Historical Narratives in University Engineering Courses as a Means of Promoting Sociotechnical Education

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As technological innovations proliferate, they confront us with two problems. First, any innovation that actually works well enough to matter to people will also bear important but nonobvious ethical implications. Second, those with sufficient technical expertise to develop such innovations are those who most need the sociotechnical competence necessary to identify and responsibly examine such implications. In university curricula, a liberal or social scientific education (including ethics) on the one hand, and STEM education on the other, have typically been framed as two distinct, divergent, and mutually exclusive paths of study; students who follow one of these paths cannot follow the other. But if we depend upon STEM-trained people to develop innovations that affect people in non-obvious and sometimes unethical ways, then we need STEM experts who are competent in sociotechnical analysis. Incorporated into STEM curricula, historical narratives can reunite these divergent paths, contributing to the sociotechnical competence of STEM experts. Such material can integrate sociotechnical concepts into technical courses in ways that elevate student engagement and learning.

Review of Research

Researchers have studied the use of narrative in education. Oaks (1995) showed significant improvements to both short- and long-term (5 weeks) retention of information taught in narrative form. In a study of digital storytelling, Taylor et al. (2018) concluded that storytelling improved student engagement. In the context of science education for 11-13-year-olds, Solomon (2002) discusses stories as a means of posing ethical questions in addition to promoting science education. Klassen (2007) and Schiffer & Guerra (2015) offer useful examples of historical narratives.

While narrative-based education has demonstrated benefits, it is also essential to consider other lesson modalities to fully contextualize its effectiveness. Erickson et al. (2020) conducted a study to characterize student engagement across hands-on, problem-based, and lecture activities in a college introductory course. Similarly, Mello & Less (2013) explored the impact of active learning on student outcomes, finding statistically significant benefits in a variety of college subjects. This research suggests that active learning methods will typically outperform lecture-based approaches regardless of whether historical narratives are used.

The Benefits and Costs of Including Historical Narratives

Historical narratives can make lessons more engaging for many people. Many successful STEM channels on YouTube suggest that historical narratives help STEM subjects reach large, voluntary audiences. The Fast Fourier Transform (FFT) is a deeply technical topic and a cornerstone of modern signal processing. In a search for FFT on YouTube, the top two results were: “The Remarkable Story Behind The Most Important Algorithm Of All Time” (Veritasium, 2022) and “The Fast Fourier Transform (FFT): Most Ingenious Algorithm Ever” (Reducible, 2020). In the first, a historical narrative introduces the FFT and the algorithm is briefly explained. The second is solely an explanation of the FFT algorithm, without historical narrative. In the absence of more complete viewership data, a simple comparison of viewing numbers might suggest that in this case, the historical narrative attracted more viewers to a video about a STEM subject.

The YouTubers faced a tradeoff: time committed to a historical narrative is time not spent on the technical details of the topic. Although Veritasium has 58 times the subscribers of Reducible, its FFT video has registered less than 4 times the number of views as Reducible’s.

This raises the question of how Reducible, as a relatively small channel, managed to attract so many viewers to its FFT video. One possible explanation is that viewers seeking in-depth understanding of the FFT were not satisfied with the more popular video, which prioritized historical context, and actively searched for content that focused on the technical aspects of the algorithm. To this point, in the week following the release of Veritasium's video, Reducible's weekly video views went from an average of 27,000 views per week for the previous 5 weeks (with a maximum of 32,000) to 123,000 without having uploaded any new videos (SocialBlade, 2023). This tradeoff between historical narratives and technical depth is also relevant when considering the integration of historical narratives in university STEM courses, as educators must strike a balance between engaging students and delivering comprehensive technical instruction.

The varying audience preferences present an important distinction: some people appreciate historical narratives as a means of making technical topics more engaging, while others are primarily interested in the technical content and may perceive historical context as a distraction. This distinction suggests a possible trend across university years. Incoming students might be more similar to the general YouTube audience, appreciating hooks or varied lecture styles to maintain their attention. However, as students become upperclassmen, they may develop a deeper appreciation for technical topics and no longer need additional engagement strategies. Their increased freedom in choosing classes likely results in a greater intrinsic interest in the subject matter. This is not to say that upperclassmen would not be interested in the history of their field, but they might be more focused on the technical aspects of their chosen discipline. Another factor may be whether the class is targeted at those in major or not. "How Things Work" is an example of a physics course targeted at non-physics majors. In such classes, historical narratives may be even more beneficial to student engagement.

Sociotechnical Lessons Through Historical Narratives

The Veritasium video also serves as an example of how historical narratives can offer sociotechnical lessons. As the host explains, the development of the FFT was driven in part by the need to detect atomic bomb tests, which was essential for enforcing test bans. Had the algorithm been developed sooner, the nuclear arms race could have been decelerated more quickly. This case illustrates the social origins of technological innovations and underscores the value of incorporating such lessons in engineering education.

One particularly relevant example can be found in aerospace education, where incorporating sociotechnical topics might involve discussing the Turkish Airlines Flight 981 disaster (1974). Flight 981 serves as a prime example of the consequences that can arise when engineers ignore their judgment due to pressure from higher-ups (Witkins, 1975). A striking parallel can be drawn between the events leading to the Flight 981 disaster and the Boeing 737 MAX incidents (Lion Air Flight 610 & Ethiopian Airlines Flight 302), in which engineers' concerns were similarly disregarded (Kitroeff et al., 2019). If the engineers at Boeing had been familiar with the Flight 981 case, they might have been more persistent in voicing their complaints to management and better equipped to argue their case. A sociotechnical education implemented through in-major lessons, would likely present more relevant examples to engineers in each major.

As it stands, sociotechnical lessons are confined to STS courses for many engineering disciplines at UVA. The upside of this is that the lessons are handled by faculty with expertise in sociotechnical topics rather than engineering PhD’s reaching outside of their expertise. This should not be neglected as these lessons often touch on issues of racism, sexism, and controversy which must be handled with care or risk alienating many students. However, a significant number of students are largely uninterested in the general approach to STS. This can be seen in the reviews for STS 1500 on theCourseForum (a UVA-specific course review site). Across the 53 ratings, the course averages a 2.03/5 (TheCourseForum, 2023). The major themes are that the course is boring (mentioned 8 times) and useless/pointless (mentioned 14 times). The general sentiment is expressed in the following quotes: “Very little of what you learn is actually relevant to anything you do” and “None of the information will be used in engineering.” There is certainly a degree of selection bias on these third party review cites, but the reviews do communicate that there are a vocal subset of students who fail to see a point to this general STS education. Some students are more sympathetic to the professor’s plight but still make the issue clear: “It's hard to make engineers interested in a more humanities-focused class.”

The proposal to integrate sociotechnical lessons into STEM courses could remedy the issues seen in a generic STS education. How could a student seriously question the importance of an STS education if they had been armed with a litany of examples of the interplay between society and technology in their field? How could they question the relevance if they had seen the consequences of engineers in their future line of work failing to understand the concepts discussed in STS courses? Anecdotally, there is only one lesson from STS 1500 that has been discussed in the electrical and computer engineering student lounge several times in the last few months (2-3 years after those involved took STS 1500): the lectures on the Current War between AC and DC power. It should come as no surprise that electrical and computer engineers seem most interested in STS topics related to electrical and computer engineering.

There would likely be knock-on benefits to STS courses, as well. The upper-level STS courses are typically discussion-based, and the quality of such classes often hinges on the quality of the discussions. The primary obstacle in these discussions is student apathy. If more students entered the course having embraced the value of a sociotechnical education with their own arsenal of case studies accumulated over years of STEM education, the professors of these upper-level classes wouldn't have to do so much of the legwork.

Considerations for Engineering Professors

The potential benefits of incorporating historical narratives into STEM education have been discussed for engineering students and STS professors, but it is important to consider the implications for engineering professors as well. An instructor who is genuinely interested and passionate about a topic is likely to be more engaging than one who feels forced to teach something they have no interest in. Many professors already perceive administrative interference in their teaching as overbearing, and such interference can impact their motivation and job satisfaction. This sentiment is evident in online discussions among professors, such as those found on the r/Professors subreddit, where faculty members share their frustrations about standardization, diminishing creativity, and increasing administrative burdens in their teaching. In one such post, a professor vents:

> Monday morning email that indicates one more element of my teaching being standardized. Made uniform.
> The ability to be creative and thoughtful in my teaching is what makes my job a delight. At a certain point I can't keep fighting them on this. They, like so many employers, consistently fail to recognize the added value of all these little things we do to make the student experience more. (WDersUnite, 2023)

The concerns raised in these discussions suggest that integrating historical narratives into STEM courses might not be universally welcomed by all engineering professors, and this potential challenge should be considered in the broader conversation about promoting sociotechnical competence in STEM education.

Extended Example

Given the benefits of active-learning mentioned in the research review, it is worth exploring how historical narratives might be incorporated into teaching methods beyond traditional lectures. One potential approach involves using case studies, where students are tasked with putting themselves in the shoes of characters in the story. Erickson et al. (2020) found that case studies were more effective than lectures in promoting student engagement and motivation. In this context, historical narrative-based lessons could emphasize hands-on activities instead of being solely lecture-centered. For example, students could be prompted to retrace the steps leading to the development of a specific technical innovation.

To illustrate how the ideas discussed could be applied in college curricula, an example using a topic from Electromagnetic Fields will be provided before the conclusion. The lesson would start with a reading or brief lecture to set the stage. Then, students would be guided through the theoretical innovations that proceeded. When relevant, experimental work can be conducted to validate the theoretical models developed.

In the 1850s, the British Association in London began considering the possibility of a trans-Atlantic cable (Klassen, 2007). By this point, telegraph cables had connected most population hubs on each side of the Atlantic, and those in power had experienced the commercial benefits they provided (Science Museum, 2018). Such a cable could reduce trans-Atlantic communication time from weeks to minutes. The progression of trans-Atlantic cable technology would eventually enable the transmission of billions of words per second, forming the foundation for today's global internet.

Students would be asked to imagine what the world would be like without the ease of long-distance communication we have today. Then, they would discuss in groups the potential limitations of typical circuit theory assumptions that might arise in this application. In standard abstractions, electrical signals are assumed to travel instantaneously across conductors. Since electricity travels close to the speed of light and circuits typically don't span such large distances, this is often an effective model. Another assumption that breaks down in this context is that of a perfect conductor. It is often assumed that the wires of a circuit don't resist the flow of electricity (their resistance is zero) and that charge does not build up on the wire (their capacitance is zero). These are the most apparent issues, so students would be expected to start here. If students are having trouble during the small group discussions, the instructor can merge groups or lead a class-wide discussion.

At this point, it’s worth introducing William Thomson, better known as Lord Kelvin. Kelvin had taken on the task of developing a theoretical framework for a trans-Atlantic cable. The theory of the time, backed by Morse and Faraday, hypothesized that the delay for signal transmissions would scale linearly with the length of the cable: if the length of the cable was doubled, the transmission time would double. Their analysis was only taking into account the capacitance of the cable. Kelvin, however, included resistance in his model. At this point, students should be asked to consider what impact resistance will have on transmission time. Accounting for resistance led Kelvin to theorize a square relationship between length of cable and transmission time: if the length of the cable was doubled, the transmission time would quadruple.

The lead electrician for the project, Wildman Whitehouse, was a fierce opponent to Kelvin. Whitehouse considered electrical engineering to be an art to be approached through intuition from experimentation rather than mathematical models. Kelvin was able to predict several pitfalls the early trans-Atlantic cable would face through his analysis, but was ignored by Whitehouse. Their disagreements climaxed after the cable was laid when Whitehouse ramped up the voltage on the cable, causing the insulation to fail and the cable to break. Whitehouse was then dismissed from the project. Students would be asked to consider some of Whitehouse's ideas. Is electrical engineering an "art?" Are there any subjects today that are considered "arts" that might stop being considered so in the future? What does that mean for participants in such a field?

Decades after the establishment of the first working trans-Atlantic cables, companies were still dealing with slow communication rates over cables. As Kelvin has foreseen, clear distinct pulses on one side of the cable are smoothed and dispersed as they traverse the cable. This meant that information had to be sent very slowly to keep adjacent pieces of information distinct. No one could see a way around the problem. It wasn't until the 1890s that Oliver Heaviside, a self-taught British telegrapher, made an important breakthrough (Donaghy-Spargo, 2018). He added the final two fundamental circuit quantities (inductance and conductance) to Kelvin's model for the cable. After presenting the complete model for the cable, students would be asked to consider how the problem of dispersion could be solved. The added parameters can be used to balance out the effect, theoretically eliminating dispersion. Without dispersion information could be sent along the cable without pauses between packets of information, and the rate that information could be sent greatly increased.

Conclusion

Integrating historical narratives into engineering courses presents a promising way of increasing engagement and broaching ethical topics. The conversation is complicated by the superior efficacy of active-learning approaches for engagement and the onus this would put on engineering professors to handle lessons that are potentially outside of their expertise. Due to this nuance, a blanket mandate of any sort is not recommended. It is worth considering the levels to which historical narratives could be introduced into a class.

Without sacrificing any class time, professors could add optional readings to the course. This would provide an easy point-of-entry for professors considering the inclusion of historical narratives in their curriculum. It would also enable them to gather feedback on the readings and topics while gauging student interest in the history of their field. Interested students would receive professor-curated reading recommendations to expand their knowledge in their chosen discipline. Even if only a small minority of students opt for the readings, they are likely to discuss some of what they found interesting with classmates and friends, further enriching the educational experience.

When introducing a new topic, professors could describe the historical context of its original development and the ramifications. They could present a brief, factual recounting or opt for a narrative approach, setting the stage and taking on the perspective of one of the key players. The narrative approach would ideally address questions like: “What prior experiences set the historical figure onto the path of discovery?” and “Were there any unintended consequences to the innovation?" By humanizing the development process, this method emphasizes that innovations typically do not result from a sudden stroke of genius but from an attempt to address a societal need. Discussing the context and consequences in this way would train students to consider the interplay between society and technology.

Professors can take more active-learning approaches, too. A Machine Learning and Image Analysis professor could dedicate some time to discussion groups on the (recent) history and current state of race and sex biases in facial recognition software (Raji et al., 2020). Professors would get students into the practice of dealing with the difficult ethical questions present in their field. On the upper end of commitment, professor could plan entire classes around these lessons. As described in the extended example, a professor could walk the class through a case study related to the development of their chosen topic, rotating through brief lecture sections, discussions, and hands-on work.

Ultimately, Engineering professors should be encouraged to introduce historical-narrative based lessons in whatever way they feel comfortable with to the extent that they believe is right for the class. This might mean no adoption in most classes. This is not an issue. These lessons are by no means a replacement for a traditional STS education. The lessons are there to help establish the relevance to STS for their discipline, equip students with a diverse set of case-studies to exploit in upper-level STS courses, add variety to STEM classes, and to introduce students to the history of their discipline. Even low participation from professors could make a large difference towards these objectives. It only takes a couple of professors teaching required courses embracing historical narratives to reach every student in the department.

References

Donaghy-Spargo, C. (2018). On Heaviside's contributions to transmission line theory: Waves, diffusion and energy flux. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *376*(2134), 20170457. https://doi.org/10.1098/rsta.2017.0457

dragonfeet1. (2023, March 16). At the end of my proverbial rope, admin student double team! [Reddit Post]. *R/Professors*. www.reddit.com/r/Professors/comments/11t0fie/at_the_end_of_my_proverbial_rope_admin_student/

Erickson, M., Marks, D., & Karcher, E. (2020). Characterizing student engagement with hands-on, problem-based, and lecture activities in an introductory college course. *Teaching and Learning Inquiry*, *8*(1), Article 1. https://doi.org/10.20343/teachlearninqu.8.1.10

Grandzol, C., & Wynn, P. (2011). Retention, Motivation, and Enjoyment: An Exploratory Evaluation of the Effectiveness of Hands-On Learning. *Journal of the Academy of Business Education*, *12*, 137–155.

Holodny, E. (2014). *Thomas Edison Secretly Financed The First Electric Chair To Destroy His Rival*. Business Insider. https://www.businessinsider.com/edison-financed-the-electric-chair-2014-7

Kitroeff, N., Gelles, D., & Nicas, J. (2019, October 2). Boeing 737 Max Safety System Was Vetoed, Engineer Says. *The New York Times*. https://www.nytimes.com/2019/10/02/business/boeing-737-max-crashes.html

Klassen, S. (2007). The Application of Historical Narrative in Science Learning: The Atlantic Cable Story. *Science & Education*, *16*(3), 335–352. https://doi.org/10.1007/s11191-006-9026-x

Kubli, F. (2005). Science Teaching as a Dialogue – Bakhtin, Vygotsky and some Applications in the Classroom. *Science & Education*, *14*(6), 501–534. https://doi.org/10.1007/s11191-004-8046-7

Mello, D., & Less, C. A. (2013). *Effectiveness of active learning in the arts and sciences*.

Norris, S. P., Guilbert, S. M., Smith, M. L., Hakimelahi, S., & Phillips, L. M. (2005). A theoretical framework for narrative explanation in science. *Science Education*, *89*(4), 535–563. https://doi.org/10.1002/sce.20063

Oaks, T. (1995). *Storytelling: A Natural Mnemonic: A Study of a Storytelling Method to Positively Influence Student Recall of Instruction*. 107.

Raji, I. D., Gebru, T., Mitchell, M., Buolamwini, J., Lee, J., & Denton, E. (2020). Saving Face: Investigating the Ethical Concerns of Facial Recognition Auditing. *Proceedings of the AAAI/ACM Conference on AI, Ethics, and Society*, 145–151. https://doi.org/10.1145/3375627.3375820

Reducible. (2020, November 14). *The Fast Fourier Transform (FFT): Most Ingenious Algorithm Ever?* https://www.youtube.com/watch?v=h7apO7q16V0

RodneyisGodneyp2x555. (2023, March 17). I'm resigning [Reddit Post]. *R/Professors*. www.reddit.com/r/Professors/comments/11tvdg8/im_resigning/

Rust, S. M., & Blick, K. A. (1972). The Application of two Mnemonic Techniques following Rote Memorization of a Free-Recall Task. *The Journal of Psychology*, *80*(2), 247–253. https://doi.org/10.1080/00223980.1972.9924802

Science Museum (2018). *How perseverance laid the first transatlantic telegraph cable*. Science Museum. https://www.sciencemuseum.org.uk/objects-and-stories/how-perseverance-laid-first-transatlantic-telegraph-cable

Schiffer, H., & Guerra, A. (2015). Electricity and Vital Force: Discussing the Nature of Science Through a Historical Narrative. *Science & Education*, *24*(4), 409–434. https://doi.org/10.1007/s11191-014-9718-6

SignificantFidgets. (2022, October 19). Any examples of admin reducing any responsibilities of faculty? [Reddit Post]. *R/Professors*. www.reddit.com/r/Professors/comments/y852nr/any_examples_of_admin_reducing_any/

SITNFlash. (2020, October 24). Racial Discrimination in Face Recognition Technology. *Science in the News*. https://sitn.hms.harvard.edu/flash/2020/racial-discrimination-in-face-recognition-technology/

SocialBlade. (2023, March 20). *Reducible's YouTube Stats (Summary Profile)—Social Blade Stats*. https://socialblade.com/youtube/c/reducible/monthly

Solomon, J. (2002). Science Stories and Science Texts: What can they do for our students? *Studies in Science Education*, *37*(1), 85–105. https://doi.org/10.1080/03057260208560178

TheCourseForum. *STS 1500—W Carlson—TheCourseForum*. https://thecourseforum.com/course/7185/1481/

Tatman, R. (2017). Gender and Dialect Bias in YouTube's Automatic Captions. *Proceedings of the First ACL Workshop on Ethics in Natural Language Processing*, 53–59. https://doi.org/10.18653/v1/W17-1606

Taylor, M., Marrone, M., Tayar, M., & Mueller, B. (2018). Digital storytelling and visual metaphor in lectures: A study of student engagement. *Accounting Education*, *27*(6), 552–569. https://doi.org/10.1080/09639284.2017.1361848

Veritasium. (2022, November 3). *The Remarkable Story Behind The Most Important Algorithm Of All Time*. https://www.youtube.com/watch?v=nmgFG7PUHfo

WDersUnite. (2023, February 6). If admin keeps insisting on making my job miserable, I have to care less about it. That's just self preservation. [Reddit Post]. *R/Professors*. www.reddit.com/r/Professors/comments/10vblx3/if_admin_keeps_insisting_on_making_my_job/

Witkin, R. (1975, March 12). Engineer's Warning on DC-10 Reportedly Never Sent. *The New York Times*. https://www.nytimes.com/1975/03/12/archives/engineers-warning-on-dc10-reportedly-never-sent.html