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Learning from Engineering Disasters: A Multidisciplinary Online Course

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Learning from Engineering Disasters: A Multidisciplinary On-Line Course

Abstract:
This paper describes the first on-line offering of a course on Learning for Engineering Disaster, taught originally (in a traditional classroom format) since 2010 to fulfill a Diversified Educational Curriculum requirement, and now a STAS ("Understand relationships between Science or Technology and the Arts, Humanities or Social Sciences") requirement for students in the Engineering Science B.E. program. It has been expanded via the on-line format to accommodate additional students from other majors, as well as to be potentially offered outside the University. The course uses a narrative and inquiry-based format to satisfy learning objects related to the professional and ethical responsibility of engineers, the role of engineers as problem solvers and designers, the importance of life-long learning and a multidisciplinary approach to understanding risk and he broader implications of technology. The advantages of the on-line format for expanded multidisciplinary learning opportunities are discussed, along with the results of the initial on-line offering and an analysis of student learning gains. We will discuss how teaching activities using engineering disaster enhance student learning about both "hard" engineering topics and the ethical, legal and societal implications of engineering, how these activities also address learning goals in communication skills, global impact, multidisciplinary and life-long learning, and how studying failures enables engineering students to better "see" complexity, and understand the special design needs which arise as engineered systems become more complex.

Background:
Engineering disasters (spectacular and catastrophic failure of engineered systems) are lead focal points in the news and in our lives. They impact the general public emotionally and viscerally – their narratives become the background for societal perception of risk and the source material which drives policy and politics. From the way in which first Three Mile Island, then Chernobyl and now Fukushima have changed our belief in and our approach to nuclear power (despite the fact that the nuclear industry actually has a relatively strong safety record and may be a potential solution to reducing carbon emissions from energy production, at least in the short term), to political fallout from the failure of the hurricane protection system in New Orleans during (and after) Hurricane Katrina, engineering failure has a profound effect on how we view our institutions, our infrastructure and our vulnerability. Engineering disaster is the stuff of myth (e.g. Icarus), poetry, popular movies and novels, because it engages us on such a deep level. Indeed, just single words or phrases – Hindenburg, Titanic, Deepwater Horizon, and World Trade Center – trigger our fears and misgivings, impact how we vote and safeguard ourselves and our families, and may even influence our choices in education and careers.

Hence, learning from engineering failures is a critical need, not only for engineers, but for an informed citizenry which must contend with navigating an increasingly complex technological landscape. For those learning to become engineers or technology managers, especially in fields critical to solving major challenges in growing energy needs, aging infrastructure, the impacts of climate change, and managing emerging technologies for human health, manufacturing and maintaining environmental integrity, the study of engineering disasters and the nature of risk in complex systems (and their broader societal and ethical context) will be an educational necessity.[1]

For engineering, science and technology students in particular, the study of engineering disasters in their broadest context is critical. On one level, it is obviously necessary to learn from our mistakes. But just as, if not more importantly, it is the broader context of failure – failure understood through the lens of the "open system" – which must be understood, especially in an increasing complex engineered world. A key need exists to educate students who will be the creators and users of technologies which may not exist yet – a challenge which vexes all engineering programs today. The solution is to create educational opportunities which train students (including life-long learners) not just in technical matters, but in how to think about technology and engineering with a systems approach incorporating ethics and societal impact. This societal impact is a two-way street, including not just how a failure impacts society, but how society (institutional culture, regulations, standards, politics, prejudices and biases, psychology, etc.) may create a situation in which a spectacular failure may not only be possible, but sometimes inevitable. Our next (and current) generation of engineers must recognize these complex interactions and develop methods to limit the potential for failure where influences and impacts on and of technology are increasingly difficult to predict.

In addition, a key need exists to educate students who will be the creators and users of technologies which may not exist yet – a challenge which vexes all engineering programs today. The solution is to create educational opportunities which train students (including life-long learners) not just in technical matters, but in how to think about technology and engineering with a systems approach incorporating ethics and societal impact. Starting in 2010, a course entitled "Learning from Engineering Disaster" was developed. Taught to over 800 students from at least 20 different majors, the course has been very popular and has proven to enhance student engagement in engineering-related topics for students from diverse academic backgrounds.
To broaden the opportunities for students, an on-line version of the course has been developed which transforms the current course through: enhanced use of electronic portfolios and on-line collaboration tools for group work; design of peer evaluation activities which leverage the on-line nature of the course to provide additional collaborative content and encourage the development of communication skills; a modular approach to provide key readings and video content while linking the analysis of real-world examples to key engineering and management principles; design of a multimodal assessment methodology which would provide valuable

feedback to students and necessary knowledge for course management and improvement; and integration of course design and accreditation criteria. The proposed content and format of the course is ideal for direct assessment of student outcomes for all accredited programs in engineering, in particular for the ability of engineering students to function on multidisciplinary teams and have an understanding of professional and ethical responsibility, the broad education necessary to understand the impact of engineering solutions in a global and societal context, and a knowledge of contemporary issues.

Course description and learning objectives:

Engineering disasters are usually catastrophic failures of a human-made system, structure, process or material, which are perceived to result in an outcome with a high cost to human life or health, the environment, our communities and societal structures, our industry, or the economy. The potential for disaster is often judged based on the probability or likelihood of failure, the vulnerability of a community, ecosystem or business to failure, and the likely severity of such a failure should it happen. The role of engineers (and others) is to design, create and maintain human-made systems so that the likelihood of failure (which causes a system to not perform its intended function) is as low as reasonably achievable and so that any failure that would occur would have as benign an impact as possible.

The purpose of this course is to help students to understand the nature of engineering disaster and failure. This includes learning objectives focused on:

- The multidisciplinary nature of engineering failure, including both technical and human factors
- How engineering failures/disasters affect society (including business, politics, and the human psyche – how we think and react)
- The nature of "risk" and how we perceive risk from engineered systems, structures and materials
- How engineers learn from engineering failure (and why they must learn from these incidents to create better designs)
- The role of ethics and values in engineering
- How the learning objectives of this course fit into the student's overall course of study

The on-line content and format of the course is ideal for direct assessment of the student outcomes developed by ABET for all accredited programs in engineering. This is especially applicable to the following current outcomes:

- An ability to function on multi-disciplinary teams
- An understanding of professional and ethical responsibility

- An ability to communicate effectively
- The broad education necessary to understand the impact of engineering solutions in a global and societal context
- A recognition of the need for, and an ability to engage in life-long learning
- A knowledge of contemporary issues

In order to achieve these learning objectives, the course has been organized as follows:

Topic	**Schedule**	**Material to review**	**Assignments**
Introduction	Week 1	Lecture (via VoiceThread) introducing course topics and the nature of engineering disaster	Create electronic portfolio, familiarize yourself with course management software and on-line format
Nature of engineering and design	Week 2	Lecture 2 on multidisciplinary nature of engineering design Readings on design process Readings from "Lessons Amid the Rubble" (by S. Pfatteicher)[2]	Reflection (in eportfolio) on first two lectures; Assignment on design process (and Design for Reliability)
Risk and reliability	Week 3	Lecture 3 on risk assessment, including nature of probabilistic risk assessment (PRA); case studies involving Challenger, World Trade Center, etc. Readings from "Lessons Amid the Rubble"	Reflection on lecture Assignment on Failure Modes, Effects and Criticality Analysis
Causes of failure and failure analysis	Weeks 4-6	Lecture 4, parts 1-3, on causes of engineering failure (including background on materials causes) and failure analysis; Videos on Titanic, Readings from "Lessons Amid the Rubble"	Reflections on lectures; Directed reflection on videos (causes and broader implications of Titanic disaster, use of impact testing to understand materials issues).
Perceptions/ psychology of failure; broader impacts	Week 7	Lecture 5 on psychology/human factors, biases related to disaster; Videos on Hindenburg; Moderated discussion	Reflection on lecture; Directed reflection on Hindenburg, including questions on modern airship design and risk
Role and importance of	Weeks 8-11	Lectures 6 on the role of complexity, 7-9 on a complex systems-based, interdisciplinary approach to design	Reflections on lectures; Directed reflection on videos (with assignment on

complexity and systems		and problem-solving; Reading from “Drilling Down” by J. Tainter and T. Patzek;[3] Videos about Great Long Island RR Pickle Wreck and RR safety; Moderated discussion	nature of complexity and design for open systems and their role in failure)
The role of ethics in failure and Value sensitive design	Weeks 12-13	Lectures 10 and 11 on case studies highlighting ethics and value sensitive design; ASCE report on the failure of the New Orleans Hurricane protection system; Video case studies; Moderated discussion	Reflections on lectures; Assignment on role of ethics and values in engineering failure and success.
Final presentation	Weeks 14-15	View and comment on group presentations	Final presentation and report; comments on peer presentations

To support course development, we have leveraged institutional technologies to increase the quality of education, as well as affordability and accessibility. This includes:

- Blackboard course management software to coordinate activities, and provide assignments as well as background readings and videos (recorded as part of the proposed project as well as some gathered from other sources, including archival news footage). Blackboard is also used for moderated discussion forums (for specific topic discussion as well as open forums acting as peer-to-peer help sites and collaboration tools), as well as to distribute links to assessment tools such as the Student Assessment of Learning Gains survey.[4]
- Videotaping and captioning – materials developed for the course have included interviews with experts in particular disasters, site visits (e.g. to the Navy Lakehurst Historical Society and the site of the Hindenburg disaster). Laboratory experiments and discussions also filmed (e.g. impact testing of alloys related to the Titanic disaster, electron microscopy of materials from Hindenburg recovered after the disaster).
- Lectures making use of VoiceThread (created by the instructor) for a number of *asynchronous* discussions of videos of engineering failures, news reports, videos of laboratory testing methods, and Powerpoint presentations to provide background information on engineering principles (such as materials properties, soil mechanics, probabilistic risk assessment, etc.) which relate to topics in modules.
- VoiceThread (created by students) for final group projects concerning analysis of a recent failure/disaster and its impact – invited peer groups (as well as potentially the entire class) watch and comment on the projects through VoiceThread for peer-to-peer interaction and evaluation.

- Electronic portfolios to allow students to provide evidence of their overall learning gains in the course, including assignments and reflections.[5] Every lecture/assignment includes a reflection by the student on their eportfolios which allows the student to better understand the learning process and connect materials in the course with their area of study, as well as overall academic and career plans. Eportfolios are reviewed by instructor and teaching assistants to both provide feedback and assess student performance.

In summary, the design of the course and its implementation follows our teaching philosophy, that all learning is multidisciplinary. The course includes aspects of engineering design and analysis, mathematics, physics, chemistry, biology, business, economics, political science, sociology, psychology – hence incorporating a broad spectrum of student areas of study and interests, leading to engagement and motivated learning. Problem-based and project-based learning strategies integrate real-world case studies (including site visits, interviews, laboratory analysis and discussion) and a final report and presentation on a current failure, with special emphasis on ethical, legal and societal implications, and the role of complexity and "system-ness". Assessment is essential, both in the evaluation of student learning gains as well as in the case of course design and implementation. Hence our assessment process includes our ABET-reviewed process utilizing direct (via eportfolios) and indirect assessment tools, review by the home Department, the Teaching and Learning Technology department, the program's Industrial Advisory Board, and consultation with members of the Open SUNY Center for On-line Teaching Excellence. This process will occur during and following the first on-line course offering.

Results:

It has taken longer than originally planned to develop the on-line format for the course due to the complicated nature of building a set of resources ready for deployment. As mentioned before, an important goal of course development has been to explore the use of a narrative-based approach combined with background on technologies and engineering principles. To do so in a way which best takes advantage of on-line presentation required the recording and editing of diverse materials, combining video interviews, laboratory demonstrations, and background lectures. An important lesson comes from the fact that doing so takes a great deal of time, and is subject to scheduling difficulties and resource availability which complicates planning. This process in fact is still ongoing, and materials will continue to be developed during implementation of the course.

Student feedback, on the other hand, as evidenced by the content of required student reflections on lectures and videos, has been overwhelmingly positive, indicating that the format has enhanced learning and engagement. The only negative comments have concerned initial technical difficulties, which have been resolved over the first few weeks of the course offering. Prior to the start of the course, students were asked to complete a customized Student Assessment of Learning Gains base-line pre-survey. The survey is available at www.salgsite.org and available for use by others, if interested.   Over 175 students responded to the survey. An analysis of the results shows that students expressed a less than 50% confidence rating (lower than 3 out of 6 on a Likert scale on which 6 is understand 'a great deal') that they currently (prior to taking the course) understand:

- How engineers estimate risk in systems or devices they design
- How engineers analyze a failure
- The potential materials related mechanisms which can lead to failure
- The psychological factors critical to engineering success or failure
- The role of complexity in risk and failure
- The broader implications of engineering failure for society, business, the environment, etc.
- Engineering ethics, and its role in helping to prevent failure

They also expressed a low degree of confidence (lower than 4 out of 6 on a Likert scale) that they currently have knowledge of contemporary issues in engineering and have an understanding of professional and ethical responsibility in engineering.
In terms of attitude about their current abilities, the students scored less than 4.5 out of 6 on the Likert scale that they can:

- Successfully navigate and complete an on-line course
- Write documents in discipline-appropriate style and format
- Prepare and give oral presentations
- Acquire the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context

Students also express a generally low confidence level that they understand the subject (3.6 out of 6), are interested in taking additional classes in the subject (3.8/6), and are comfortable in general working with complex ideas (4.3/6).

All these areas are expected to improve based on the design of the course and the learning objectives. An end of course survey will focus on these issues (which of course is not available at the time of writing, but which will be presented at the 2017 ASEE National Meeting). However, we can surmise some improvements in student knowledge from electronic portfolio comments provided to date.

The first lectures and assignments focused on the role of engineers as problem solvers and designers, and the assessment of risk in the engineering design process.   Students from all backgrounds and majors reported that the on-line materials and readings enhanced their understanding of the engineering profession, and indicated in general that they discovered the importance of realistic risk assessment in making decisions and making informed decisions.

Their responses also indicated that the nature and manner of presentation (despite some technical difficulties) enhanced their engagement with the material and their ability to connect the lessons learned with their further academic and career goals (as well as their jobs and life experiences). Such a connection is extremely valuable in enhancing learning and integration of knowledge, and is central to the goal of developing "significant learning experiences".[6]

Examples of student comments:

> *"The more I learn in this class the more respect I have for the profession of an engineer." (Journalism major)*
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> *"The most interesting thing I learned through this assignment was the ways in which engineers account for things beyond their own systems….I work as a contractor's apprentice and had never thought like an engineer when it came to designing windows, but now that I have, I believe I have a much better understanding of their function." (Engineering major)*
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> *"I found it incredible that having to start over was not only common, but it wasn't considered a failure. I know that for myself if I work really hard at something and then in the end fail, I would be reluctant to start again. For engineers that is not the case. With starting over their process they actually are closer than ever to perfecting their goal and society around them. I am really looking forward to learning more during this course now that I have a greater understanding of the goals and processes of engineers." (Nursing student)*
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> *"From the assignment, I leaned what will cause engineering failures and ways to reduce risk…. If I have a designing course or job in the future, I can use this knowledge to improve my own design product. Besides, I can use this knowledge to help me avoid injury from the failed products in my life." (Computer Science major)*
> *"Coming into this course I was nervous and curious about what I was going to be learning about, and whether or not it would interest me. However, I can definitely say that as a Psychology major, I actually found lecture 2 very interesting…. Knowing that psychology plays a role in engineering is extremely interesting to me, and has me curious as to what other aspects of psychology apply to the risks and failures of engineering." (Psychology major)*

An analysis of the demographics of students enrolled the current course offering as well as the previous seven years of classroom based offering provide a number of interesting and valuable insights. In general, the course has always appealed to a broad cross-section of student majors and interests, and this has continued and may in fact be enhanced by the on-line nature of the

current offering. For the past six years of the classroom version of the course, an average of 121 students per year have taken the course (limited by the size of the available classroom). Of those students, 44.7% (approximately 54 students each year) have been engineering majors. An additional 14% have been physical sciences (biology, chemistry, physics, and health sciences) majors, and approximately 10% have been business majors. These results have been consistent from year to year. The rest represent 13 other majors, primarily general/multidisciplinary studies, psychology, economics, mathematics, history, sociology, languages and the arts.
For the current on-line version, the percentages have proved similar, even though the number of enrollees has increased from 120 to 185. The current enrollment includes 37.8% engineering majors (70 students), 12.9 % (24) physical sciences majors, 11.9% (22) business majors, and the rest from 16 other majors (including general/multidisciplinary studies (12.9%), psychology (8%), economics, sustainability, mathematics, history, sociology, English, linguistics, languages and the arts. While this may represent an increase in academic diversity (while still accommodating the needs of a greater number of engineering students), the differences are small enough that it will require multiple years of data collection to determine the level of significance.

The course has always included a significant number of female students and students from underrepresented minority populations (as compared to other courses offered in the College of Engineering and Applied Sciences). Over the first six years of classroom offerings, the course averaged 35±4.4 % female enrollment, and 13.4±2.8% students who identify as black or Hispanic. The current on-line offering enrollment includes 40% (74) female students and 19% (35) students from underrepresented groups. Again, this may reflect an increase in diversity, but further data from future offerings will be required to determine the significance.

The largest difference is the expected increase in the percentage of senior (U4) level students (which has nearly doubled, from 19% to 36% of the class). This is not surprising, as the on-line format allows for students with complicated or “tight” schedules to fit this course into their academic plans. This is quite important in that it allows for students to find a way for timely completion of academic requirements, preventing delays in graduation. This is one of the goals for developing on-line offerings in the first place.

Conclusions:

Overall, the results indicate that the course appeals to a broad range of students, both in terms of academics and demographics. The on-line format makes it possible for students with scheduling restrictions to take the course, which promises to benefit time to degree completion, and make it possible for students with restrictive work (and life) schedules – including adult learners and returning students, to take the course. While our assessment of learning gains is incomplete at this time, it is clear from student comments (and based on the previous classroom version of the course) that the course meets it goals of helping students understand the multidisciplinary and broad impact of engineering design and engineering practice, the role of ethics and values in successful engineering problem solving design (where success takes into account the societal, economic, environmental, legal and personal impacts of technology in our lives).

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