to be a biomechanical engineer and never thought that she would be reading something like this in her first semester of college. She is a soft spoken student that responded to this question of why engineers need to know about biological systems in class. Lindsey said, *"What is Life? discusses the great complexities and amazing capabilities of life. It shows us how we as engineers have a great deal to learn from the perfected complex systems of life. A striking example is found on page 92: 'Ancient bacteria mastered nanotechnology. Already miniaturized, bacteria control specific molecules in ways of which human engineers can only dream. Far more complex than any computer or robot…' The author then goes on to describe the flagella of bacteria that are made of 'rings, tiny bearings, and rotors' and that spin about '15,000 rpm.' Today in the 21st century with all of the extensive advanced technology available, humans have not come close to designing something so complex, so miniaturized as bacteria. In fact the search is on for a living computer chip. This example of the bacteria only scrapes the surface of the amazing complexities and systems of life that engineers can only hope to mimic."*

This question of "Why study Biology?" reappeared every time that a class discussion was held. Only after completing the book did the students start to understand the relevance of "living complexity" to their future careers as engineers.

> Corrine discussed this on her final exam. *"I was rather surprised how a topic so seemingly different from engineering as biology would have so many connections to such a technical field."*

The goal of studying complex systems through reading *Are Your Lights On?* and *What is Life?*, was for the students to start to understand how the life's complexities will show up in their careers and in everyday life. We also wanted our students to leave this course with a desire to think outside of the box.

> One student, Richard, explained that: *"Sagan and Margulis in the last chapter discuss that despite this vast knowledge we have of life there is still so much more left to be discovered. This is perhaps the most significant concept in the book—the idea of pushing, asking, improving—all qualities of an engineer."*

Experiential Learning Exercise:

An experiential learning exercise was used to stress the difference between simple and complex systems. This exercise involved building and testing downhill racers.

Each team was given a kit and instructed to build a downhill racer. These were the only instructions that were given and we clarified things only as students had questions. The kit consisted of the following:

- 2- 2” x 4” pieces of wood (one was 3’ and the other was 2’)
- 1- 2” x 8” piece of wood that was 4’ in length
- 4 inflatable tires
- an ½” metal rod that was 6’ in length
- one piece of rope that was 10’ in length
- 2- $^{5}/_{16}$” x 4” carriage bolts
- 1-½” x 4” carriage bolt
- 8 washers
- 4 cotter pins
- 4¼” x 2½” u- bolts

The students were also given access to common hand tools such as an electric drill, a hacksaw, hammers, wrenches, and screwdrivers. The students were instructed to study the parts and determine a design for their downhill racer. A constraint on the design was that the wooden pieces could not be cut. They were to sketch a plan for building their downhill racers (see Figures 1 and 2.) The next three class meetings would be devoted to starting construction of the downhill racers. The carts were then built according to these plans (see Figures 3, 4, and 5.)

Figure 1—“Smarties” team drawing a preliminary design for their downhill racer

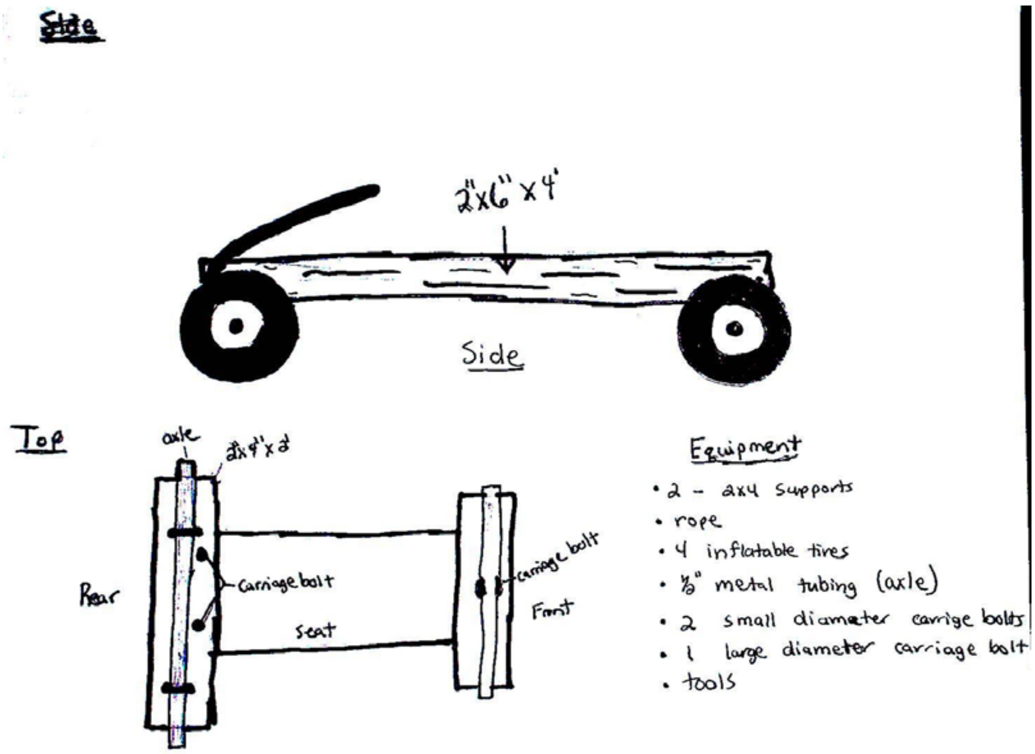

Figure 2—"Smart A's" team design for their downhill racer

Figure 3—"Smart A's" team building their carts

Figure 4—"Team Thing," with the help of professor Wally Peters, constructing their downhill racer

After the downhill racers were constructed, the class was told about the next step in the project. They were required to gather data by rolling the downhill racer with a rider down a hill and on a half pipe at a local skate park. They were required to analyze this data using a computer software program such as MathCad or Microsoft Excel. Before they could receive an admission ticket into the skate park they were required to write up a short story about what they thought was going to happen at the skate park. Then, after each day at the skate park, they were required to write up what happened that day. The "before" and "after" write-ups were assembled into personal "experience" journals by each student.

At the skate park, students were supplied with tape measures, chalk, stopwatches, levels, plumb bobs, and a digital video camera. They began the first day at the skate park by collecting shape data about the half pipe. They began by using the ground as the x-axis, and quickly observed the half pipe was level, but that the ground on which it rested was not (see Figure 5).

> Corrine wrote that *"when we arrived we were so consumed with getting started that we overlooked some obvious complexities in the task with which we were faced."*

To avoid having to do too much complex analysis, they decided to use an extension of the bottom, flat part of the half pipe as the x-axis. Next, they recorded the height of the half pipe from this x-axis. They quickly decided to share their data amongst the groups, so that less error would be present. Collecting this data took the entire class session, which was a surprise to the students. Many made comments about how a seemingly simple task took a long time to complete.

> Caroline wrote in her journal that: *"Our first day at the skate park was not what I expected. We spent most of the day measuring the half pipe."*

Figure 5—Collecting data in order to model the shape of the half pipe

When the class arrived at the skate park on the second day, the skate park was locked. To keep the class engaged, we modified the initial plan and had the class determine the slope of the parking lot and determine and collect data in order to quantify the velocity of the downhill racer as it accelerates from an initial "zero" velocity. They all talked about different ways to do this. Solutions were discussed from using the camera to record the downhill racer and counting frames to determine the exact time between marks ten feet apart to using timers and calling out the times as the front wheels went over the marks. After some discussion the class decided on the latter option. First they used chalk to make marks ten feet apart along a line that was painted on the pavement. Then they had a trial run. They marked a line where the rider sat on the downhill racer and started her at the beginning. They let go of her and it started rolling forward. One person, the Timer, walked beside the downhill racer and the Rider, and called out the times while the Recorder recorded the times. It worked well in the beginning, but when the racer and rider picked up some speed, the Timer did not have enough time to run beside it and take accurate measurements. Therefore, when the procedure was repeated two Timers were used and they called out alternative times. This procedure was repeated three times for each group and each time, different Riders, Timers, and Recorders were used (see Figure 6.) After sufficient data was collected the class tackled the problem of determining the slope of the hill. First a few students laid down on the pavement and looked up the incline to see if it looked relatively consistent and flat (see Figure 7.) Next, they took a straight edge and a level to determine the height of the incline. With this they used the right triangle that they constructed to determine the angle of the decline. They determined this height at many places along the line which defined their downhill racer's path and it yielded consistent results which verified the "sight" measurement of flatness.

Figure 6—Collecting data to determine the change in velocity of the downhill racer when rolling down the sloped asphalt

Figure 7—Students lying on the ground to check the consistency of the incline

On the third day at the skate park, complexity was introduced into the experience. Up to this point everything had been easily and fairly accurately modeled with simple systems. To introduce the complexity, air was released from the tires decreasing the air pressure from 30 psi to 10 psi. This was done without the students knowledge. The gate to the skate park was initially locked, so the class had a few minutes to play on their downhill racers. One student noticed that the downhill racer would not start rolling down the parking lot without a push. He started looking at the vehicle and noticed that the tires had less air. He quickly asked if there was a pump so that he could put some more air in the tires. This was discussed and the class was told that after collecting some data on the downhill racers, more air could be put into the tires and more data could be collected to investigate the tire pressure versus the downhill racer performance. Each team had one team member hold the downhill racer, a rider, and two recorders to mark the furthest that each tire reached on the other side of the half pipe. After a few trial runs, they noticed that the distances did not seem consistent. They decided that it may be because the wheels were not lined up properly before it was released. They took data for each of the downhill racers and for different air pressures in the tires (see Figures 8 and 9.)

Figure 8—Students devising a plan for testing their downhill racers

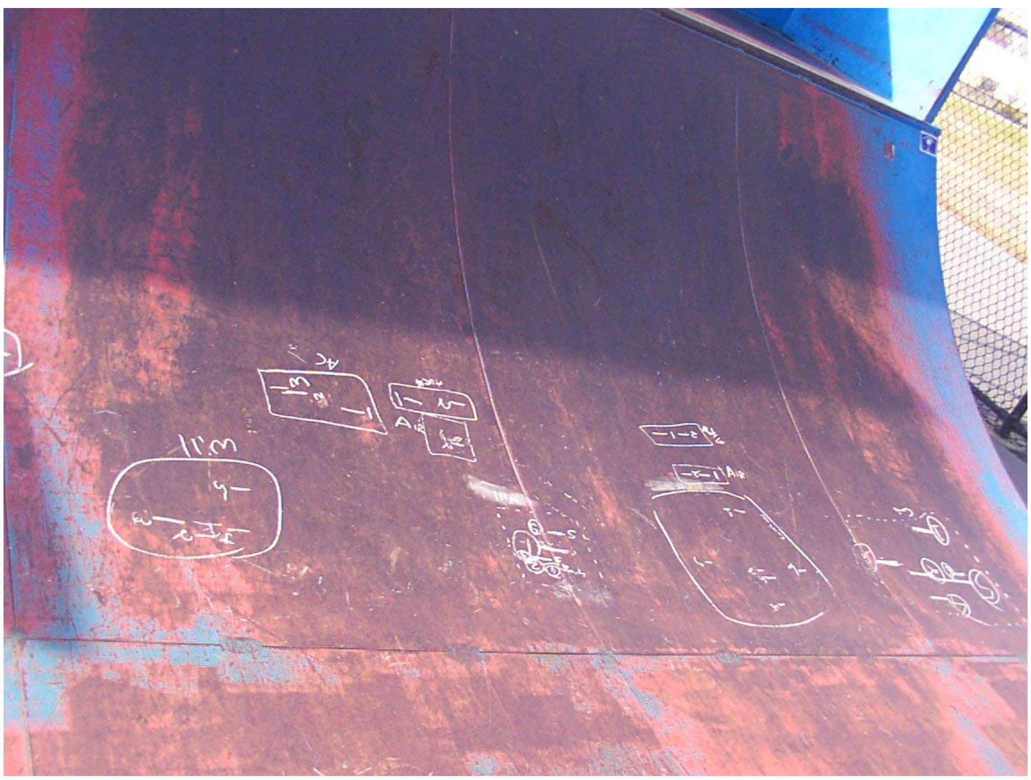

Figure 9—Chalk marking the distance that the downhill racer rolled on each run

The Final Experience

The last day of class which wrapped up the "story" of this freshman honors engineering course, involved group presentations, final exams, and cooking a stew. It was a chance for the students to draw conclusions about the complexities involved throughout the "story" of this course.

In wrapping up the class projects, each team was required to present the experiential learning project involving the downhill racers and their results. They were told that a presentation should include the following: what you are going to talk about, the story, what you just talked about. The senior author of this paper evaluated the presentations as equivalent to ones that he has experienced in senior level classes.

> The students were concerned that the presentations would be boring, because all three teams had collected the same data. They were all surprised by the differences in the way that each team tackled the results and how they presented similar subjects differently.

The final exam was the final check of the Shewhart Cycle. These exams assess whether the students grasp the concepts of simple and complex systems. They also provided a chance for the students to assess themselves and their teammates. In assessing themselves, the students were required to give a self-evaluation of their performance in the class. They were reminded that the syllabus indicated that the final grade will be determined from attendance, class participation, homework, presentations, the midterm exam, and the final exam.

> Most of the students said that they did well, and gave convincing arguments for this. One student who had missed some classes and not turned in all of his work wrote, *"Not a "B." A "B+" perhaps, or maybe even an "A." Not an "A+" that's for sure. This class has been one of my least missed classes this semester. I made a strong effort to always come (I enjoyed this class.)"*

A goal of incorporating teamwork into this project was to stress the effectiveness of having people with different personality types on a team.

> After doing the presentations, Anne explained why she would want a team of different personality types on the final exam: *"If I were working on a team I would want different temperaments. Not only do we need organization, we also need leaders, workers, people with innovative ideas and methods as well as practical ideas and methods. All of these different qualities found in varying temperaments combine to form an efficient group."*

The final exam showed that learning occurred throughout the semester. The students demonstrated that they understood the concepts of simple and complex systems. This class will be taught similarly in the future, but because of the nature of the Shewhart Cycle it will be adapted to meet the needs of the students in the class.

A final "stew cooking" metaphorical experience that demonstrated the complexities involved in almost every facet of their lives took place during the presentations and final exams, so that the stew was ready to eat after all of their hard work. Each student was required to bring a different vegetable that could be used in a stew for admission into the final class meeting of the semester. We had prepared cooked ground turkey and spices as a base for the stew. When the students arrived in the classroom, each student dropped their prepared vegetables into the pot. After the stew started cooking, each team presented their project and completed the final exam with the smell of the stew in the background. After the final exam, we discussed the stew. The class was prompted to talk about the inherent properties of the ingredients of the stew and the emergent properties of the stew after it had cooked. This "stew cooking" metaphor is a simple exercise that provided a way to make connections about the complexities of life in many of their everyday activities.

Conclusion

The complexities of the systems that we "engineer" are beginning to be understood because of the many breakthroughs in science. These complexities must be incorporated into engineering curriculum. Industry realizes the need for this change. Desmond Hudson, President of Northern Telcom Inc., said that, "My concern is for the students who come out of school suitably versed in mathematics, physics, and the sciences, but lacking an appreciation for literature, history, and philosophy. The view they have is that modern technology is a collection of components rather than an integral part of our society, our culture, our business environment."[2] There is a need for a change in the current engineering curriculum. The Accreditation Board of Engineering Training addresses this need in the current accreditation method, Criteria 2000. It states that the graduates must possess the broad education necessary to understand the impact of engineering solutions in a global and societal context.[11] This freshman honors engineering class is a start to developing a complex systems oriented method of educating our future engineers.

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