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The Curious Case of Thomas Midgley Jr.'s Innovations

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Work-In-Progress: Thomas Midgley Jr., Systems Failure, and the Pedagogy of Unintended Consequences

Abstract

This work-in-progress paper describes the use of the Midgley case in an undergraduate systems engineering course to engage students in structured reflection about technological responsibility, risk evaluation, and long-range consequences. Students read an account of Midgley's development of tetraethyl lead and chlorofluorocarbons and participated in guided discussion connecting these cases to modern engineering decision-making. Written reflections and end-of-semester metacognitive exercises were collected as part of ongoing ABET assessment. Pending IRB approval, future work will include qualitative thematic analysis of student responses to examine how the case influences students' understanding of systems boundaries, professional responsibility, and uncertainty in design. Preliminary classroom implementation indicates that the case may support the development of systems-level ethical awareness and attention to long-range consequences. This work is intended to contribute a structured case-based approach for engaging systems-level ethical reasoning in undergraduate engineering education.

Introduction and Background

The story of Thomas Midgley Jr. is little known by the general public, who have archetypes of the innovator such as Thomas Edison. It also provides an almost mythic warning in engineering ethics, but is not well known even among technicians, managers, and engineers. An inventive, gifted mechanical and chemical engineer, Midgley contributed to two innovations that transformed industry: tetraethyl lead (TEL) as an anti-knock gasoline additive, and chlorofluorocarbons (CFCs) used as refrigerants and aerosol propellants. [1] Each solved a pressing technical problem of its day. Each also produced global, decades-long environmental damage. It is illustrative that in his day he was praised and received many awards, such as the Priestly medal, but might be thought of more as a villain if he is thought of at all in the 21st century.

In the first instance the dangers of organometallic leads such as TEL were known by the 1920s. In that formulation the lead is bonded to carbon and easily vaporizes and disperses into the atmosphere. What makes it useful in this form is its ability to mix with gasoline but also makes it much more dangerous to human health than lead salts. Leaded gasoline was introduced in 1923 [2] and made Midgley a successful businessman. Shortly after a press conference in 1924 where Midgley sought to prove that TEL was safe, he was diagnosed with severe lead poisoning and had to move away for a year of recovery. [2] It was not until the mid-1970s that leaded gasoline was removed from use [2] and not until the year 2000 that it was fully eliminated in the European Union. That means there were almost 50 years of environmental input and exposure to lead among the population. No particular safety protocols were instituted at various automotive plants and repair shops to mitigate the dangers of leaded gasoline.

This can be thought of as a clear lesson about unintended consequences and the hubris of technology, but this was about an *already known risk* where economic and development forces found the benefit to the creation of the global automotive industry outweighed the risks to workers and the public. The ways in which such risks are calculated were more implicit than explicit. On the other side of the ledger what were the benefits to creating the automotive industry? Without some effective anti-knocking agent, cars would not be able to accelerate or pass each other smoothly, a significant feature when people are considering adopting a new mode of transport. Despite the independence the automobile provided, if the ride were not adequate for consumer needs, it would not be adopted. The question remains to this day in environmental regulation how one should measure and weigh the risks to human health of various decisions. The health and environmental costs were not borne by either the inventors or the business stakeholders who developed the industry but were effectively dispersed until they were invisible across the public. Although not a simple analogy, to achieve acceptance for electric vehicles (EVs) today, concerns about range, for one, will have to be overwhelmingly addressed to ensure successful adoption of innovative technology. In addition, all the attendant questions of weight, wear, and maintenance by the owner will have to meet consumer requirements for EVs to overtake the marketplace. None of these are strict engineering criteria; rather, they reflect a complex mixture of consumer expectations, habits, and technical constraints.

Thomas Midgley's next big idea and invention was chlorofluorocarbons (CFC) refrigerants. [1] The misstep here was not obvious at all. This was a perfect example of the unknown risks that are not even imagined. Earlier refrigerants were quite dangerous, explosive, and toxic. In making such a safe refrigerant, Midgley made the long-distance transportation of foodstuffs, the 'cold chain' possible, among other things. As Charles Kettering noted in an appreciative biography of Midgeley [3], these refrigerants were also excellent propellants and were used in insect sprays during WWII. He also identifies the systematic use of the periodic table in new chemical exploration as one of Midgeley's revolutionary contributions. The idea that one could carefully survey an array of candidates for a technological problem by methodically traversing their material and chemical properties which could be deduced from theory was radical and greatly shortened development time.

The connection between CFC gases and ozone depletion was not made until the 1970s and 1980s [4], some decades after Midgley's death. One might conclude that there was no responsibility that could be assigned to him for the negative consequences of the use of CFCs, such as Freon 12. But it might be a better question to ask to what lengths one must go in managing risk and what kinds of mechanistic models need to be explored when trying to discern those unknown and unintended consequences. He saw the ordered methodology that the periodic table provided in looking at certain aspects of materials properties. With enough foresight, might one also model mechanism for undesirable interactions? There are advocates today for a green chemistry approach to chemical engineering [4,5] and yet they too may fall susceptible to thinking they have explored all possible consequences and can assume safety. One lesson from this is to maintain humility about one's understanding of underlying biology, chemistry or even physics. A more imaginative approach to risk management is necessary as engineers confront competing claims about emerging technologies such as energy and transportation systems.

In a systems engineering course at a Jesuit university, students read a New York Times article on Midgley [1] and wrote reflections on what his story reveals about modern engineering practice, decision-making, and responsibility. They also attended a discussion about Amitav Ghosh's book "The Great Derangement" [6] which was part of a spring symposium on campus. Reading, writing, a video summary of Ghosh's ideas and discussion with another class who were not necessarily engineering majors were all elements of the program to better teach junior and senior undergraduate engineering majors how to think about their own roles as future designers. Finally, students were asked to provide a final reflection for the semester as a whole and point to the course assignments or elements where they may have learned the most or honed some specific durable professional skill. The assignments are presented in the appendices of this paper, and the analysis of student work will wait for a second paper with IRB approval. This paper presents the instructional framing and implementation of this module as a work-in-progress. It is intended to motivate a subsequent study, pending IRB approval, that will more formally investigate student learning through qualitative analysis.

As a research study in engineering education, I wish to ask the following questions:

RQ1: How does engagement with the Midgley case influence how students identify long-range consequences in engineering innovation?
RQ2: In what ways does reflection on unintended consequences shift students' understanding of professional responsibility and ethical judgment?
RQ3: How do students analyze uncertainty and risk when prompted to consider both known and unknown consequences?

This paper contributes a structured case-based instructional module and establishes a foundation for future qualitative study of students' ethical reasoning.

Midgley as a Systems Case

Midgley operated within a fast-growing industrial economy. The automobile age demanded higher-performance engines, and industrial refrigeration promised new markets. For engineers like Midgley, the problem-solving mandate was clear: remove engine knock, create a non-toxic refrigerant, deliver reliable performance, and do so economically. This was certainly what his stakeholders and employers had as their clear and articulated goals.

Students were prompted to consider that Midgley was operating in a very ordinary systems engineering frame of reference. Although we often frame engineering ethics in terms of individual ethics and decision making, this case may be read not as an individual failing, but rather as a systemic failure in goals, motivations, and risk analysis. The distance between immediate performance metrics and long-term environmental outcomes exemplifies precisely the kind of cross-timescale complexity that modern systems engineering must learn to address. The impact on future generations for decisions today is often discounted very steeply, to where it barely registers in terms of probability of the outcome and magnitude of the impact of the potential negative outcome.

Student Activities

Students submitted written reflections as part of the class module that was also part of assessment practices for ABET. This assignment and its grading rubric are shown in the article appendix A. This course is one used to assess the achievement of a couple of the seven ABET outcomes. The assignment prompted them to evaluate the Midgley case not only as history but as an example of how design decisions propagate through social, political, economic, and environmental systems and what leads people to make the decisions that they do. The students were also asked to think of another example of such ethical dilemmas in product development and how their own approach to such challenges may develop.

At the end of the semester, students were asked to choose an activity from class and reflect on the ways in which it reflected or helped them in important professional skills, whether so-called soft skills or hard skills, or preferable to start thinking of them as durable and perishable skills. This end-of-semester exercise is a metasynthesis of student learning. It is new for this class, its instructor and department and is hoped to foster growing conscious professional development. A longer-term goal is to have students perform such activities at the end of most of their engineering classes, such that, by the end of their degree program they have a product (portfolio) that they can download and take with them of the most significant experiences they had through their engineering education. Such a portfolio can at the least act as a jumping off point for networking and job-related conversations. It can help prompt students' memories and narratives about their activities and learning. Active reflection activities can help make learning coalesce, solidify one's mind and consciousness, become explicit, and become available for a student during job interviews and searches.

Discussion

Time Blindness

In class discussion students are encouraged to consider that solving an immediate problem often becomes the overriding objective for students and professionals. Midgley's TEL innovation succeeded brilliantly on its own terms: it reduced engine knock and allowed automakers to achieve desired compression ratios. Without this improvement, a lack of acceleration and smooth drive may have significantly dampened the adoption of the automobile as a primary means of transportation. However, the risks of lead were known at that time, it already impacted workers as well as Midgley himself. But that was not enough to stop his own drive towards success in business and career. He is lauded by major figures like Kettering and receives significant prizes for his work. What we want students to begin to see is that achievement of objectives and requirements can mask other hidden costs and consequences. Ones that industry and society may not be able to avoid in the future. Midgley optimized combustion; society inherited lead poisoning. Costs were borne by others, until such time as regulation was able to step in and overcome the inertia in the system. That took more than four decades. Class discussion considered how the sociotechnical context shaped Midgley's decisions. General Motors, DuPont, and Standard Oil had enormous financial motivation to commercialize TEL and later CFCs.

Difficulty of Predicting Long-Range Consequences

An intended learning outcome for this module is to prompt consideration of how difficult it is to anticipate second- and third-order effects. A deeper dive might have students observe that Midgley's team conducted toxicity tests, but only within the narrow domain of acute exposure. They did not imagine atmospheric lifetimes, global distribution, or chronic low-dose impacts. This is a critical point that is often underemphasized in engineering and related disciplines in applied physics but is often more prominent in the biological and social science arenas. Namely that to truly create valid research into causation, one must consider things well beyond correlation, such as mechanisms, dose-response rates and exposure curves and time delayed effects and impacts. These are much more common in biological systems than in 'simple' engineering ones. Health physics has become more sophisticated in thinking about these issues, in terms of accumulated exposure to low doses of radiation for example, but the ways in which a virus can reemerge in the body with other symptoms and diseases are not usually part of an engineering world view. This may help students connect this to other contemporary issues that involve spatially distributed and time delayed effects in products, power, climate, and environment. Midgley is a cautionary tale for long-range thinking in emerging technologies. The module is intended to highlight that design choices embed themselves in infrastructure, behavior, and social, economic, political, and cultural systems.

Teaching with Unintended Consequence Cases: Why Midgley Works as Pedagogy

The Midgley case works because it is not cartoonish. Students cannot simply say "Midgley was unethical;" instead, they must grapple with how ordinary engineering can produce extraordinary outcomes. Many times, even in 'real' ethical case studies, the intended lessons are almost self-evident, such as 'don't cheat', 'tell the truth', 'stand up to evil bosses' and it is difficult for a student to speak against the intent or fully express why someone would not 'whistle blow'. Midgley's two great inventions have none of that but a much more subtle and typical unraveling of their good intent. A contrast can be made with an earlier assignment that was created for the same general learning aims of ethical considerations in product development and for ABET outcomes. In that earlier assignment, two readings were assigned about the development of a neural implant, the first detailing the development and the second article discussing what happened when the company went out of business. Comparable questions were asked of students as to the implications of this product failure and how the company handled it. Although quite a fascinating case, it does not have the nuances and subtleties that Midgley's two achievements do, which highlights so clearly two outcomes, one where certain consequences could have been known but were not fully investigated and the second where one might reasonably argue that the consequences would not *ordinarily* have been understood. Therein lies one of the more interesting questions, with how much fervor one should pursue understanding and anticipating unintended consequences. Although students are likely to say to the nth degree of safety, they begin to understand more clearly in the Midgley case how difficult that may be.

Structural Lessons for Systems Curriculum

The structure of the module is designed to foreground several educational strategies:

– Explicit identification of system boundaries

– Examination of incentive structures shaping "requirements."

– Exposure to long-range risk propagation models

– Encouraging ethical imagination alongside technical reasoning

Midgley reveals that engineers operate locally while consequences propagate globally. The reflection activities are intended to support the development of humility, care, and systems awareness. This resonates well with the work of Amitav Ghosh. He looks at the impact of technological systems in regularizing our lives and the environment such that catastrophic events, the improbable is not long accepted in any kind of 'narrative' as being 'too unbelievable.' However, his point is that we must learn to think about those improbable events as well, such as the impacts of climate change, even as they seem to be the stuff of unreasonable adventure tales and not anything to concern ourselves with in our well-ordered lives. The well-organized lives, economics, urban centers that technology has brought are not ‘guaranteed,’ which brings us back to heightening awareness for our students about risk and decision-making under uncertainty. This is a central framing goal of these activities. That kind of judgment can serve students well as future professionals facing complex and uncertain technological landscapes.

While formal analysis of student work is pending IRB approval, several preliminary instructional observations can be noted based on classroom implementation:

(1) Students demonstrated increased engagement when confronted with a case that resists simple moral categorization.
(2) Students showed a tendency to initially focus on immediate technical success criteria, but through guided discussion began to articulate broader system impacts, including temporal and distributed consequences.
(3) Reflective assignments suggested that students are able to connect historical cases to contemporary engineering challenges.

These observations are based on instructor experience, informal observation and intended as instructional insights rather than research findings. A more rigorous qualitative analysis of student responses will be conducted following IRB approval.

Conclusion

This work contributes to engineering education in three ways. First, it presents a structured, case-based instructional module centered on unintended consequences that integrates technical, ethical, and systems-level reasoning. Second, it provides a replicable pedagogical framework that connects historical case analysis with student reflection activities aligned with ABET outcomes. Third, it establishes a foundation for future qualitative research on how students develop ethical awareness, particularly in relation to long-range and uncertain consequences in engineering innovation.

Thomas Midgley’s innovations illustrate how tightly coupled technology, industry, environment, and society can be. This historical case study with discussion, reflection, and other materials is intended to support the expansion of an engineer’s ethical and systemic imagination. Midgley’s story becomes a tool not for shaming engineers of the past but for preparing engineers for the future. The intended outcome is for students to acknowledge the impossibility of perfect foresight yet recognize their responsibility to decide and design with care, humility, and awareness of the larger systems distributed in space and time that they inhabit. This activity will continue to be used in systems engineering class and with IRB approval a method of qualitative thematic analysis will be applied to students’ products from the class and presented in future work.

References

[1] S. Johnson, “The brilliant inventor who made two of history’s biggest mistakes,” The New York Times, Mar. 17, 2023.

[2] F. Edelman, “The life and legacy of Thomas Midgley Jr.,” 2016.

[3] C. F. Kettering, “Biographical memoir of Thomas Midgley Jr.,” National Academy of Sciences, 1947.

[4] M. Viana and C. Porto, “Thomas Midgley Jr. and the development of new substances: A case study for chemical educators,” 2013.

[5] D. T. Allen and D. R. Shonnard, Green Engineering: Environmentally Conscious Design of Chemical Processes. Upper Saddle River, NJ, USA: Prentice Hall PTR, 2001.

[6] A. Ghosh, The Great Derangement: Climate Change and the Unthinkable. Chicago, IL, USA: University of Chicago Press, 2016.

Appendix A

Assignment Instructions

"An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts."

The above statement is an official ABET learning outcome for your development as engineers.

Read the article about Thomas Midgley Jr., *"The Brilliant Inventor Who Made Two of History's Biggest Mistakes"* (NY Times, March 17, 2023).

Address the following in your essay:

1. **Describe and summarize the situation.** Specifically, what were the two mistakes? How were those mistakes fundamentally different from each other?
2. **Reflect on responsibility.** What do you think the people and companies involved should have done? What is their responsibility to their customers? To their investors?
3. **Consider societal implications.** What do you think we, society, should do? Is there any responsibility for the customers who are now caught with complex decisions?
4. **Critical inquiry.** What questions does this raise for you?
5. **Ethical reflection.** Consider the video and group discussion of Amitav Ghosh's *"The Great Derangement."* How does this illuminate the ethical dilemmas of unintended consequences?
6. **Find a parallel case.** Find and describe another example of such a dilemma of competing needs, goals, or requirements from varying groups of stakeholders that also had a significant engineering component or contribution to the problems that engineers and their companies faced (e.g., power, environment, biomedical, computers-AI, automotive, etc.). How did the situation resolve?
7. **Compose your response.** Write a 750-1,250-word essay addressing these points.
8. **Submit in the learning management system.**

Grading Rubric

Learning Objective	Exemplary (A)	Proficient (B)	Developing (C)	Beginning (D/F)	Weight
Demonstrate understanding of the impact of engineering solutions in global, economic, environmental, and societal contexts	Provides insightful analysis of how the system affects users, society, and environment; connects design choices to global or community context.	Addresses key impacts with reasonable awareness of broader context.	Mentions some impacts but lacks depth or connection to design decisions.	No discussion or understanding of broader impacts.	40%
Recognize ethical and professional responsibilities and make informed judgments	Identifies ethical issues and demonstrates sound, well-reasoned professional judgment throughout design and reflection.	Identifies key ethical considerations with reasonable justification.	Mentions ethics superficially or inconsistently.	No evidence of ethical awareness or reflection.	40%
Communicate professionally and present ideas with clarity	Report and presentation are clear, well-organized, visually effective, and professional in tone; writing and visuals enhance understanding.	Communication is clear and mostly professional; minor organization or formatting issues.	Communication is uneven or lacks clarity and polish.	Unclear, incomplete, or unprofessional communication.	20%

Appendix B

End of Semester Reflection Instructions

A. Reflect

For this assignment, reflect on your experiences in this course and:

1. Select one project or task where you discussed ethical and professional responsibilities in engineering situations and made informed judgements that considered the impact of engineering solutions on global, economic, environmental, and / or societal contexts.

2. Consider how that one project or task relates to the following Engineering Program Student Outcome:

   Recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

B. Upload

1. Relating to your selected work, describe your approach to making informed judgments that consider two of the following contexts:

   - Global
   - Economic
   - Environmental
   - Societal

2. Imagine that all your work in this course was recorded on video, capturing your efforts, problem-solving approaches, and interactions. Now, picture yourself reviewing this footage to assess your progress. What specific moments or actions stand out as evidence of a skill you have developed? How do your actions demonstrate your readiness for a career in engineering? Include the following information:

   - Name the project or task that you are reflecting upon as well as uploading a copy.
   - Describe your thinking processes about making informed judgments for two specific contexts (i.e., global, economic, environmental, societal).
   - Specifically state one skill that you believe you have demonstrated in this course, and why you believe this to be true.

The following list highlights many diverse types of skills that might demonstrate your career readiness in the field of engineering, which include but are not limited to:

- **Problem-Solving** – Ability to identify problems and develop creative solutions.
- **Teamwork and Collaboration** – Working effectively within multidisciplinary teams.
- **Communication** – Clear written and verbal communication, particularly for technical topics.
- **Time Management** – Prioritizing tasks and meeting project deadlines.
- **Adaptability** – Ability to learn new skills and adapt to changing technology.
- **Critical Thinking** – Evaluating information and making decisions based on logic and analysis.
- **Leadership** – Leading teams or projects, mentoring peers.
- **Attention to Detail** – Being thorough and meticulous when working on designs or data analysis.
- **Creativity and Innovation** – Thinking outside the box to develop novel solutions or designs.
- **Ethical Judgment** – Applying ethical standards to engineering projects and decisions.
- **Interpersonal Skills** – Building positive relationships with colleagues, clients, and stakeholders.
- **Project Management** – Organizing and overseeing engineering projects from inception to completion.
- **Conflict Resolution** – Managing and resolving disputes or disagreements within teams.
- **Emotional Intelligence** – Understanding and managing one's own and others' emotions.

- **Resilience** – Ability to bounce back from setbacks and continue progressing on projects.
- **Initiative** – Proactively identifying opportunities or challenges without being prompted.
- **Presentation Skills** – Effectively communicating project outcomes to a non-technical audience.
- **Cross-Cultural Competence** – Ability to work in diverse teams and global environments.