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Intentional Small-scale Disasters: Simulating Oil Spills to Develop Hands-on Environmental Remediation Experience

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ABSTRACT

Oil spills pose substantial threats to ecosystem structure and function, and remediating ecosystems can be both time consuming and labour intensive. Crude oils contain hazardous heavy metal compounds, can be odorous, sticky and viscous, and may adhere easily to sand, rocks and biological tissues. Such properties make crude oil contamination immensely difficult to clean from shoreline communities.

In order to provide an effective and memorable learning experience for university students enrolled in the subject 91159 Environmental Remediation, a laboratory simulation experiment was developed to realistically recreate both the impacts of an oceanic oil spill and the procedures required to remediate ecosystems at a microcosm scale. Students were tasked with creating their own miniature coastal ecosystems, complete with seawater, rocks, sediment, plants, small-scale model animals and a model shipping vessel. A small quantity of crude oil was then spilled from the model ship's location and tidal forces were mimicked. Students were provided with an arsenal of remediation equipment in order to enact their own realistic management strategies for cleaning and extracting oil from their ecosystems, as well as protecting natural and assets. At the completion of the simulation, students were asked to reflect on their experience and to extrapolate their microcosm experiment to real world, full-scale oil spills.

Learning and teaching educators noted a high level of enthusiasm and engagement from students. The Student Feedback Survey at the end of semester also revealed high student satisfaction and strong positive feedback from students in regard to managing the simulated oil spill. This laboratory simulation proved to be a very effective educational tool which also created a fun and memorable experience for university science students.

1. INTRODUCTION

Petroleum is an important energy and material resource in modern society due to its wide range of applications. Besides serving as raw material for the production of plastics and other useful compounds, it is a major fuel source used in the production of electricity for vehicular transport, infrastructure generators and other industrial machinery (Lehr *et al*. 2001). Crude-form petroleum oils are complex mixes of many different chemicals, varying in density and composition depending on the geographic location of their extraction (Lehr *et al*. 2001). Ecosystems in areas exposed to oil extraction and refining, as well as oil transportation corridors, are highly vulnerable to a broad suite of environmental impacts resulting from crude oil spills. As extraction fields are located in coastal areas, these environments are the most likely to be affected, although other ecosystems also suffer influence of the petroleum activities too (Kalligeros *et al*. 2001).

Figure 1 – A Skimmer Boat remediating the Deepwater Horizon oil spill disaster (NOAA 2010)

Oils spills and leakages can have immediate and devastating effects on the environment that can also be long lasting. These effects include generalized mortality of animals and consequent ecosystem destruction (Kalligeros *et al*. 2001).

Oil spills also provoke more persistent effects, linked to the entry and long-term residence of compounds derived from petroleum in ecological food webs, such as alteration of animal behaviour and permanence of compounds derived from petroleum in the food webs (Graham *et al*. 2010). Given that accidents with crude oils are largely unpredictable spatially and temporally, the resources needed to minimize their impacts and provide remediation are often not available for immediate application.

The first course of action for any oil spill is to contain the spread of the pollution, for instance through the implementation of boom lines (Lehr *et al*. 2001). Second-tier strategies developed to remediate impacted environments include mechanical cleaning methods, skimmer boats, high pressure hot water sprays, chemical dispersant products and use of biological remediation treatments; each method has its own utilities and limitations and are often used in combination (Lehr *et al*. 2001). Remediation strategies are considered effective when they prevent further migration of crude oil to more sensitive ecosystems while extracting as much of the pollutant as possible.

A consequence of life in the modern world is that oil spills and leakages are likely to occur, despite best intentions to prevent such events. Often, thousands of people are needed to manage and remediate spill events. Targeted training for such situations, that promotes understanding and awareness of the environmental conditions and the materials required, is an incredibly valuable endeavor that will lead to well-trained and experienced people providing the best management solutions.

2. RECREATING A DISASTER

2.1 Active Learning

Active learning is a teaching approach that directly involves students in learning about materials and concepts in a hands-on way, rather than dictating information to them (Bonwell and Eison 1991). Students are more likely to retain and recall knowledge from active learning compared to when they are the passive recipients of instruction (Cross 1987). Working carefully through an actual potentially-hazardous scenario also serves to increase awareness of the safety-related procedures involved in environmental remediation practices.

2.2 Industry-desired Professional Experience

Australian environmental career providers frequently ask their job-seeking candidates to demonstrate hands-on professional experience. Short of industry internships and postgraduate study, this leaves many environmental graduates with a skills gap between what they have learned in their degrees and what their desired job expects of them. One of the core aims of this class was to bridge this gap and provide an educational experience firmly analogous to a real-world scenario. While a university class cannot replace several years of field experience, what it can offer is a skills advantage over other graduates who have no experience in the scenario of interest whatsoever.

2.3 Real-world Significance

In order to make the class meaningful and increase the relevance of the activities, materials were selected to reflect the real-world conditions of Port Botany, New South Wales (South-Eastern Australia). These materials include Hawkesbury sandstone rocks which could be used to simulate both flat, man-made rock walls or craggy, natural rock platforms, depending on the rocks selected and their positioning in the microcosm (Table 1).

Table 1: Key Ecosystem Supplies for Students

Ecosystem Equipment	Purpose
Australian Beach Sand and Gravel	Forming the foundation to the coasts and the main strata to remediate
Hawkesbury Sandstone Rocks	Smooth pieces acted as Seawall, craggy pieces acted as rocky outcrops
Plants	Useful for aquatic purposes (e.g. seagrass) as well as shoreline plantings
Model Animals	Aquatic animals included whales, sharks and turtles. Terrestrial animals included seabirds and mammals.
Model Ship	The small-scale model source of the simulated oil spill

3. MATERIALS FOR AN AUTHENTIC EXPERIENCE

3.1 Crude Oil

There are no reported analogs for crude oils that would effectively mimic the physical and chemical properties of the oils, including the strong odor and the adhesive properties. Furthermore, student buy-in is increased if there is a particularly exciting element of real-world connectivity in a lesson (Eison 2010). For these reasons, we sourced actual medium-weight crude oil for the simulated oil spill experiment to promote an exciting and authentic learning experience for students. UTS Chemical Safety and Ethics forms were completed several months prior to the class commencement. Best-practice safety procedures were researched to ensure students could work with this hazardous mixture safely, responsibly and with confidence.

3.2 The Contained Aquatic Microcosms

The oil spill simulation was designed to be contained in a small-scale aquarium-type microcosm, preventing the spillage or movement of hazardous chemicals beyond the boundaries of the simulation. These microcosms were made of moulded polypropylene containers and were 57cm wide, 38cm long and 24cm tall. This particular size of microcosm was selected so it could be filled to one third of the total volume with seawater, approximately 20 litres, leaving enough room for adding the ecosystem features while having the impermeable surrounding microcosm wall above the waterline to minimizing potential splashback from simulated wave action.

3.3 The Remediation Supplies

In order to give students a wide range of options for their oil spill management strategies, models of remediation equipment were created with the aim of mimicking or representing technologies at a small scale (Table 2).

Table 2: Remediation Equipment Provided to Students

Model Equipment	Brief Description	Intention
Oil Booms	Long lines of buoyant, absorbent materials	Contain spread, Oil extraction, Asset protection
Skimmer Boat	Plastic scoop with a wide lip and a shallow graduated dip to capture surface oil	Oil extraction, Oil recovery
Bioremediation Microbes	A labelled container filled with a mock-up tinted liquid	*In situ* oil degradation
Dispersant	A labelled container filled with a mock-up solvent	*In situ* oil dispersal and degradation
Detergents	Two types were provided: A plant-based detergent and Dawn brand detergent	Oil removal from animals and ecosystem structures
Scrubbing Brushes and Sponges	Various types of scrubbing brushes and sponges of different thicknesses	Oil removal from animals and ecosystem structures
Disposal Bags	Thick plastic bags with hazard labelling	Safe disposal of oiled materials

A mock up of bioremediating microbes was provided, though actual crude oil-consuming bacteria could not be readily sourced. Likewise, chemical oil dispersant was represented by a tinted commercial solvent. Two types of detergents were provided to remediate animals and surfaces: one plant-based detergent and Dawn brand detergent, which was specifically imported from North America due to its reported success as a gentle cleanser for oiled animals (Shogren 2010). A range of small and large-bristled brushes were provided, as well as disposal bags for cytotoxic wastes.

4. LESSON PLAN

Collaborative group work with in-class activities significantly increases higher learning gains and better conceptual development for students of biology (Knight and Wood 2005). With this in mind, the oil spill was designed to be a group activity, where teams of students would work together to construct their ecosystems, pollute them, and then remediate them together.

4.1 Setting the Scene

A fictional scenario was created to give an Australian context to the oil spill incident. The scenario provided was as follows:

"This microcosm experiment will be simulating an oil spill occurring in an Australian sandy coastal-type marine ecosystem; A commercial cargo ship "The YARIS" has run aground off the coast of Port Botany, NSW. A rocky seafloor outcrop has pierced a hole in the ship's lower hull (and the hole has been temporarily repaired by AMSA). A quantity of thick shipping oil has spilled out of the ship's bow and in to the ocean. The oil is drifting with the tide over a seagrass meadow and is heading towards a sandy Sydney beach."

Students were then asked: "*What can we do with the surface-lying oil slick before it begins to harm the species in the coastal ecosystem?*"

4.2 Choose (and Justify) Your Own Adventure

To engage students in the science and history of oil spills beyond the walls of the classroom, students were tasked with studying real-world cases of oil spills to assist them in designing a remediation plan that could be effective in an actual disaster event. Naturally, students had to plan to apply their methods effectively at the smaller laboratory scale. Nevertheless, this experiment aimed to teach students the fundamental principles of environmental remediation of oils spills, as well as engage the creative abilities of students.

4.3 Setting up the Classroom

Materials for the ecosystem features (Table 1) and remediation equipment (Table 2) were organized on a single long laboratory bench on the against the outer classroom wall. Each central laboratory bench had four microcosms for teams of four students to work together on.

4.4 Environmental Health and Safety Talk

Preceding the class, the Subject Coordinator gathered all students and staff together in a single class group and discussed all PPE requirements, equipment, safety protocols and disposal procedures needed for the simulation.

4.5 The Oil Spill Simulation

The Aquarium Microcosms were constructed by students over a 15-minute period. 10ml of crude oil was then spilled from the approximate location of their shipping vessel (Figure 2) whilst agitating the water surface, mimicking rough wave activity.

Figure 2 – The simulated oceanic oil spill (Phillips 2015)

Students were asked to document every step of the process, and measure the effectiveness of their remediation strategies based on three metrics: i) the amount of crude oil they quantitatively recovered; ii) the amount of oil they visibly removed from seawater, animals, plants and the ecosystem and iii) clear evidence from other research studies that indicates their management plan has long-term efficacy in the real world.

The simulation lasted for two hours, including student set up, the oil spill, and all following remediation processes. Disassembly was completed following the simulation and oiled materials that cannot be cleaned were disposed of via a cytotoxic substance disposal service

5. POST-CLASS REFLECTION

Students evaluated how effective their management strategies were in a post-class written report. They were asked if their plans could be realistically implemented at a larger scale, and if they would adjust their strategy at all if they repeated the simulation. Students were also asked specifically about the limitations of microcosm-scale simulations and the benefits to using microcosm to model potential real-world solutions. The demonstrated their knowledge of oil spills, as well as their logic in selecting their methods.

6. LEARNING OUTCOMES

6.1 Oil Spill Reports

Students described their procedures and the outcomes of their actions, both observed and anticipated; linking their own remediation choices to historical case studies of oil spills. Many students had suggestions as to the conditions that could not be accurately shown in the microcosm simulations, including the biotic elements of smaller animals, phytoplankton and complex community interactions, as well as abiotic features like sunlight, winds, ocean stratification and deep sea oceanic currents.

Some students talked about why they avoided certain remediation methods due to historical failures and unpredictability. Most students commented that microcosm-scale research was a good way of pilot-testing new remediation approaches, despite the limitations of trying to mimic complex environments in a controlled laboratory.

6.2 Student Feedback Surveys

A specific statement was added in to the UTS Student Feedback Survey to test whether participants of the class agreed that the skills and knowledge taught would be useful in the workplace:
"This subject provided practical learning activities to develop new skills and knowledge I may need in the workplace."

Of the respondents, 86% of students strongly agreed with the previous statement, 11% agreed, and 3% were neutral on the statement. No students disagreed (or strongly disagreed) with the statement. Specific feedback on the simulation included:

"*This subject (...) posed both problems and solutions that promoted an engaging learning experience. I would say that this subject has possibly been the most crucial in my course for the career I wish to pursue*."

"*The oil spill practicals were also fascinating."*

"*(The) practicality of the subject (is) almost mirror imaging a chunk of what we may continue (doing) in a profession."*

"*The content in this subject is very interesting and it has inspired me to move my career in the direction of remediation. I would love to work on modified bacteria to remediate oil or other contaminants. We actually used one of these bacterial species in an oil spill prac. This was a very hands-on prac that was enjoyable and interesting*."

A constructive suggestion for the class was that students would like to have followed their oceanic environments over a period of weeks, seeing if residual oil was an issue.

7. CONCLUSION

The active learning experience engaged students by bringing what would be a dangerous fieldwork experience into the safer confines of a laboratory simulation. Subject feedback clearly indicated that students enjoyed working with actual crude oil in this microcosm set-up. Many students felt pride in their work and demonstrated creativity with their ecosystem establishment and remediation efforts. Furthermore, teamwork was specifically promoted with the activity, again simulating a real-world scenario in environmental management. Importantly, the pre-work requiring students to start conceptualizing their remediation strategies meant that students had an awareness of the scenario beforehand, which gave their procedures real-world meaning. The assessments linked to the simulation showed that students had a memorable learning experience and were able to vividly recall the key concepts and remediation procedures they performed.

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