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The Use of Narrative in Undergraduate Engineering Education

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Abstract:

Many theories of engineering education identify methods to engage students and enhance learning that leverage mechanisms by which learning occurs. Most commonly, techniques such as problem-based learning, discovery learning, scaffolding, and hands-on or active learning have been promoted to enhance learning of engineering concepts and design methods. But less systematically studied are approaches that specifically address student motivation (and its assessment). One especially overlooked modality in this regard, despite (and probably also because of) its pervasive presence in instructional discourse, is the use of narrative. In this paper, we discuss the use of narrative in undergraduate engineering education. In particular, we explore the theory and background of narrative-based instructional methods and review the use of narrative in several undergraduate engineering courses at Stony Brook University. We will discuss models for the various uses of narrative, and examine the results of the use of disaster literature and science fiction (both reading and writing) to enhance the learning of engineering ethics, value sensitive design, and risk assessment. We will also discuss further roles for the concepts of narrative pedagogy (NP) in engineering (for example, having students tell stories of their own relationship with technology, or productively repurpose features of existing narratives) and, in a broader sense, explore the potential for enhancing teaching and learning in engineering and the humanities through seeing engineering designs as narratives themselves.

Background:

Merriam-Webster's dictionary simply defines narrative as "the representation in art of an event or story"[1]. In a broader sense, we can think of narrative as a basic form of human communication, one through which "humans experience and comprehend life.[2]" Narrative is nothing less than the context in which we all live and interact: people performing actions in time and space, inevitably infused with conflict and attempts at resolution. Because it is universal as such and also highly engaging of both logic and emotion, narrative is potentially transferable across any contextual differences. As the first-century Roman poet and philosopher Horace put it, "Change the name, and you are the subject of the story"[3]. Many prominent contemporary theorists have similarly observed that we live and understand our lives narratively (e.g., Paul Ricoeur, Jerome Bruner, Walter Fisher, Mark Turner, Jim Corder and Jonathan Gottschall).

As an instructional tool, narrative can take on a broader meaning to include engineered designs (and their context and use), as well as the use of stories to demonstrate the impact, risks and promise of engineered solutions in a broader societal, economic, environmental and ethical context. Cognitive psychologist and philosopher of education Jerome Bruner defined two modes of thinking that apply in this context: "logico-scientific" and "narrative," (which are not mutually exclusive)[4]. The logico-scientific mode (and its attendant argumentative method) is clearly the dominant mode in engineering education for focusing on science, math, and logic to categorize and understand engineering principles and develop technological applications. But use of narrative can both improve motivation in learning and enhance mastery of engineering knowledge, and more important, it is ideal for helping students understand broader impacts (societal, ethical, historical) in engineering. The 20th century philosopher Paul Ricoeur[5] points out that narrative is built upon concern for the human condition, and ethical literary scholar Marshall Gregory contends that there is indeed no stepping outside of narrative contexts[6]. Hence, by more explicitly and imaginatively using stories (literally and figuratively) in engineering education, including case studies and cautionary tales, a more holistic approach may be achieved: one which happens to be reflected in student learning outcomes associated with ABET accreditation of undergraduate engineering programs. In addition, by exploring 'missing narratives' – voices and stories that are silenced or excluded in a given narrative – we can better understand the role of ethics and values in engineering designs and technological failures. This approach allows for a learning-through-questioning, problem-based approach which has an inherent multidisciplinary appeal and the ability to motivate STEM student learning while exploring questions of social justice, diversity, sustainability and global concerns.

In a broader context, technologies themselves are inseparable from the concept of narrative. As pointed out by David Nye in *Technology Matters*, "the meaning of a tool is inseparable from the stories that surround it."[7] He goes on to point out the similarities between stories and tools: "Each involves the organization of sequences, either in words or mental images….Tools require the ability to recollect what one has done and to see actions as a sequence in time.. To explain what a tool is and how to use it seems to demand narrative." This goes to the heart of the definition of human as a tool-maker and user, and the most basic way humans taught their next generation through the use of story-telling. Technology and narrative are inseparable elements of what it means to be human. Hence when a student is taught the process of design to create a technological solution to a need, it becomes a story – from seeking answers to better define the need, to understanding those for whom the solution is designed, to putting together tools and knowledge, and to finally manufacturing the solution and ensuring that its broader impact does not create more problems than it solves. If the engineer is tasked with creating a source of energy for a community, the moral imperative to be a conscientious engineer (and a good citizen of the world) demands that he or she discover what the energy is required for (since there may be simpler or more efficient ways to perform the task that require less energy), that he or she learns the cultural and societal implications of using local resources versus bringing energy from distant sources, and that he or she strives to limit any detrimental byproducts of the technological solutions so that, in time, the story that is created through design indeed has a happy ending. By ignoring the broader factors and impact of the design process the engineer not only risks technical failure (and disaster which can change history), but also denies the strength and promise of the engineering profession to enhance human existence.

While narratives have been used to a limited extent in engineering coursework, mostly as background reading for case studies, they are almost never utilized as a tool for questioning and learning in the form of student writing of narrative. Narrative pedagogy (NP) involves a much broader and open-ended proposition than does reading or viewing narratives on engineering topics. Reading a case study as narrative is often enlightening, but it usually designed to teach a particular concept – in essence a story with a moral. This is the traditional approach. But the use of narrative pedagogy encompasses much more in that it includes the creation of narratives by the student.

The seminal work by Nancy and John Diekelmann on narrative pedagogy explores its use in this broader context, which has found great success in fields traditionally associated with a logico-scientific approach such as nursing[8]. They cite NP as a way to go beyond the limitations of conventional pedagogy by using a methodology which explores "questioning-as-thinking" – not just a linear approach of questioning that seeks answers. In other words, NP is a mechanism for metacognition, exploring how a student thinks and learns. Or, as the Diekelmanns' state, "Narrative pedagogy is a recovery of the embodied and dialogical experiences of schooling learning teaching as an intra-related phenomenon rather than a series of unrelated neutral activities." Hence narrative can be an ideal vehicle for linking engineering to values (as engineering decision making in a societal context is inherently not neutral), and to help students explore their own values and their role in the real and perceived technological risk. It is at its center an approach which guarantees authenticity in engineering education, because the human narratives are authentic – whether we consider the missing voices in designing a chemical plant in a vulnerable environment, the personal story of how living with technology affects us, or the soul-searching in the voice of an engineer who designed a submarine lost at sea. This narrative approach can then be extended to exploring an imagined extrapolation of technology and how that might impact lives, societies, economies and the environment to understand how the act of questioning itself within a framework of values and science becomes the defining act of engineering design (and its success or failure). And, as the process of engineering design itself has been shown to follow the flow and structure of narrative, engineering students can directly apply their experience with narrative pedagogy to their own design processes.

Applications of narrative pedagogy in engineering:

Below are a few illustrative examples of narrative pedagogy (both the use of narrative, and the writing of narrative responses) used in several classes at Stony Brook University, The examples are taken from first and second year courses either taught exclusively to undergraduate engineering majors (as in the case of "Introduction to Engineering Science and Design") or taught to a variety of majors, with approximately 60% of the class being engineering majors. This is the case for the enrichment course in “Emerging Technologies, Fact and Fiction” taught to first year students in the Undergraduate College of Information and Technology Studies, or the online course on Learning from Engineering Disasters, a course taught primarily for second or third year undergraduates which satisfies university requirements for *Learning Outcomes for “Understanding relationships between Science or Technology and the Arts, Humanities or Social Sciences (STAS*)” The specific learning outcomes required for STAS courses are the ability to apply concepts and tools drawn from any field of study in order to understand the links between science or technology and the arts, humanities or social sciences, and the ability to synthesize quantitative and/or technical information and qualitative information to make informed judgments about the reciprocal relationship between science or technology and the arts, humanities or social sciences.

For these courses, the purpose of the narrative pedagogy applied is to enhance learning of particular engineering topics, as summarized in Table 1.

Engineering topic	**Methodology**	**Student learning outcome**
Engineering impact, problem solving and design	Case studies (prepared by instructor and presented to class)	• Understand the role of engineers in conscientious design and problem solving • Enhancing self-efficacy • *An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability* • *The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context* • *A recognition of the need for, and an ability to engage in life-long learning*
	Analysis of design as narrative (prepared by student)	
	Narrative about problem solving	
	Narrative about giving up technology for a day	
Assessment and reduction of risk	Case studies of engineering failure/disaster (prepared by instructor and	• Understand the responsibility of engineers to integrate concepts of safety and manage risk in their actions, concepts and designs • Identify underlying causes of accidents and failures, including a range of human factors, including

	individual students or student teams)	psychological biases, overconfidence, organizational failures, unsafe haste, a lack of conscientiousness and attention • Understand the importance of engineering ethics and value-sensitive design in controlling risk. • *An understanding of professional and ethical responsibility* • *The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context* • *An ability to function on multidisciplinary teams*
	Reading and analyzing science fiction and relating to emerging technologies	• *An understanding of professional and ethical responsibility* • *An ability to communicate effectively*
	Writing science fiction related to emerging technologies	

Table 1: Applications of narrative pedagogy to engineering topics and learning outcomes (italics denote student outcomes cited by ABET)

A. Narrative pedagogy used in "Introduction to Engineering Science and Design", a first year course for engineering majors (70-75 students annually):

Two assignments specifically address use of NP. The first asks students to tell a brief story about a problem they solved or tried to solve by building, fixing, constructing, or analyzing scientifically and how they felt about their success (or failure) in this task. While answers clearly varied based on students' prior experience or exposure to engineering problems (e.g. in high school principles of engineering or design courses, through science fair competitions or shop classes, or based on tasks they had to solve in everyday life, like building a book case or repairing a bicycle or car), responses had certain aspects in common. These could be categorized as problems or challenges overcome, lessons learned, and self-knowledge gained. These revelations were most valuable to the student when they enhanced self-efficacy; positive correlations among self-efficacy, engagement, and outcomes in writing and reading are well established among educational psychologists[9].

For example, students stated that their ‘story’ “helped [them to] realize that engineering is fun and that building things is not as difficult as one might imagine” and that “Designing and creating [their] own product from start to finish was one of the best experiences [they] had during [their] high school education” (comments taken from student portfolios). In many cases, they solved a problem which helped their families or communities (like aiding in a move or building furniture) and gained satisfaction from realizing their role and recognizing the contribution they had made. They also found that they were actually doing something that they imagined engineers would do, which again enhanced their self-efficacy. Students repeatedly commented that they felt a sense of accomplishment, especially if they had to come up with a particularly creative solution to a problem (e.g. fixing something in their house before their parents realized they had broken it) or had to seek out sources of knowledge required to solve a problem (e.g. finding YouTube videos that show how to replace a cell phone battery or repair a car). This is at the heart of self-efficacy – believing in your own ability to find information needed to solve a problem.

In a number of cases, student’s reflected on the narrative activity itself; commenting, for example, “the assignment helped me develop my skills as an engineer because I had to write about my thought process when constructing something.” This ‘meta’ experience is especially valuable, as it provides a new level of insight into ‘thinking’ as an engineer when contemplating a design or problem-solving task. Students found that even if they were not successful in solving a problem or designing a solution, the effort put into the task was valuable in that they learned some of the necessary steps for engineering problem solving. Even the process of selecting a narrative was instructional. In the words of one student “I ultimately chose the story that I did because it was one of the few occasions where my work contained very little structure. That means there was plenty of room for error as well as room for correction.” This response demonstrates insight into open-ended problem solving (which all design is) as well as an iterative approach, which is key to design optimization.

Other student reflections on their narratives indicate other revelations which enhance self-efficacy and indicate recognition of key skills for successful engineering:

> *“I realized that sometimes I will not be able to figure out the [root] of a problem [but] if I think about it and work around the problem, I can still succeed.”*

> *“I felt accomplished fixing something i thought I could have not before. All it takes to confront a problem is to use your critical thinking, past experiences, and your resources. I learned a new skill that day, but more importantly, I learned to use my resources when facing a problem.”*

“Effective communication is also an important part of engineering, and I suppose in life in general. I learned that you need to be clear about what it is that you are doing, and how you can communicate that well to other people who may or may not have had the same education as you. I learned that engineering encompasses many fields, from mathematics to science to ethics, and that they all blend and work together so that engineers have the knowledge and conduct to design, create, and improve our society.“

The second use of NP in the course is to ask student to (try to) give up or severely limit their use of technology (not including technologies necessary for health or safety) for one day. Sherry Turkle has pointed out two important aspects of students’ dependence on technology: first, that their “expectation of continuous connection” exposes insecurities and anxieties in our human relationships mediated by technology, and second that the values expressed in this connection indeed shape our lives[10]. Aside from the great difficulty students’ found in completing this task, their narratives of their experience reveal again some common aspects and in particular common insecurities and anxieties which reflect the values presented by our personal relationship with the technologies in our lives. Most comments reflecting on the narratives focused on students’ recognition of how dependent they had become on technology or how extensively technology had become integrated into their lives and the lives of those around them. Some students were disturbed by the degree of their and other student’s technology dependence, while others accepted this as an inherent and in fact necessary characteristic of modern life and welcomed it. Such comments included:

“This assignment has made me reflect upon how we are dependent on technology to get through our everyday lives.”

“I came to the conclusion that the day seemed to last a lot longer and that more things go on around us than we notice when we are not constantly on our phones. It was also interesting to see how many people were glued to their phones when they are eating or just walking around campus. I have decided that I am going to try and be less like those people and not use my phone or technology when I’m walking around campus or eating lunch with my friends.”

“As is the case with many things throughout life, one does not realize how important something is until they lose it. We may take for granted how many functions of our everyday lives rely upon technology, and this assignment made me rethink the vital role that technology plays in 21st century society. “

“My time without technology showed me how dependent people are…. When I walked outside almost every single person was looking at their phone. Everybody

in my dorm was using their computer when I was home. … This challenge really made me think about how technology is affecting us and how much worse it will get in the future. "

"All in all, I realized what a huge impact technology has on me and everyone around me. It is definitely excessive, but it is the way society functions today"

"Through this assignment, I've realized how reliant I am on technology and the benefits that I get through [it]…"

"A day without technology, especially in modern society, is a rather challenging task. Specifically, in college … technology is used almost constantly throughout the day whether it is for online homework, key cards or emails about class changes."

"Even though it was a tough day, I learned that we are so consumed [with] technology that our lives don't function without it. We are fully dependent on the convenience technology provides us. From a calculator to music player to texting, [my] phone is in every part of what we do. And I feel that we have reached at a point where giving it up isn't a viable choice either. Without the phone book, I realized that I didn't remember any phone number of my friends … without a GPS … I bet I can't even go to the next town. "

"Although this assignment made me realize how attached I am to my phone and laptop, it also allowed me to do the things I had liked to do [without technology], such as sketching and reading."

"Without technology, it becomes clear how I would need to plan out my social life with others (which is something I'm not big into). Technology allows for the spontaneous making of plans with others, even if it's [only] ten minutes before…."

Overall, through creating a personal narrative of their relationship with technology (as revealed by trying to limit its use), students discovered the values inherent in technology, and in turn learned about their own values – especially those values that define their relationships to other people. This is also considered later in the course, when students are requested to analyze the values expressed in engineering design and to contemplate the ethical decision making this indicates (both conscious and likely unconscious) on the part of engineers. Consequently, students are asked to show how values and ethics play a role in the broader implications (societal, tec.) of technology and how ethics and value-sensitive design play a role in reducing risk.

B. The disaster narrative and the assessment and reduction of risk

The use of narrative can both improve motivation in learning and enhance mastery of engineering knowledge, and more important, it is ideal for helping students understand broader impacts (societal, ethical, historical) in engineering. Bruner states that "The imaginative application of the narrative mode leads to good stories … and deals in human intention and action and the vicissitudes and consequences that mark their course." Of course, it is the "human … vicissitudes and consequences" in most cases that generate the risks which engineers need to consider in their designs and their application.

Probabilistic risk assessment (PRA) encompasses how engineers, regulators, policy makers, and scientists understand the potential risk of engineering developments in a broad context of technology, the environment, and society as well as how mitigation and preparedness can decrease the impact or probability of failure and, hence, decrease risk. A shorthand (yet comprehensive) way of looking at this is expressed in the equation[11]:

Risk ≈ Consequences of failure ≈ {vulnerability x rate of occurrences x cost} ÷ mitigation

Where we can define these terms as follows**:**

- **Vulnerability** – exposure to risk (e.g., placement of a facility on a geological fault line, or designing a system without sufficient means of monitoring operation)
- **Rate of occurrence** – potential for failure, based on models or experience
- **Cost** **–** cost to economies, human health, society, environment, industry, etc.
- **Mitigation** **–** ways to reduce any of these factors, from better models, to design of more robust facilities or those which would impact the environment less in case of failure, to adding sensors and rapid response systems

Two additional notable factors should be considered, impacting the role of engineers in preventing or minimizing the impact of failure or in designing systems less likely to fail in the first place. First, it is necessary to realize that all of these factors can, and will, change with time (due to materials degradation, shifting populations, changing weather patterns, changes in economies and industry, etc.). Second, and perhaps most challenging for the education of future engineers and scientists, is that complex behavioral and societal factors such as ethics, sustainability, and social justice play crucial roles in the perception of risk by both engineers and the public at large (perceptions that can be vastly different from each other). Understanding and teaching how societal factors, environmental factors, ethics, and values impact the success (and failure) of engineered solutions is one of the greatest challenges for engineering educators today and for the foreseeable future. Further, the accurate and realistic perception of risk is a crucial skill for an informed citizenry and is certainly critical for the education of the next generation of business, societal and political leaders. Hence, a thorough and effective engineering education must integrate design with values, problem solving with ethics, conceptualization and planning with social justice, and operations with sustainability. Design must be taught with recognition of psychological and human factors that result in overlooked controls, incorrect procedures, lapses in judgement, and poorly designed systems and use of incorrect standards or poorly chosen materials.

An online course has been developed to respond to these needs, Learning from Engineering Disaster. This course was formerly taught in a classroom format to about 120 students each year, but has grown to over 180 students in the current offering (and likely to expand further through the availability of the online offering and the recognition of the value of the course and its associated materials beyond our University). To broaden the opportunities for students, the online version of the course has been developed to transform the current course through: enhanced use of electronic portfolios and online collaboration tools for group work; design of peer evaluation activities which leverage the online 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 that provides valuable feedback to students and necessary knowledge for course management and improvement; and integration of course design and accreditation criteria. In addition, the course has been used 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.

The course takes a unique approach to risk assessment not only by analyzing the disaster narratives we are familiar with (though in an incomplete sense), such as the Titanic, the Hindenburg, the Space Shuttle Challenger, the failure of the hurricane protection system in New Orleans, or the collapse of the World Trade Center in the events of 9/11, but also by asking teams of students to build a narrative focused on a current engineering failure of their own choosing. The student teams almost always include multiple majors from within and outside of the engineering disciplines, providing an opportunity for multidisciplinary collaboration, and in fact demonstrating the value of having multiple perspectives in creating a comprehensive narrative.

Study of well-known historical disasters as mentioned above starts with the known (and impactful) narrative known to the students and influenced by movies, popular media and online sources (with of course varying levels of reliability), and reveals the broader issues and nuances which are key to understanding both the risk inherent in technology and the manner in which societal perception of risk influences our decisions and policies. Missing voices, cultural influence, and false narratives are all considered and discussed to build a more accurate picture, critical for engineers and non-engineers alike.

Case study	**Immediate cause/source of risk**	**Broader issues identified and explored**	**Techniques to expand the narrative**
Titanic	Iceberg	The business culture of the ocean liner industry; psychological biases including overconfidence, conflict of interest	Interview with curator of ocean liner museum, expert on ocean liner industry history in NYC and Europe
		Use of substandard materials due to external pressures on shipyard culture	Videos of laboratory tests (at ocean temperature) on materials similar to those used versus once which should have been used
Hindenburg	Hydrogen-fueled fire/explosion	Airship business and culture	Interview with president of Navy Lakehurst Historical Society
World Trade Center collapse	Burning jet fuel reducing strength of steel	Role of engineering analysis and design in the context of terror attacks	Narrative case study in “Lessons Amid the Rubble” by Sarah Pfatteicher; interview with building designer
Local train disaster	Failure of railroad switching mechanism	Lack of attention to detail in operations due to changes in corporate culture	Interview with director of the Railroad Museum of Long Island
Deepwater horizon	Gas explosion and subsequent uncontrolled leak	Increasing technological complexity (beyond ability to safely control technology) due to increasing energy needs of society	Readings from “Drilling Down” by Tainter and Patzek; stories of technological complexity and unknown environments pushing the cognitive limits of designers
Failure of the hurricane	Failure of floodwalls and generators to	Societal, economic, cultural and political issues which caused a failure to upgrade	The ASCE report on the failure of the hurricane protection system (available

protection system in New Orleans following Katrina	power water pumps	the protection system and have a proper response during and after the disaster	online); news reports and video documentation of the disaster and its impacts

Table 2: Examples of disasters studied in class and expansion of the narrative

Note that it is especially valuable to provide insight from individuals who have studied the broader organizational and cultural environment associated with a particular failure or disaster in order to provide key insight into how a failure occurred and its impact. These interviews (filmed for the online course) are narratives, and often engaging ones in and of themselves. Feedback from student surveys have indicated that the use of these narratives have enhanced student engagement and understanding of the failures and their broader impacts. As mentioned above, such an understanding is crucial for future engineers (as well as an informed citizenry).

Students in the course also form multidisciplinary teams to explore a recent failure. This assignment extends well beyond a standard failure analysis report (as would be prepared by forensic engineers). It has to include an analysis of the failure in a broader societal context, including its impact on business, the environment, and human health and quality of life. Students must consider the human factors and the psychological and ethical causes of this failure. In doing so, they construct a narrative which must take into account news sources, which themselves involve uncertainty and sometimes questionable ethos. In doing so, students must learn to judge the veracity of sources, defend their arguments and find supporting documentations. This involves development of skills which are essential for societal, industrial and political leadership and policy-making, as well as accurate risk assessment by engineers.

These narratives, researched and written by students, reveal that the fate of technology, the technology we train our students to design, build, and operate, is necessarily linked to the human condition. This is clearly true of not only the engineered systems of the past and present, but also the emerging technologies of the future. From nanotechnology to drones, the Internet of Things, robotics, deep sea oil, hydraulic fractioning (fracking), and artificial near-intelligence, there may not be a more critical time in human history to focus on how and what we teach our engineers and scientists. In the words of E.O. Wilson: “The problem … is that we have stone-age emotions, medieval institutions, and god-like technology.”[12] Harnessing innovation within our educational system is essential to meet this challenge.

Reflections written by students who have taken the course (in its classroom version) clearly have recognized the value of this exercise in raising their awareness of the complexity of engineered systems, the impact of the open system (the engineered device or system within the greater context of the environment, society, corporate culture, etc.), and the critical need for informed decision-making and analysis of risk.

C. Emerging Technologies, Fact and Fiction

Another direct use of narrative occurs in a one credit enrichment course that employs science fiction narratives to teach about perception of risk and ways in which engineers and policy makers seek to reduce risk. This course, Emerging Technologies: Fact and Fiction, is taught to first-year students in the undergraduate college for Information and Technology Studies, one of six learning communities established by the university to enhance the academic experience of students.

By emerging technologies, we refer to technologies which are considered 'disruptive' (but not in a negative sense) which are transforming our world and which often evoke concern or fear by the general public because of their potential for danger (as often illustrated in popular media, books, games, etc.). These are often referred to as the "GRAIN" technologies, the letters standing for Genetic engineering, Robotics, Artificial Intelligence (or artificial life), and Nanotechnology. As in the case of engineering disasters, these technologies evoke a visceral response. This is due primarily to two factors, the degree to which they or their effects are unknown, and the potential for dread that their impact may create. These psychological factors have been cited by Slovic and Weber[13], among others, as the source of perceived risk form technology (figure 1).

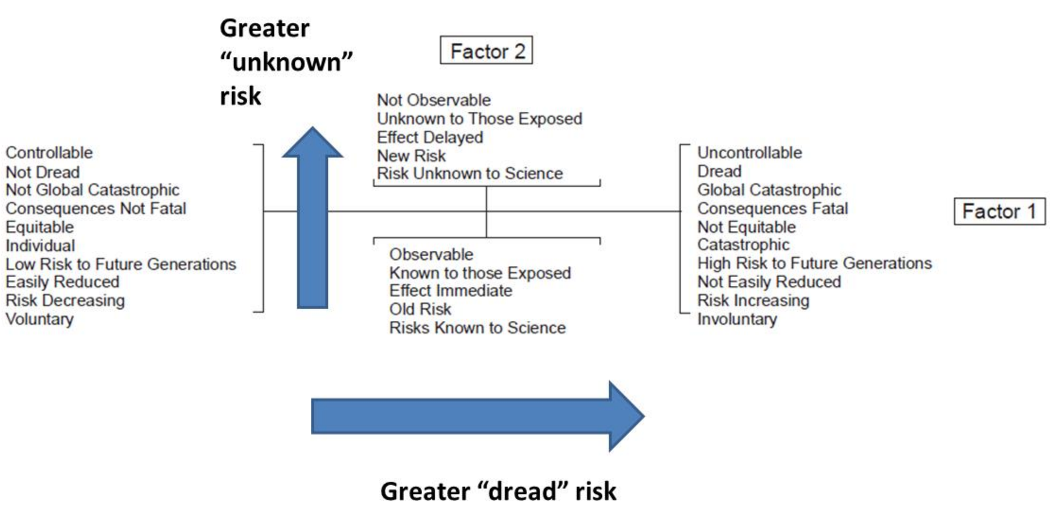

Figure 1: Psychological factors affecting perception of risk, adapted from Slovic and Weber.

In a study by Kahan and Rejeski associated with the Woodrow Wilson International Center for Scholars Project on Emerging Nanotechnologies, they determined that members of the public form a rapid, visceral, emotional response when evaluating nanotechnology risks[14]. When asked to consider balanced information about nanotechnology risks and benefits, the inferences study subjects drew were conditional on their cultural values. They found that "subjects tended to adopt the views of experts whose perceived values were similar to their own, and to reject the views of experts whose perceived values were different from their own, no matter what position those experts took on nanotechnology…. Individuals interpret information on nanotechnology risks varies depending on whether the emphasized application of nanotechnology *affirms or threatens their cultural values.*" Hence we can already say that perception of risk is dependent on our personal narratives, and the public perception of risk is created by the group narrative expressed through new sources, cultural narratives, and popular media, including science fiction. The problem arises when these perceived risks vary widely from engineers and policy-maker perceptions of risk (which may be completely unrelated to each other as well). This does not bode well for informed decision making and technology planning, design and deployment. Hence, it is important for students to consider both the fact and fiction of emerging technologies which will play an increasingly important role in their lives. Engineering students in particular must understand this, because their ability to design technological solutions does not exist in isolation and must take into account the narratives that exist.

In light of this, students are asked to read and reflect on a number of carefully chosen science fiction short stories which contain conflicts related to particular technologies or technological concepts (Table 3). Students discuss dystopian aspects of the results of technological developments, and reflect on utopian potential and suggest methods for mitigating potential risk.

Story	**Dystopian impact**	**Utopian potential**	**Mitigating factors for risk (as suggested by student reflection)**
Alpha Ralpha Boulevard (1961, Cordwainer Smith)	Dissatisfaction with lack of freedom in a techno-utopia	Reduction of uncertainly associated with illness, weather, etc.	Understanding the psychological and emotional needs of humans to promote healthy co-development of advanced technologies and society
Nano Comes to Clifford Falls (2008, Nancy Kress)	Nanotechnology eliminates need to work resulting in a breakdown of society	Nanotechnology providing a cure for disease, access to material goods, agricultural	Developing conscientiousness in engineering; the need for well-informed and realistic risk

		improvements	assessment
Axiomatic (1995, Greg Egan)	Nanotechnology used to eliminate internal morals, alter personality	Nano-drugs to enhance learning, treat illness	Role of government in regulations and legal controls over use of technologies with potential for dangerous, extreme impact
Frankenstein (1818, Mary Shelley)	Abandoned synthetic life threatens humanity	Overcoming death	Teaching, building responsibility for one’s creations
Blood Music (1983, Greg Bear)	Loss of control over artificial (nano-based)_ life form leads to emergent dominance over humanity	“Nano-bots’ to enhance human abilities, repair inherent defects, cure disease	Designing in controls (“kill switch”, restrict life spans) for artificial life; regulations and laws for oversight
I Have No Mouth and I Must Scream (1967, Harlan Ellison)	Enslavement (and annihilation) of humanity by artificially intelligent super computer which becomes ‘insane’ due to isolation	Limitless control over environment, enhancement of human capabilities for control over every aspect of life	Limiting technological capabilities; taking responsibility for creations
Super Toys Last All Summer Long (1968, Brian Aldiss)	A.I. seen as subservient, less than human despite self-awareness, needs for human interaction	Robots, A.I. to provide companionship, even ‘love’	Treating A.I. with respect, concern; acting as responsible ‘parents’ to artificial life forms; striving to understand creations; conscientiousness in engineering
The Wedding Album (1999, David Marusek)		Tremendously complex programs providing new levels of recording events, emotions	
People of Sand and Slag (2004, Paolo Bacigalupi)	A post human world in which modifications which allow for tolerance of polluted, extreme environments leads to lack of concern for	Enhanced human ability to adapt to harsh conditions, ability to take nourishment from any source (ending lack of abundance of food,	Deep self-reflection and awareness of how technology changes humanity and our values and ethics; sustainable engineering and

	natural environment and beings	etc.)	development
Rates of Change (2015, James S.A. Corey)	Mixed impact on people who can change bodies easily in response to disease, accident or just desire – some find a loss of self and deep unease with rapid change	Ability to replace bodies if terminally ill, damaged; for some, a more complete sense of self-expression through extreme modification	Understanding the psychological impact of human emotional impact of extreme and rapid change; role of regulations and informed decision making

Table 3: Science fiction narratives

Students are requested to assign a rating to the stories from 0 (completely dystopian) to 10 (completely utopian) in terms of how they feel the author expresses the influence of the emerging technology discussed in the story. Students are required to explain their rating, and are discuss (and often debate) these ratings in class. Students are also given an introduction to the current state-of-the-art in these technologies, so that they may make a better comparison of the author's use of technology to its real-world applications. The result of this exercise is quite interesting, and results in two primary findings. First, almost no technology as described in these stories is completely dystopian or utopian – 'shades of gray' exist, which show students that it is often human values (and not the technology itself) which leads to the positive or negative implications of the technology. Secondly, the most common causes for negative results from technological developments are misuse of technology (intentionally or by accident) and loss of control over technology (escaping the laboratory, etc.). Hence, the story of Frankenstein by Mary Shelley, for engineers and scientists, becomes a cautionary tale about what can happen when the creator of a potentially hazardous technology abandons or loses control over the technology, or undertakes the process of creation without understanding the responsibilities which come with it.

Students also read two non-fiction articles which help them to understand how precautions and recognition of ownership of implications can help to avoid dystopian outcomes, and most importantly the role of engineering and scientific ethics and values in the responsible development of technologies. These are a chapter on value sensitive design, prepared by Dr. Ronald Sandler, which specifically looks at the role of values in development of nanotechnology[15], and the Testimony of Arthur L. Caplan to the Presidential Commission for the Study of Bioethical Issues on development of synthetic life from 2010[16]. These readings help students understand the role of ethics and values in avoiding the potential dystopian outcomes of emerging technologies.

Finally, students must write their own science fiction short stories detailing a mostly dystopian outcome of one of the emerging technologies discussed in class. Of course, the nature and writing of narrative is discussed in class so students may have some additional instruction on story writing; however, the best lesson in writing narratives comes from reading them, so the stories chosen for the class are very helpful in this regard. Common dystopias described by students include out of control military technology, out of control medical technology, release or misuse of technology due to terrorism, intentional misuse of technology by shadowy corporations, organizations and government (political control), stolen nanotechnology for human enhancement or wealth, drug addiction, technology which becomes self-aware and 'turns on' its creators – in other words, the full range of science fiction tropes. Students are then asked to write a reflection to accompany their stories which describes ways in which such dystopias may be avoided. These often include strict monitoring of research and use; including laws and regulations; a built in mitigating technology (to stop accidental release, prevent misuse, etc.), and better understanding of technology (and the need for safety) by scientists, engineers, end-users, manufacturers, technicians, and the general public.

For many students (in fact most) this class represents the first time they have ever read science fiction (other than perhaps Frankenstein or an H.G. Wells tale assigned in a high school class). However, the class always makes a strong impression, especially as students come to reflect on the source of their own perceptions of risk and the role of their own values. Surveys collected at the end of the course have indicated that students become more motivated and engaged; they show an increase in appreciation for factors which can lead to appropriate and safe use of technology; students see a link between their perceptions and the development of technology; and many wish there were more courses like this. Clearly, narrative plays an important role in enhancing both student engagement and learning gains.

There are two quotes which are included in the course express these conclusions quite well:

> "The real problem of humanity is the following – we have Paleolithic emotions, medieval institutions, and god-like technology."[17]
> E.O. Wilson, Harvard biologist

> "We don't see things as they are, we see things as we are."
> (Often attributed to Anais Nin, US (French-born) author & diarist (1903 - 1977), but has also been attributed to ancient Talmudic origins)[18]

Taken together, these quotes reflect two important conclusions – that emerging technologies, in particular, those as potentially disruptive and transformative as nanotechnology, artificial intelligence, genetic manipulation and transhumanism, can exceed our ability to control and understand them and hence must be considered and treated with the utmost care, and secondly, that our perceptions of the world (and our technologies) are defined and controlled by our personal narratives and values. It is critical for the next generations of engineers and scientists to understand this in order to better ensure that our design and use of powerful and transformative technologies are conducted in a thoughtful and conscientious manner, mindful of our own biases, anxieties, misperceptions, and politics which can sometimes cloud judgement. This was very well expressed by the physicist Richer Feynman (1918-1988) when he reflected on the hearings on the Space Shuttle Challenger disaster: “For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled.”[19]

Conclusions and further plans for a narrative approach

The examples described help provide a new model for the use of narrative pedagogy in both STEM and non-STEM fields to enhance learning through an open-ended approach integrating questioning with evaluation of case studies and writing of narratives. These applications of narrative pedagogy also provide a valuable model for multi-disciplinary efforts between humanities/liberal studies and engineering, demonstrating how teaching and learning methods from one area may be applied in the other and hence how students can be presented with a more comprehensive academic approach. These uses also provide professional development opportunities for faculty in both engineering and writing departments, an impact which will be brought to the larger educational community via presentations and dissemination online and through publication. In this way, benefits for the education infrastructure, including development of models and a community of practice, will be propagated. It is also expected that outreach to the liberal arts and writing faculty communities of practice will generate a host of new ideas and collaborations between engineering and non-engineering faculty.

A further impact is expected to be the development of an understanding of the impact of a narrative approach on enhancing diversity within the STEM fields. Clearly, students from all backgrounds become very engaged in narrative environments, from computer games to entertainment media (and hopefully in their reading). Hence by incorporating a narrative approach, it is hoped that students from diverse demographic backgrounds, including underrepresented students and students from diverse economic backgrounds, can be encouraged to explore key engineering problems in greater depth, motivated by the potential for recognizing and reducing risk. By asking students to develop their own narratives, from personal stories of engagement with technology to imaginative extrapolations of technological dystopias (and their potential remedies), we motivate students to establish personal connections to STEM concepts and impacts which can act as a pathway to draw new students to the disciplines.

As a result of these experiences, a number of other applications of narrative pedagogy suggest themselves as a means to enhance learning in engineering coursework. Within the context of the course on Learning from Engineering Disaster, an interesting use of NP would be to ask student teams to construct a completely fictional disaster narrative, including interviews with 'experts' and 'witnesses', analysis of the risks, engineering, human , environmental and otherwise, which led to the failure, fictionalized legal proceedings or other features which would build a narrative which addresses the values inherent in design of technologies in a societal and human context. The creation of such a narrative would provide an opportunity for students to more fully explore not only the causes of failure and the human factors involved, but also better understand how popular media, internet news sources (of at best incomplete or at worst questionable ethos) and the psychology of individuals and organizations can shed light on the interplay between beliefs and facts.

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