Active learning in introductory environmental engineering course

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1. Introduction

The importance of environmental engineering (EE) courses in the undergraduate curriculum is undeniable. With increasing concerns about climate change, resource depletion, and environmental degradation, the course prepares students to contribute meaningfully to global efforts toward environmental sustainability. It equips students with the knowledge and skills to design systems and solutions that address pressing environmental challenges, such as pollution control, waste management, and water treatment, fostering sustainable practices in engineering. EE bridges civil, chemical, and biological engineering, providing a comprehensive perspective on solving complex environmental problems. Students gain an understanding of environmental laws and regulations, preparing them to design projects that meet legal and ethical standards. The course emphasizes the importance of protecting public health by addressing environmental hazards, ensuring clean water, air, and soil for communities.

Integrating environmental education into the undergraduate engineering curriculum is crucial for raising environmental awareness early in students' careers [1]. It teaches students how to analyze problems, identify causes and effects, and understand the conditions under which certain processes occur and their impact on environmental quality. The growing recognition of the importance of introducing concepts such as environmental engineering, green engineering, pollution prevention, and design for the environment to undergraduate engineering students reflects this need [2]. The underlying idea is that every engineering student should gain an understanding of environmental issues and the problems that impact our lives [3].

Despite the critical importance of the EE course, the instructor has observed that students often perceive it as a mandatory obligation rather than an engaging learning opportunity. With over five years of experience teaching introductory-level environmental engineering (EE) courses to approximately 330 students at two different institutions, the instructor has consistently received feedback from course evaluations and classroom observations indicating that EE ranks among the least favored courses within the civil and environmental engineering department. This perception largely stems from students enrolling to fulfill a requirement rather than out of genuine interest. A traditional lecture-based teaching approach has been identified as a key factor contributing to student disengagement. This research reflects the instructor's ongoing efforts to redesign course content, aiming to enhance student engagement and improve their perceptions of introductory EE courses in the civil and environmental engineering curriculum.

Active learning has been extensively studied across various disciplines. Prince (2004) defines it as instructional methods that engage students in the learning process, requiring them to actively participate rather than passively receive information [4]. Key techniques include think-pair-share, problem-based learning (PBL), and flipped classrooms. In engineering education, active learning has shown promising results in improving problem-solving skills and retention of knowledge [5]. Kinoshita et. al., investigated an active learning approach for an introductory EE course (269 students) and reported statistically significant differences between learning gains in content delivered using the active learning method versus a traditional, lecture-only delivery [6].

Cupples et. al., used active learning techniques in undergraduate introductory EE courses, including problem-based learning, in-class discussions, and collaborative exercises, to enhance student engagement and comprehension [7]. Their study found that active learning improves students' critical thinking, problem-solving skills, and retention of course material. Hadibarata and Rubiyatno used problem-based learning, interactive class learning and project-based active learning approaches in mandatory EE courses and found improvement in students' ability in achieving the course outcome [8]. Luster-Teasley et. al., found that a case study based laboratory modules in a junior level EE Laboratory course increased student engagement [9].

Inspired by positive outcomes from the common active learning strategies implemented in EE courses by various educators, over the years, the instructor has continuously refined the environmental engineering (EE) course, implementing several adjustments to enhance its effectiveness. These changes include transitioning from a PowerPoint-dominated format to a balanced approach of 50% board notes and 50% PowerPoint slides, gradually incorporating active learning strategies such as think-pair-share, flipped lectures, and minute papers, as well as introducing weekly quizzes. Positive student feedback from these modifications has been accompanied by noticeable improvements in student performance. To systematically evaluate the impact of three active learning strategies currently in use, a formal study was initiated during the 2023-2024 academic year. This work in progress study examines the integration of active learning techniques into an introductory EE course at Rose-Hulman Institute of Technology implemented via three unique approaches (1) Wrap up in-class activity (2) Friday videos (3) Student project. The primary objective is to assess the effects of these strategies on student engagement, perceptions of the course, conceptual understanding, and academic performance. The student performance in Spring 2023-2024 was compared with Spring 2020-2021 when no active learning strategies were implemented. The methodology, detailed in Section 2, focuses on three specific active learning strategies implemented in the course and describes the implementation logistics.

2. Methodology

2.1 Course Context

The study was conducted during the Spring 2023-2024 term in an undergraduate introductory environmental engineering course at Rose-Hulman Institute of Technology, with 39 students enrolled. The participants included junior-level students, 35 of whom were from the civil engineering department, two from the chemical engineering department and two from the mechanical engineering department. The course curriculum covered a range of topics, including mass balance, drinking water treatment, wastewater treatment, risk and toxicity, solid waste management, air pollution, and sustainable design.

2.2 Active Learning Interventions

Well-researched and established active learning strategies have been proven to enhance student performance in the classroom. Building on established active learning strategies, we adapted and developed a modified implementation approach. This study explores the impact of three active

learning methods integrated into the course, emphasizing their effects on student perception, engagement and performance.

1) Wrap up in-class activity

   This activity was incorporated into every lecture-based class session. To conclude each lesson, students spent the final 5–10 minutes completing an in-class assignment (ICA), which varied in format, including quizzes, reflection questions, minute papers, and muddiest points. A total of 20 different wrap-up activities were implemented throughout the quarter, as detailed in Table 1. The ICAs were graded, with point values ranging from 2 to 5.

Table 1. Various Types of Wrap-Up In-Class Activities Implemented in the Course

Wrap up in-class activity	**Frequency**
Numerical problem	5
Reflection	5
Minute paper	3
Muddiest point	3
Quiz	4
Total	20

2) Friday videos

   Every Friday, the class dedicated the first 15 minutes to an activity involving the viewing of a short video on an environmental engineering topic outside the course syllabus, followed by an in-class discussion. Over the duration of the course, students watched 10 YouTube videos on various topics, including the Times Beach incident, the Cuyahoga River fire, "Life Without Clean Water," "Can the Ocean Run Out of Oxygen?", the tragedy of the commons, plastic pollution in oceans, human hair mats, inventions saving the planet, human destruction of Earth, food waste, and plastic-eating microbes. This activity was not formally graded but was taken into account for in-class participation grades towards the course.

3) Student project

   For the student project, teams of 2–3 students selected a topic of their choice related to environmental engineering. Each team delivered an 8–10 minute presentation on their chosen topic and submitted a one-page summary based on their research. Additionally, teams were required to prepare three questions for the audience to answer based on their presentation. During the presentations, all teams participated by answering the prepared questions and scoring the presenting team’s performance. In this way, the activity was graded by both the instructor and the students.

The detailed list and assignment descriptions for the three active learning activities are provided in the supplementary information section.

2.3. Data Collection

Data was collected using a post-course survey designed to measure student engagement and self-assessed understanding. The survey included eight questions, as outlined below.

Q1. How beneficial were each of the active learning activities in learning about environmental engineering? (5= Strongly Liked / Strongly Disliked=1)

Active Learning type	*Strongly disliked*	*Disliked*	*Neither liked nor disliked*	*Liked*	*Strongly liked*
Wrap up in-class activity					
Friday videos					
Student projects (presentations)					

Q2. Please explain your rationale for the ratings you gave each active learning activity.

Q3. How engaging did you find the active learning activities in this course? (5= Extremely engaging / 1=Not engaging at all)

Active Learning type	*Not engaging at all*	*Slightly engaging*	*Moderately engaging*	*Very engaging*	*Extremely engaging*
Wrap up in-class activity					
Friday videos					
Student projects (presentations)					

Q4. How much did the active learning activities increase your understanding of the course material? (5= Very large increase / 1=Slight increase)

Active Learning type	*No increase at all*	*Slight increase*	*Moderate increase*	*Large increase*	*Very large increase*
Wrap up in-class activity					
Friday videos					
Student projects (presentations)					

Q5. How much did the active learning activities increase your participation in class? (5= Very large increase / 1=Slight increase)

Active Learning type	*No increase at all*	*Slight increase*	*Moderate increase*	*Large increase*	*Very large increase*
Wrap up in-class activity					
Friday videos					
Student projects (presentations)					

Q6. How difficult were the active learning activities to use? (5= Very easy / 1=Very difficult)

Active Learning type	*Very difficult*	*Difficult*	*Neither easy nor difficult*	*Easy*	*Very easy*
Wrap up in-class activity					
Friday videos					
Student projects (presentations)					

Q7. What challenges did you face while using the active learning activities?

Q8. Do you have any suggestions for improving the use of active learning activities in future courses?

In addition to the survey, student performance on homework assignments, a midterm, and a final exam was analyzed for Spring 2023–2024. To assess the impact of active learning strategies, these results were compared to student performance from Spring 2020–2021, when active learning strategies were not implemented. In Spring 2020–2021, the course had 22 enrolled students.

3. Results and Discussion

3.1 Engagement and Participation

The student survey responses (Q1), revealed that most students appreciated the inclusion of active learning activities in the course (Figure 1). Among these activities, the Friday videos were particularly favored as they allowed students to see how course materials connected to real-world issues. The Friday videos were not graded, but students were informed of their role in contributing to in-class participation points, which made up 20% of the course grade, alongside active learning assignments.

Some student comments explaining why they enjoyed the Friday videos are listed below.

- *It was a bit of a brain break that was still related to the topics in class.*
- *I enjoyed the videos, and I really enjoyed getting to see how the topics we are learning in class relate to the real world.*
- *I liked these because they gave real world examples.*
- *I really liked these since they got you interested in the real world and allowed us to learn what was happening.*

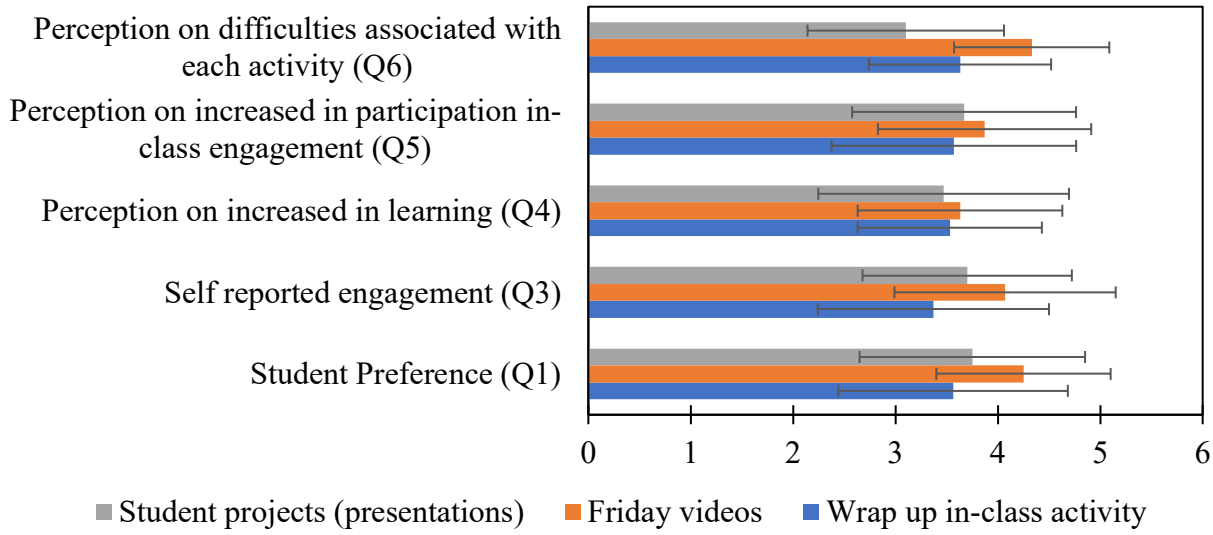

Figure 1. Student survey responses to the three active learning strategies implemented in the Course

Survey responses (Q3, Q4, Q5, and Q6) indicate that student's perceived that the Friday videos were the most engaging, enhanced learning, increased in-class participation, and were the least challenging (Figure 1). The instructor's classroom observations support these findings, highlighting increased student interactions during discussions and activities. The responses to these questions (Q3, Q4, Q5, and Q6) all exceeded the average score of 3.

The preliminary findings from the student feedback survey (Q2 and Q7) on the three active learning strategies are discussed below.

1) Wrap up in-class activity
   Several students mentioned that the ICAs were easy, concise, and effective for reviewing, recapping, and reflecting on the course material. They felt that the activities aligned well with the content, enhanced their learning, and improved engagement and participation. On the other hand, some students noted concerns such as insufficient time, repetitiveness, tediousness, or a lack of follow-up on the ICAs.

2) Friday videos
   The students found this engaging, easy to use, and helpful for exploring topics, providing additional context, visual information, and an outside perspective in the course. They also enjoyed the fun and awareness it brought. However, some felt disconnect from the course learning objectives, and some AI-generated videos did not work well.

3) Student project
   Students felt that this activity helped them develop collaboration and teamwork skills, connect with peers, share and understand different perspectives, enhance presentation skills, conduct research, explore niche topics, demonstrate competencies, and engage in hands-on problem-solving related to real-world issues. They also found it enjoyable and valuable for raising awareness. However, some students felt the activity was forced, disconnected from the class structure, and challenging due to difficulties in scheduling meetings with their peers.

Based on student feedback (Q8), the following improvement suggestions have been identified:

- In-Class Activities: Allow sufficient time for task completion, reduce frequency, and better communicate the value of ICAs to students.
- Friday Videos: Use videos to provide context and history on new or evolving practices in the field, include more videos, and allow students to contribute videos on topics of interest.
- Student Projects: Adjust project assignments to better align with course learning objectives and provide a selection of relevant topics for students to choose from.

3.2 Conceptual Understanding

Observation from student course performance on selected indicators (a homework assignment, mid term and final exam) were made for students from Spring 2023-2024 (n=39) and compared with the students from Spring 2020-2021 (n=22).

The preliminary observations on selected artifacts are discussed below.

a) The independent samples T-test revealed that the average final course grades were higher when active learning strategies were implemented (Spring 2023–2024). In Spring 2023–2024, 52% of students earned an "A" in the course (Average score = 86.77, Standard Deviation = 9.71, n = 39), compared to 32% in Spring 2020–2021 (Average score = 71.27, Standard Deviation = 30.28, n = 22), $t(59) = -2.95$, $p < 0.5$.
b) The average homework score and average mid-term grades were not statistically significantly different based on independent t-test results. Despite students from Spring 2023-2024 (M = 92.05, SD = 22.20) attaining higher average homework scores than students from Spring 2020-2021 (M = 81.82, SD = 28.1), the difference was not statistically significant ($t_{59} = -1.56$, $p = 0.06$). Likewise, although students from Spring 2023-2024 (M = 83.53, SD = 7.19) having higher average mid-term grades than students from Spring 2020-2021 (M = 81.09, SD = 11.98), the difference was not statistically significant ($t_{59} = -1.00$, $p = 0.16$). These data show that students' performance on the final exam was not contingent to their earlier performance in midterm and homework.

This is an ongoing study, and additional data points will provide a deeper understanding of the impact of the three active learning strategies on students' conceptual understanding in the course. This study will continue through the Spring 2030-2031 academic year to generate meaningful results.

3.3 Challenges and Lessons Learned

According to the survey responses, students identified time management and the difficulty of making up missed activities as challenges associated with active learning. From the instructor's perspective, implementing active learning strategies requires substantial preparation and grading efforts. It can also be frustrating for students when they do not understand the purpose behind the use of these strategies. However, providing clear expectations and offering continuous feedback were essential in overcoming these challenges.

Compared to previous years, when comments like *"the class was boring" and "I am not interested in environmental engineering"* were common, the feedback received during Spring 2023-2024 was more positive. Comments included:

"It was a fun class and the example problems that were worked in class were very helpful. I enjoyed the new style of teaching with the ICA's and the videos. They made the class more interesting."
"*What you learn in this course had me thinking about it in everyday life especially walking around campus and noticing the water management and what could potentially end up in those water sources. You just notice what you've been learning more often in the real world.*"

"*A strength of this course is that the way the material was being taught in this class worked to help me learn and understand the material better. The videos and ICA's helped me understand the concepts being taught in this class, and the example problems helped me understand the processes of how to do the calculations in this class."*

These responses suggest that the instructor successfully made progress toward the intended goal of enhancing student engagement and learning by incorporating active learning strategies. The key lesson is to listen closely to student feedback and use your own judgment to make ongoing adjustments to traditional lecture-based classes, ensuring they evolve to meet the changing needs of the classroom.

5. Conclusion

The integration of active learning strategies into an introductory environmental engineering course was perceived by students as enhancing their engagement, conceptual understanding, and academic performance. Preliminary observations of selected artifacts indicate that additional data points are needed to further validate these perceptions. These findings support the broader adoption of active learning in engineering education to better prepare students for the complex, interdisciplinary challenges of the field.

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Supplementary Information

Here we have provided the assignment details for the three types of active learning strategies implement in the course for Spring 2023-2024.

1. Wrap up in-class activity

1.1 Muddiest point:

1) Draw Concept map for Env Engineering
2) Draw Waste water treatment plant train
3) Suggest an innovative way for waste management in the US. (apart from common practices such as landfill, recycling, composting etc)

1.2. Reflection:

1) Summarize solution for times beach incident.
2) Analyze the Tenafly Sewage Treatment plant case study and sketch the WWTP train. What are the positive and negative issues with the treatment plant? Summarize your thoughts.
3) (Link: https://www.health.vic.gov.au/environmental-health/human-health-risk-assessments)
   The five general steps in the human health risk assessment process are:

   a) Issue identification: what is the identified problem or situation?
   b) Hazard assessment: what are the possible adverse health effects associated with the identified hazards of potential health concern?
   c) Understand the dose-response relationship(s): what is the dose response relationship for each identified adverse health effect? What studies are used to provide this information?
   d) Exposure assessment: develop a site or situation model including pathways connecting sources of each hazard to people; collect and analyze data about each hazard, e.g., assess/sample the amount in air, water or soil; identify populations that may be affected and how they may be exposed to each hazard.
   e) Characterize the risk: this step analyses the above information to estimate the size and nature of either past, current or future health risks for people, including communities.

Explain the details involved in risk assessment for COVID 19 pandemic using the steps suggested above.

4) Apply mass balance concept and sketch out the control volume for Gold king mine spill showing relevant flows and concentrations. Which reactor model would you use to predict how long will it take to clean the river. Explain briefly.

5) Coliform bacteria (for example, E. coli) are excreted in large numbers in human and animal feces. Water that meets a standard of less than one coliform per 100 mL is considered safe for human consumption. Is a 1 m^3 water sample that contains 9000 coliforms safe for human consumption? Show your work.

1.3 Minute Paper:

1) What could you do from your end to minimize the destruction of earth?
2) What is the impact of excessive microbial growth in the natural water bodies? How can it be prevented?
3) How does the water quality vary over time or with location?

1.4 Numerical problem:

1) Atrazine is a widely used as herbicide in US in large scale corn-production. The USGS has reported atrazine concentration in Arkansas river as high as 14 ppb. If the reference dose for atrazine is reported as 0.035 mg/kg-d, would a 50 kg female be at risk if she drank 2L of untreated Arkansas river water per day? (Risk and Toxicity)
2) In Winter, a stream flows at 10 m3/s and receives discharge from a pipe that contains road runoff. The pipe has a flow of 5 m3/s. The stream's chloride concentration just upstream of the pipe's discharge is 12 mg/L and the runoff pipe's discharge has a chloride concentration 40 mg/L. Chloride is a conservative substance. Does wintertime salt usage on the road elevate the downstream chloride concentration above 20 mg/L? (Mass balance)
3) A waste contains 300 mg/L of $C(H_2O)$ [MW = 30 g] and 50 mg/L of NH_3-N [MW of N - 14 g]. Calculate the carbonaceous ThOD, The nitrogenous ThOD, and the total ThOD of the waste. (Water Quality)

   [MW of O_2 =32 g]

   $C(H_2O) + O_2 \rightarrow CO_2 + H_2O$

   $NH_3 + O_2 \rightarrow NO_3^- + H^+ + H_2O$

4) For the given parameter which reactor (PFR vs CMFR) would you choose based on volume required? Q=50 $\frac{m^3}{s}$, $C_{in} = 100\ \frac{mg}{l}$, $C_{out} = 5\ \frac{mg}{l}$, K= 0.216 day^{-1}
5) Find the alkalinity of water sample that has pH of 10 and CO_3^{2-} concentration 32 mg/L.

1.5 QUIZ:

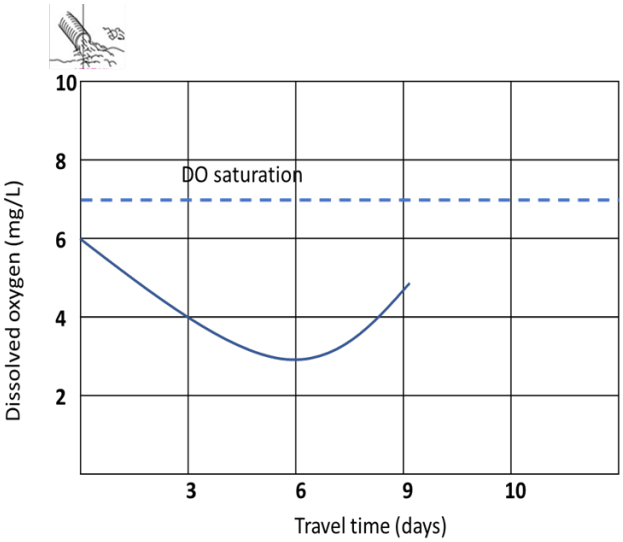
1) **(Quiz 1-Reactors) For each of the following problem statement identify if it is Steady state or Non-steady state scenario.**

a) Envision a mass balance on chloride (Cl-) dissolved in a lake. Two rivers bring chloride into the lake, and one river removes chloride. No significant chemical reactions occur, as chloride is soluble and nonreactive. What is the annual average concentration of chloride in the lake?

b) 2. A degradation reaction within a well-mixed tank is used to destroy a pollutant. Inlet concentration and flow are held constant, and the system has been operating for several days. What is the pollutant concentration in the effluent, given the inlet flow and concentration and the first-order decay rate constant?

c) The source of pollutant in problem 2 is removed, resulting in an instantaneous decline of the inlet concentration to zero. How long would it take until the outlet concentration reaches 10% of its initial value?

2) <u>Quiz 2-BOD</u>



Dissolved oxygen deficit in the river on day 3 after waste disposal into the stream is _____ mg/L.
Critical point is reached in _____ days.
Dissolved oxygen at critical point is _____ mg/L.
Distance travelled in achieving critical point is _____ miles.

3) <u>Quiz 3- Solid waste</u>

a) Which of the following is a problem caused by incinerators?

I. Pollution of soil and water
II. Methane released into the atmosphere
III. Air pollution and carbon dioxide emissions

b) Most of the trash in US is sent to

I. Land fills b. Recycling c.Ocean d. Incinerators

c) Which of the following is the cheapest way to dispose of waste?

I. Incineration b. Recycling c. Landfills

4) Quiz 4- <u>Environmental Regulations</u>: Answer the following questions after watching the video. https://www.youtube.com/watch?v=XU_AFnCuj_o

A) Cuyahoga River in the past around 1969 _____

1) Caught fire several times.
2) Was majorly used as source of food (fishing)

B) What was dumped into the river?

_____

C) Cuyahoga River incident led into the development of _____

1) Clean water act 1972
2) Fishing permit requirements
3) Boating permit requirements

2. Student Project

Sampel of topic and questions proposed by the students are listed below.

Group 1: Reversal of the Chicago River

What was reversal of the Chicago River? (Include the year it occurred when you answer)

What is its impact in the environment?

What could have been an alternative solution to reversal of the Chicago River?

Group 2: Amazon Rainforest Deforestation

Why is Amazon Rainforest important?

What efforts are being taken to stop amazon rainforest deforestation?

What is the impact of amazon rainforest deforestation in the environment?

Group 3: 2020 Russian Oil Spill in the Arctic Region

What was a state of emergency declared in the region after 2020 Russian Oil Spill? (Include information on volume of oil spill when explaining)

What is the impact of the incident in the environment?

What are the lessons learned from the incident?

Group 4: Minamata Disaster in Japan

Briefly describe the incident: Minamata Disaster in Japan.

What is its impact in the environment?

What can be done to prevent this kind of incident?

Group 5: Brumadinho Dam disaster in Brazil : Importance of tailing ponds

When did the incident occur and briefly explain what caused the disaster?

What are tailing ponds? In your opinion does tailing ponds have any negative or positive environmental impacts?

What are the lessons learned from the incident ?

Group 6: DuPont chemical dumping and PFAS contamination

What is PFAS? What are some of the environmental concerns of PFAS contamination.

Is DuPont still dumping PFAS in water?

What can be done to prevent DuPont from contaminating water with PFAS?

Group7: Tennessee Valley Authority Coal Ash Spill

Describe the incident.

What is its impact in the environment?

What can be done to prevent this kind of incident?

Group 8: Deepwater horizon oil spill in the Gulf of Mexico

What caused the oil spill?

What was the cleanup effort?

What is its impact in the environment?

Group 9: 2000 Baia Mare cyanide spill in Romania

Discuss the incident briefly.

What was the cleanup effort?

What is its impact in the environment?

Group 10: Nitrogen Dioxide pollution

What are the sources of nitrogen dioxide?

How can you combat the nitrogen dioxide pollution?

What is its impact in the environment?

3. Friday Videos list:

1	Times Beach - Toxic Towns	https://www.youtube.com/watch?v=F3hDKGfi3tQ
2	After the Cuyahoga River fire- Great Lakes Now	https://www.youtube.com/watch?v=XU_AFnCuj_o
3	Our Land: Gold King Mine Spill Revisited	https://www.youtube.com/watch?v=bLBr8-VM4oM
4	The Journey Episode 2: Life without Clean Water	https://www.youtube.com/watch?v=yPxMOzN0Uq4
5	Can ocean run out of oxygen?	https://www.youtube.com/watch?v=ovl_XbgmCbw
6	What is tragedy of commons?	https://www.youtube.com/watch?v=CxC161GvMPc
7	POWERFUL VIDEO: Why We Need to Stop Plastic Pollution in Our Oceans FOR GOOD | Oceana	https://www.youtube.com/watch?v=Yomf5pBN8dY
8	10 Inventions That Are Saving The Planet	https://www.youtube.com/watch?v=Hof0Sss2138
9	Human destruction of the Earth	https://www.youtube.com/watch?v=wrlhljHeluw
10	Food waste is the world's dumbest problem	https://www.youtube.com/watch?v=6RlxySFrkIM How This Town Produces No Trash https://www.youtube.com/watch?v=eym10GGidQU