The Role of Disasters and Infrastructure Failures in **Engineering Education with Analysis through Machine** Learning

Andrea Hicks, Wissam Kontar

Department of Civil and Environmental Engineering, University of Wisconsin-Madison

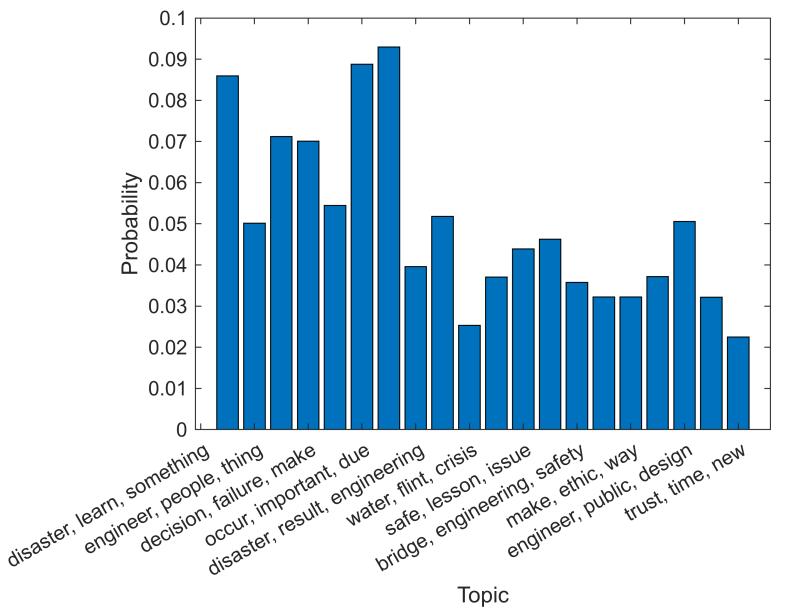
Abstract

Engineering programs must produce graduates who are able to consider multicriteria decisions including ethical implications during engineering practice. Teaching students in a meaningful manner to consider these multifaceted decisions is investigated through the usage of disasters and primary coverage of the infrastructure disasters. Students provided reflections as part of the course, which were then analyzed using a topics discovery Latent Dirichlet Allocation (LDA) model. We found six major themes that were frequently touched upon by the students: engineering, ethics, community, monetary, case scenarios on engineering failures, and change. The analysis shows the connections students built between engineering failures and its multi-faceted implications. Ultimately, this teaching framework can guide engineering class design that embraces real life failures as avenues of education.

Word Clouds

Initial processing of the data, allows us to examine the general word clouds from student reflection results, seen in Fig. 1. It is noticeable that students focused on words pertaining to engineering and its connection to safety, ethics, and decision-making. However, an indepth analysis is needed to reveal complex topics from the data. This is achieved through our LDA model.

Each discovered topic reveals the top words that students focused on, seen in Fig. 3. It is evident that there exist several themes of discussion within student reflections.

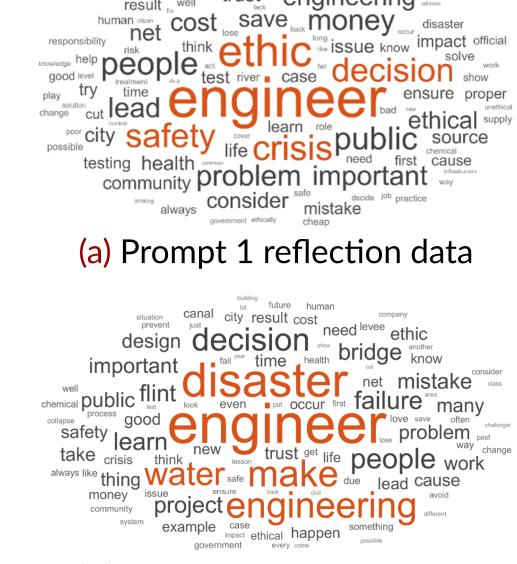




Research Goals

The principal motivation of this work is to design a learning experience for engineering students aimed at reinforcing a sense of connection between engineering disasters, ethics, and the profession's implications in the real world. This work then presents a case study on such innovation in engineering education and reveals the analysis of its outcome.

- Teaching engineering students' multicriteria decision-making through exposure to engineering and infrastructure disasters.
- Analyzing student's learning experience through collecting reflection data on the teaching approach, and using machine learning methods to reveal major insights.



(b) Prompt 2 reflection data

Figure 1. Word clouds from student reflections

Text Analysis: Latent Dirichlet Allocation (LDA) Model

To discover topics from student reflection data, we use an LDA model defined as the following. Consider a word as an item from a vocabulary indexed by $\{1, ..., V\}$. Then a document (i.e., student reflection) is a sequence of N words denoted as $\mathbf{w} =$ $(w_1, w_2, ..., w_n)$. A collection of documents is denoted

Figure 3. Word probability in the first 10 topics

Themes of Discussion in Student Reflections

Our analysis reveals six unique themes touched upon by students in their reflections. These themes are naturally interconnected, and our probability analysis of student documents shows that most students uniformly touched upon all these themes. Anlysis suggests that students were capable of performing multicriteria reasoning on the case studies they were subjected to, specifically through deconstructing multiple themes. These themes serve as a form of lessons learned from disasters, that students are expected to encounter in their future careers

Themes	1st	2nd	3rd
			, •

• **Promoting** the usage of such learning methods, and highlighting its implications.

Methods

Methods for data collection and analysis in this work is summarized as the following:

- 1. **Data Collection:** The data were collected as part of regular instructional activities occurring in CEE 494: Civil and Environmental Decision Making at the University of Wisconsin-Madison (UW-Madison) during the Fall 2021 and Spring 2022 semesters.
 - Mid-semester data collection prompt: "As you go out into the world as an engineer after graduating from UW-Madison, ethics will continue to be a relevant consideration in your work. In class we discussed the Flint, MI water crisis. Reflect in 3-5 sentences on the role of ethics in engineering with respect to the Flint, MI water crisis."
 - End of semester data collection prompt: "What can we learn from engineering disasters about decision making and ethics in engineering?"
- 2. **Text Analysis:** We analyze the reflections provided by students through text analysis and topic discovery methods. We derive a Latent Dirichlet Allocation (LDA) model, whose goal is to discover a set of topics

as $\mathbf{D} = {\mathbf{w}_1, ..., \mathbf{w}_n}$. Accordingly for each topic K we define a multinomial distribution over the words as:

$$p(x|\alpha_1, ..., \alpha_K) = \frac{\Gamma \sum_{i=1}^K (\alpha_i)}{\prod_{i=1}^K x_i^{\alpha_i - 1}}$$

1)

were α is a positive K-vector and Γ is the Gamma function. given parameters α and β (to be estimated), we can write the joint distribution of topic mixture θ , including a set of N topics z (a topic index), a set of N words w, is written as:

$$p(\theta, z, w | \alpha, \beta) = p(\theta, \alpha) \prod_{n=1}^{N} p(z_n | \theta) p(w_n | z_n, \beta)$$
 (2)

Note, that to estimate the optimal number of topics that best represents our data, we use the perplexity measure.

$$\operatorname{perplexity}(D) = exp\{-\frac{\sum_{d=1}^{M} logp(w_d)}{\sum_{d=1}^{M} N_d}\}$$
(3)

Ľ	ngineering	decision	design	practice
E	Ethics	trust	impact	save
(Community	public	help	health
ľ	Monetary	cost	time	cut
	Cases	chemical	hurricane	canal
(Change	learn	future	govern

 Table 1. Major themes in student reflections and top 3 words in
each

Conclusions

Producing engineers who can consider multiple criteria, including ethics, in decision-making is an imperative of engineering undergraduate degree programs. Teaching these skills in a meaningful and impactful manner is challenging, as often this is approached from a purely objective and quantitative manner. In this work, engineering disasters were utilized to provide a more impactful experience around ethics and decision making in the context of engineering, including the use of primary footage and interviews presented in class. Major findings from this study are:

- Students were able to build meaningful connections to the class discussions.

identified as a probability distribution over words.

Topic Discovery

Using the LDA model, we are able to discover 20 different topics that students focused on in their reflections. Fig. 3 shows the different topics.

Topic1	Topic2	Topic3	unethical corrosion really decide CTISIS long allow or lead involved corr of the level and involved	Topic5 aterinative identity failure conduct identity failure conduct source need think solve high active problem address testing end possible plan
Topic8 recognize serve bring sample ethical utimately ethical cause replace first cause sppear prevent	Topic7	Topic8	regard - ignore pace why role time factor - especially - play - project	Topic10
Topic11	Topic12	Topic13 let understand base change control admit easy speak big good reach research throughout	Topic14	Topic15
ropic16	Topic17 society lesson	Topic18	Topic19 infrastructure unsafe Safe often avoid PIOPEraware skill chemical harm	Topic20 - acceptable practice common

- Text analysis reveals six unique major themes in student reflections that are derivative of in-class discussions.
- Students were better able to present multi-criteria reasoning to engineering problems.

Acknowledgements

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Figure 2. Topics Discovery



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