Weaving Computer Science into a Non-Majors Science Course

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Abstract

Service courses can significantly increase student credit hours. In the past, literacy courses could be used for such purposes. As more students enter university with such literacy, the need for courses such as these has essentially vanished. Moreover, many liberal arts departments have dropped a computing-related course as a degree requirement. To increase student credit hours, we have developed a course offered by the Computer Science department that satisfies science requirements. The course, titled "Disasters & Failures", examines science and engineering primarily through the lens of significant historical disasters. The role of computing in contributing to these failures, and in how to prevent future such events, is studied. Over the past seven years, the course has grown to 200 students per semester. We describe the course, give examples of topics demonstrating how it interweaves computing into science topics, and describe the experiences of students and faculty.

Keywords: University Service Courses, Educational Case Studies, Increasing Student Enrollment, Pedagogy.

1. INTRODUCTION

Students at our university have many options to fulfill their science requirements. In looking for ways to increase student-credit hours, we have developed a course offered by the Computer Science department that satisfies science requirements (Hannon, 2013). Through a rigorous College evaluation curriculum review process, the course was approved in 2007 for students not majoring in STEM programs (Science, Technology, Engineering, and Mathematics). It has become one of the most popular such courses on campus.

While the number of students majoring in Computer Science has gradually increased since the precipitous decline following the "dot-com" bust, service courses have significantly increased student-credit hours. In the past, literacy courses could be used for such purposes. As more students entered University with such literacy, the need for courses such as these essentially vanished. Moreover, many liberal arts departments have dropped a computing-related course as a degree requirement.

The course, titled "Disasters & Failures", examines science and engineering primarily through the lens of significant historical disasters. The role of computing in contributing to these failures, and in how to prevent future such events, is studied. Additionally, contemporary problems, future technologies, and their impact on society are examined. To satisfy requirements for science courses, laboratory activities are an integral part of the course.

Science courses for liberal arts majors are generally offered at other colleges throughout the U.S. These are sometimes informally referred to as "Physics for Poets" (Morley, 2006). This type of course broadly surveys popular physics concepts without the mathematical rigor or the depth found in traditional introductory physics courses. Morley argues against such courses. He offers alternatives that include raising the expectations of students and modifying majors' courses so that they are suitable for science and non-science majors alike. Several universities offer physics for non-majors courses based on texts by Muller (2008, 2010). These include UC Berkley, Carnegie-Mellon, U. of Colorado, and U. of Georgia. An analysis of non-science students taking a science course "suggests that instructors should strategically connect science concepts to the careers of non-science majors through such means as case studies to increase motivation and achievement" (Etkina & Mestre, 2004).

An evidence-based analysis of separate non-majors biology courses recommends "focusing on the process of science and its connection to students' lives will better engage and motivate non-majors while still helping them learn the fundamental concepts " (Knight & Smith, 2010).

One take-away from these studies is that students must be able to connect the course material to their lives. Of course this is a reasonable goal for all courses. Given the impact that science literacy has on society, it may be argued that making this connection is particularly important. Others agree with this notion. "The future of our society will be determined by citizens who are able to understand and help shape the complex influences of science and technology on our world" (Unger, 2010).

Unlike courses offered in physics and other natural sciences, the Disasters & Failures course examines its topics through an Information Technology lens. For example, the bridges module explores the use of sensors to monitor bridge structural integrity. The electrical power grid module explores the use of intelligent software to adjust power supply to meet predicted power needs. The Internet module clearly focuses on IT topics.

We describe the course and give examples of topics demonstrating how it interweaves computing into science topics. In addition, experiences of students and faculty are summarized. Two labs are given in the Appendix.

2. WHY THIS COURSE?

Many universities offer innovative and interesting computing courses for non-majors. For instance, a course entitled "Great Insights in Computer Science" introduces non-majors to computational concepts (desJardins & Littman, 2010). The described course, offered at Rutgers University and The University of Maryland, Baltimore County is designed to "help students gain an intuition for computational concepts". Many Computer Science topics are covered, including Boolean algebra, robotics, and computer organization. Many other courses suitable for non-majors exist. Davies, Polack-Wahl & Anewalt (2011) surveyed 371 schools across the United States and found a great variety of approaches to introductory, usually breadth-based courses. These types of courses focus on topics within Computer Science and Information Technology. Our university needed to expand coverage beyond these fields.

We chose to add our own interesting and innovative course that would maximize the number of students choosing to take the course. All graduates of our university are required to satisfy literacy in the "Natural Sciences". In contrast, very few majors now require any computing courses. This is what led to the creation of the Disasters & Failures course. It satisfies a requirement for all non-technical majors. It has allowed us to add over 1200 student credit hours per year. In a department with less than one hundred total majors, this has had a tremendous impact on the department. To qualify for natural science credit, the course must produce the following outcomes (TCU, 2010).

Students will demonstrate a basic understanding of some of the methods of investigation in the natural sciences.

Students will demonstrate a basic understanding of some of the great ideas in the natural sciences.

Students will demonstrate a basic understanding of some of the relationships among the natural sciences, technology, and society.

Natural science is defined in the usual sense: "A branch of science that deals with the physical world, e.g., physics, chemistry, geology, and biology" (Oxford Dictionaries, 2014).

3. THE COURSE

The stated purpose of the course is defined as follows.

In this course we work with fundamental methodologies and tools used in science, engineering and information technology. We apply the Scientific Method and learn the difference between science and engineering. The use of these concepts with the right balance of information and experience can help us avoid errors made in the past; furthermore informed citizens can make better policy decisions and become more astute consumers.

This course focuses on how we can develop technological solutions to problems by applying the scientific method to the study of major technological accidents and failures. The lecture material will be augmented by laboratory experiences where the student will be able to experiment with some common everyday complex systems and study their failures under carefully controlled conditions.

Course objectives are as follows. Students must demonstrate their understanding of topics through weekly quizzes, lab write-ups, and final exams for both lecture and lab topics. Outcomes for the course are defined as (1) an understanding of the investigation methodologies, computer models and simulation methods used by engineers and scientists in the development of modern technologies, (2) the engineering and underlying natural science behind a set of modern technologies, and (3) how the engineering and the underlying natural science behind modern technologies controls not only what we can do, but how society must deal with both the positive and negative effects of a technology.

Lectures are held twice per week for one hour. All students in a given section attend these. Students attend one two-hour lab session each week. One-half of the students attend one of two lab sessions held each week. For example, student A attends lecture at 2:00 pm Monday and Wednesday, and has lab from 3:00 pm – 5:00 pm on Monday. Student B attends the same lecture but attends lab on Wednesday. During course registration, students must select their lab day.

We now teach eleven sections of the course each year, with forty students per section. Four of the seven faculty members in our department teach it. All sections cover the same twelve core topics (as shown in the appendix) and each can choose a relevant topic of interest for a thirteenth unit (e.g., the pharmaceutical industry). While the core modules' lecture material and labs share significant commonalities, each faculty member has the flexibility to adapt these. Lecture materials evolve as new events and issues present themselves (e.g., the role of private corporations in space exploration, computer modeling of new pharmaceuticals, and computer security breaches). Updated materials are shared among the faculty to be used at each member's discretion. There is no text book for the course; all materials are provided to the students.

4. COURSE MODULES

Course modules include telecommunications, medicine, alternative energy, aircraft, space exploration, and the internet. A complete list of science and engineering topics and how they related to Computer Science are given in the Appendix. Each is covered in two to three lectures. A typical full semester schedule is also shown in the Appendix. In addition to conventional lectures, videos are shown in class and others are assigned for outside viewing. Showing videos during class time gives the instructor the ability to answer questions, comment on key concepts, and tie these to the lecture notes. Videos that are shown in class range from the humorous (Porter, 2008), to the motivational (Hite, 2008), to the serious (Hancock, 2013).

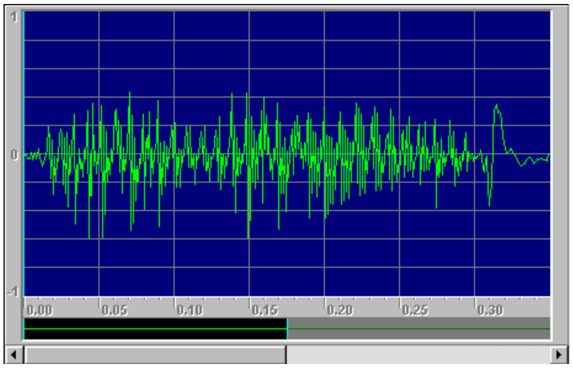
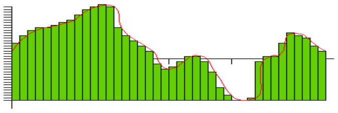
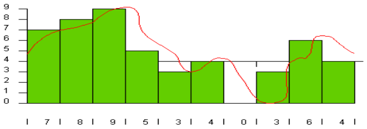


Figure 1. Analog signal representation from student slides.

As an example, the telecommunications module includes analog/digital signals (Figure 1), distributed computing, software, and a 1990 AT&T network failure. Part of the failure was due to a bug in software. The initiating and subsequent events of each disaster are also covered. Examples of quiz questions are shown in Figure 2.

Question: Consider the two analog to digital conversion diagrams shown below. Which digital signal should sound better?





Question: Deadlock in concurrent software means:

a. one software process "kills" another, leading to partial system failures
b. the computer rooms are flooded with Halon gas, so operators cannot restart computers
c. the software crashes (is "dead")
d. two processes wait on each other to do something

Question: Consider the AT&T network failure. The NY switch software tells connected switches it is out of service, automatically resets its hardware, and puts itself back into service to start sending call messages again. What happens when the NY switch starts sending these call messages again?

a. An untested part of the software leads to improper message handling, cascading the problem to other switches.
b. A switch had an electrical failure, caught on fire, and burned down the entire station.
c. The SS7 caused an STP.
d. Computer programmers start manually rebooting all the switches

Figure 2. Example quiz questions for the telecommunications module.

Some laboratories focus on a single key concept from the lectures, while others, like the bridges lab, cover many concepts presented in lecture. An example laboratory exercise for the Internet module emphasizes sending and receiving encrypted messages. The Medicine module primarily discusses diagnostic and treatment equipment. The most well-known failure here is the Therac-25 disaster in which software was ported from an earlier model and not thoroughly tested. The lab emphasizes the importance of unit and systems software testing using the Mouse Trap™ children's game (manufactured by Hasbro). Both the Internet and Medicine labs are shown in the Appendix.

5. EVALUATION OF STUDENT PERFORMANCE

Weekly quizzes are administered that cover a single topic. These are multiple choice and short answer and take about fifteen minutes. The lowest quiz grade is dropped, and two make-up days are available for University excused absences. The labs require recording experiment results, performing calculations, summarizing results, and briefly interpreting how their experiences relate to the topic covered. Example lab write-up sheets are given in the Appendix. Comprehensive written final exams are given for lecture and for lab. Roughly ninety percent of students make an "A' or 'B' in the course.

Active engagement in the lecture portion of the course presents challenges. Discussion is encouraged but it is difficult for students to engage in the discussion of topics about which they have little or no prior knowledge. They are encouraged to share any experiences and observations. The medical topic, for example, affords opportunities for students to do so.

The labs offer the most opportunity for active learning; they include significant student-student and student-instructor interaction. The labs also afford greater opportunity for deeper learning.

In assessing the nature of student learning, we can consider Krathwohl's (2002) revision to the classic Bloom taxonomy for learning (Bloom et. al, 1956). Quizzes focus on Krathwohl's "remember" stage, a variant of Bloom's knowledge level, in which students are asked to recall facts, terms, and basic concepts. The labs explore learning at the "understand" and "apply" levels, or what Bloom's taxonomy refers to as comprehension and analysis.

6. STUDENT RESPONSE

The number of sections offered per year has grown from two up to the current eleven. If the staff were available, more sections could be offered. Waitlists and requests for special permission to take the class occur regularly.

For all sections, some of the most common positive comments from the University's formal student evaluations, student letters, and "Rate My Professor" include:

- "Best class ever!"
- "The labs were like games, and they were actually fun!"
- "This whole class is so fun and interesting; it makes it very easy to learn."
- "Videos had a huge impact on me and made me go home and look more into the topics. (Apollo missions, Science Fiction, etc.)"
- "I wanted to say again how much I enjoyed the Disasters and Failures class and thank you for sharing knowledge I might never have realized was so important"

Though many students enjoy them, criticism is mostly aimed at the labs being too easy or not always clearly linked to the lecture material. This is an area that we are examining. We have traditionally opted to use physical materials rather than simulations (e.g. building wooden stick bridges). Last semester, one faculty member introduced an electricity simulator that was well received. The students had more time to focus on the concepts because no time was required to set up the physical components of the lab (e.g. wiring batteries).

7. CONCLUSIONS

The Disasters and Failures course offers a unique experience that exposes students to a broad range of topics that satisfies both a science course requirement and teaches students how technology affects the lives of all of us. The course is popular. It is also fun for many students.

The course offers a new option for educators wishing to expose students to computing concepts. It explores how technology is, or could be, used to avoid past disasters in many familiar domains with which students commonly interact. Moreover, the course explores exciting future technologies that may radically change society.

Some students express interest in learning more about computing as they progress through the course. This can enrich student experiences given the ubiquitous use of information technology across virtually all majors. We have not measured how many students subsequently take another course in the department. On occasion, our majors take the course as a lower level elective. We have found that they enrich the student experience by stimulating discussion, offering additional information about the topics, and helping other students with lab concepts.

Carl Sagan (1990) stated that "we live in a society exquisitely dependent on science and technology, in which hardly anyone knows anything about science and technology. This is a clear prescription for disaster. It's dangerous and stupid for us to remain ignorant". Ultimately, our desire is to teach students to rationally question what they are told, to make good decisions, and to continue to explore the wonders of the universe.

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Appendix A

Typical Course Topics and Schedule

Week	Day	Topic	Quiz	Lab	Lab Assignment
1	Mon	U1 Process & Tools		U1	Measurement
Aug 25, 27	Wed	U1 Process & Tools		U1	
2	Mon				Labor Day
Sep 1, 3	Wed	U2 Bridges	Quiz U1	--	
3	Mon	U2 Bridges		U2	Bridges
Sep 8,10	Wed	U2 Bridges		U2	
4	Mon	U4 Airplanes	Quiz 2	--	Airplanes
Sep 15, 17	Wed	U4 Airplanes		--	
5	Mon	U3 Nuclear Medicine	Quiz U4	U3	SW Testing
Sep 22, 24	Wed	U3 Nuclear Medicine		U3	
6	Mon	U5 Power Grid	Quiz U3	U5	Electricity
Sep 29, Oct 1	Wed	U5 Power Grid		U5	
7	Mon	U6 Nuclear Power	Quiz U5	U6	Solar Energy
Oct 6, 8	Wed	U6 Nuclear & Other Power		U6	
8	Mon	Fall Break			Holiday
Oct 13, 15	Wed	Quiz Makeup Units 1-6		--	
9	Mon	U7 Telecommunications	Quiz U6	U7	(A)Sync Proc
Oct 20, 22	Wed	U7 Telecommunications		U7	
10	Mon	U8 Tech Markets	Quiz U7	U8	Product Innovation
Oct 27, 29	Wed	U8 Tech Markets		U8	(robots)
11	Mon	U9 Internet	Quiz U8	U9	Protocols
Nov 3, 5	Wed	U9 Internet		U9	(networks)
12	Mon	U10 International Space Station	Quiz U9	U10	ISS
Nov 10, 12	Wed	U10 International Space Station		U10	(scheduling)
13	Mon	U11 Space Explorations	Quiz U10	--	--
Nov 17, 19	Wed	U11 Space Explorations		--	--
14	Mon	Q&A / Selected Topic	Quiz U11	--	--
Nov 24, 26	Wed	Thanksgiving			Holiday
15	Mon	U12 Limits: Science Fact/Fiction		U12	Fuel Cells
Dec 1, 3	Wed	U12 Limits: Science Fact/Fiction		U12	
16	Mon	Selected Topic	Quiz 12	--	
Dec 8, 10	Wed	Quiz Makeup Units 7-12		--	
Final Exam	Mon	3:00-5:30 pm			
Dec 15		Confirm via Univ. Schedule	Grad Seniors: arrange with instructor		

Appendix B

Comprehensive List of Science and Engineering Concepts Covered

The Engineering Perspective

- Some Tools (unit 1)
- The Product Lifecycle (units 2-7)
    - Requirements (unit 2) – Bridges
    - Design (unit 3) - Radiation Therapy
    - Testing (unit 4) – Jet Aircraft
    - Operation (unit 5) – The Electrical Power Grid
    - Maintenance (unit 6) – Nuclear Power
    - Upgrading (unit 7) – The Telephone Network
- Economics (units 8-10)
    - Market Changes (unit 8) – Failed Products
    - Requirement Changes (unit 9) – The World Wide Web
    - Policy Changes (unit 10) – The International Space Station
- Complexity (units 11-13)
    - Dangerous Things (unit 11) – Space Exploration
    - Limits (unit 12) – Energy and Communication
    - Modern Challenges in Our World: Selected Current Topic

The Science Perspective

- Biology
    - Oxygen-CO_2 cycle (unit 10)
    - Radiation effect on cells (unit 3)
- Chemistry
    - Biological weapons (unit 13)
    - Chemical weapons (unit 13)
    - Fuel cells (unit 10)
- Computer Science
    - Fault tolerance (units 7 and 10)
    - Parallel/Distributive Processing (units 7 and 8)
    - Software engineering (units 3 and 7)
    - Networking (unit 9)
- Information Science
    - Modeling (unit 8)
- Mathematics
    - Probability and statistics (unit 1)
- Physics
    - Dynamics (units 4, 10 and 11)
    - Electromagnetism (units 5 and 12)
    - Nuclear (units 3 and 13)
    - Statics (units 2 and 13)
    - Thermodynamics (units 4, 6 and 12)

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Appendix C

Laboratory Exercise for the Medicine Unit (Abridged)

Purpose: To learn how to analyze potential failure in a system using some simple failure analysis techniques. In the lectures, we are concerned with testing **safety-critical systems,** like a complex medical device or airplane. In such cases we would conduct more tests and have them independently verified by another group.

Things to know

A **unit test** is a test of *part* of a system. While it will not tell you details about how a trap's units work together it will provide information about each unit's performance. If a unit fails, we can isolate and correct the failure before trying to assemble it with other units.

A **system test** is a test of the complete system. It will not tell you details about how each unit of the trap is working. It provides information about the relationship between these units. When we discuss combining units of a any number of units of a system, this is called **integration testing**, We need to do integration testing because *failures in the game's trap are not independent of each other*-- *a failure in one place may cause other failures in other places.*

Probability is a measure of the chance that something will happen. It can be represented as either a number from 0 to 1 or a percentage between 0% and 100%. For example, if you predicted a failure would happen 3 out of 4 times, your percentage failures would be 75% (3/4).

Procedure:
Assemble the following units and *predict* how many times you think it will fail (as a percentage). Now actually test each one four (4) times. Each time you are ready to do a unit test, move the previous unit off the board. You are just testing 1 unit of the system at a time.

Unit Testing

UNITS	What percentage of the time do you ***predict*** it will fail? (Out of 4 trials). Do these ***before*** you actually test the unit.	What percentage of the time did the unit actually fail?
Unit 1 Crank and gears (The 1st part of the game)		
Unit 2 Lever, boot, bucket. (the elastic-loaded lever that hits the swinging boot, causing it to kick over the bucket.		
Unit 3 Incline, chute. A marble goes down a zig-zagging incline which feeds into a chute.		

Unit 4 Vertical pole, open hand, bathtub. The vertical pole has an open hand, palm-up, to support a ball. The movement of the pole knocks the ball free to fall through a hole in its platform into a bathtub		
Unit 5 Seesaw, diver, tub, pole, cage. The seesaw launches a diver on the other end into a tub which is on the same base as the barbed pole supporting the mouse cage. The movement of the tub shakes the cage free from the top of the pole and allows it to fall.		

System Testing

1. Try to correct any problems with the units (if you had any).
2. Connect Units 1 and 2. Test and fix problems. Now add 3 and test and fix again. Do the same until you have assembled the entire mousetrap game.

What percentage of the time do you ***predict*** the entire system will fail? (Out of 4 trials). Do this ***before*** you actually test the system.	What percentage of the time did the system actually fail?	How many of the failures occurred at the interface between the individual units? (If you had no failures, write “N/A”)	How many of the failures occurred in the individual units? (If you had no failures, write “N/A”)

Questions

1. How good were your predictions? What do you think caused your predictions to either be right or wrong compared to the actual test results?

2. Would you have changed any of the units (what parts made up a unit? If yes, what would those

3. What did the **unit** tests tell you about your trap’s failures? Would you change the design of the trap units in any way based on this knowledge?

4. What did the **system** tests tell you about your trap’s failures? Would you change the overall design of the trap in any way based on this knowledge?

Appendix D

Laboratory Exercise for the Internet Unit (Abriged)

Purpose: To explore errors in encrypted communication using different protocols.

Things to know

Communication protocols are designed to allow messages to be transmitted in a fast, shared and secure way among various members of a network. In this lab we concentrate on the study of two protocols. We have seen in class the issue of digital transmission in terms of encryption of switched packets. This lab is designed to simplify these protocols, yet it will still give you a flavor of how they take place.

Experiment Description (*Sending multiple coded messages over a single line***)**

Assume you need to transmit a message(s) to your partner over a line, but you do not want the other teams to know the content of the message. The easiest way to do it is to send it encrypted. Also assume that other teams also want to transmit their own private messages over the same line, at the same time; the easiest way to this is to use a communication protocol that allows the sharing of information without losing data over the line and giving a chance for everyone to communicate.

Messages will be passed in packets of three words at a time. The receiving member will decipher the messages with his/her own copy of the code. If the message needed to be transmitted is: *"The White House, 1600 Pennsylvania"* the message in packets of three characters would look like this:

(THE) 36,52,64 --- *(WHI)* 35,52,48 --- *(TEH)* 36,64,52 --- *(OUS)* 24,33,38 --- *(E16)* 64,91,96 ---- *(00P)* 90,90,20 --- *(ENN)* 69,28,28 --*(SYL)* 38,41,39 -- *(VAN)* 34,80,28 ---*(IA_)* 48,80,13 --- 000 (Stop)

To partially simulate the compression of messages, a given message might be transmitted by simply selecting the most important letters of a word and transmit only those in packets. For example, should the word to be transmitted is *TELEVISION*, instead of coding in packets to represent *TEL--EVI—SION***,** *blank*, *blank*, the sender of the message might choose only to send the packet *TV*, *blank* – coded something like (45,34,13). The receiver of the message will need not only the use the code, but also some knowledge that will let him or her to decompress the packet (45,34,13) back to the original *TELEVISION***.**

Questions

In addition to conducting the experiments and reporting results, the students answer the following questions.

1. What was the effect of the encryption schemes in the experiments?
2. What are the advantages and disadvantages of a polled protocol based on your experimental runs?
3. What was the effect of the incomplete information in the compressed messages to decode a message and why?