A Case Study for Teaching Toxicology: Using Whales as an Indicator for Environmental Health

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Abstract

One of the challenges of teaching scientific courses is helping students understand research methods, biological models, and data analysis, which can be especially difficult in classes without a laboratory component. Within the field of toxicology, it is also important for students to understand how living organisms are affected by exposure to toxicants and how these toxicants can impact the ecosystem. Resources focusing on active learning pedagogy are scarce in the field of toxicology compared to other disciplines. In this activity, upper-level students in an introductory toxicology course learn to interpret data from primary literature, draw conclusions about how toxicants, specifically metals, can impact susceptible populations, and understand the One Environmental Health approach. Students work in small groups to answer questions concerning data from a paper and then share their responses with the entire class building their communication skills. The instructor serves as a moderator, allowing the students to work through concepts, intervening only when necessary. This approach enables a deeper level of understanding of content and allows the students to engage actively in the learning process. As such, students think critically through relevant problems and find connections to the real world. This lesson can be adapted for several levels of students and could be modified depending on the objectives of the course.

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Supporting Materials: S1. Environmental Health - Student Data Set; S2. Environmental Health - Instructor Notes; S3. Environmental Health - Matched Student Questions; S4. Environmental Health - Matched Student Questions-Instructor Notes

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Learning Goals

◊ Society of Toxicology:
- » What differences occur in how individuals or populations are affected by exposure to different doses of a toxicant?
  - Students will understand how sex can impact the accumulation of heavy metals within the whale population.
  - Students will be able to explain how the rate of accumulation of different metals varies with type of whale and year of collection.
- » How are organisms living in the natural environment affected by natural and anthropogenic toxicants?
  - Students will know how heavy metals enter and accumulate within the ecosystem.
  - Students will be able to describe the toxic effects resulting from exposure to heavy metals.
- » How do toxicants move through the environment to affect ecosystems?
  - Students will understand the concepts of the One Environmental Approach.
  - Students will value the significance of accumulation of metals within the food chain.

◊ Scientific Processing Skills:
- » Interpreting results/data.
- » Displaying/modeling results/data.

Learning Objectives

Students will be able to:

◊ Explain the limitations of studies with small data sets.

◊ Draw conclusions about the impact of metals on biological systems using data from a primary paper.

◊ Understand the difference between essential and non-essential metals within the environment and biological organisms.

◊ Explain the sources of heavy metal exposure and indicate which metals have higher rates of accumulation.

◊ Explain the One Environmental Health approach.

◊ Describe how data collected from whale populations can be used to make predictions about overall human health.

◊ Gain an understanding that whales can be used as a valuable organism for understanding the overall health of the environment.

INTRODUCTION

Educational resources for most biology, chemistry, and environmental sciences are readily available but resources for some highly specialized disciplines including toxicology are sparse. Even more limited are toxicology-based activities which emphasize not only content but also the teaching of important scientific skills. Reforms in the ways we teach science are widespread, and finding effective methods to teach critical thinking, data analysis, communication, and problem solving are essential (1, 2). Activities need to actively engage students while building scientific knowledge, reinforcing skills, enhancing critical analysis, and encouraging group work with communication, as opposed to a focus on recall and fact-memorization (3, 4). These types of activities require a deeper level of understanding in the content allowing students to critically think through relevant problems (5). In turn, they will help students learn about principles in the field of toxicology but also recognize connections to other fields and the real world (3).

Problem-based learning (PBL) is an instructional strategy that can be implemented by educators to drive education with small group collaboration to solve problems or analyze data. This promotes content knowledge while also engaging the students to think critically and creatively. The instructor can vary their level of leadership within the classroom by facilitating all open-ended problems. In these situations, the role of the student and instructor changes from a traditional classroom style in that the students become the leaders and the instructors guide them through the learning process. Assessments in these situations may also change. Students are answering problems that may have multiple answers and tests will measure the application of these skills rather than the actual answer (6). An education in the biological sciences involves both the acquisition of knowledge and the development of skills to apply that knowledge. In some circumstances, it is not possible to provide students with hands-on experience in the laboratory. Providing students with the opportunity to construct their own knowledge during an engaging activity leads to improved learning, promotes group discussion, and facilitates development of higher levels of Bloom's taxonomy of cognitive learning. The use of case studies facilitates interdisciplinary learning and provides connections to real-world applications (7–9).

Our case study

We developed a case study to allow students to examine the levels of several heavy metals in whales in the Gulf of Maine. This activity can be completed in a single session or spread over multiple sessions, with the goal of student-driven inquiry. Students work in small groups on a problem from knowledge-based questions. At the end of the case study, students engage in a class discussion, and the instructor helps the students identify any misunderstandings if necessary.

The Gulf of Maine serves as an important aquatic ecosystem for many marine organisms. Whales are one of the most important species that migrate there each year; however, scientists have begun to see a drop in overall whale fitness, potentially due to an increase in water pollution. Whales, such as humpback, fin, and minke, play a key role in maintaining the health of the ecosystem: their excrement fertilizes the sea water, yielding phytoplankton blooms that absorb carbon dioxide. Therefore, maintaining the health of whales has an impact on the overall survival of other marine organisms and the general water quality. The One Environmental Health approach has emerged, focusing on whale fitness and health and relating it to environmental health (10–13). Within the greater research field, the One Health approach recognizes the interconnections of humans, animals, and the environment in order to make connections that impact overall health. The One Environmental Health, a subspecialty within the One Health approach, recognizes relationships between human health, organism health and ecosystem health but focuses specifically on the impact of toxic chemicals (13). This approach indicates that data gathered from humans, animals, or the ecosystem can highlight potential common hazards and provide insights into the mechanisms of action for these hazards. The data can also be used to extrapolate and predict potential risks to organisms in the ecosystem. The One Environmental Health approach suggests that a toxic chemical that directly impacts one organism in an ecosystem will affect essential resources that support other organisms. These data can be used to make predictions about overall health (10, 12).

Metals are often overlooked as environmental threats because they occur naturally; however, increased metal concentrations in water and soil from industrial or consumer waste has been well established as an environmental and biological concern (14). Heavy metals, such as iron, chromium, nickel, zinc can bioaccumulate resulting in increased concentrations in an organism over time (15). Though metal toxicity in whales in generally poorly understood, human exposure to toxic heavy metals has been linked to organ failure, blood disorders, cardiovascular disorders, and increased risk of cancer. More specifically, chromium (Cr) and nickel (Ni) exposure induces reproductive and developmental toxicity (16, 17) while lead, iron, and aluminum affect brain physiology and immunity (15). Understanding the toxic potential of heavy metals and their continued accumulation in the environment can lead to an understanding of how these toxins can impact the ecosystem and humans.

Students in toxicology courses need to understand different toxicological models and be able to interpret data sets. In our 300-level Introductory Toxicology Course, which is taken by juniors and seniors, we wanted to help students understand how to interpret data and relate this to the One Environmental Health approach. To meet these goals, we created a case study analyzing data from a paper by Wise et. al (11). Within this study, scientists analyzed metal levels that are present in the Gulf of Maine with respect to their effect on whale health. They took skin samples from the backs of whales and analyzed for metal levels and genomic data. The skin acts as a barrier and is responsible for the absorption of toxic compounds but typically carries lower concentrations than found in internal organs because the metals are eventually absorbed and distributed (11). The authors used the data on Cr to extrapolate and make comparisons to concentrations from occupationally and non-occupationally exposed Cr(VI) workers. Interestingly, the levels of Ni and Cr observed in the whales in this study were higher than those reported in humans without occupational exposure and similar in level to humans with occupational exposure over several decades suggesting that these levels in the ecosystem are concerning for overall health.

We centered our case study activity specifically around the Wise et al. article because the results provided students with the opportunity to analyze toxicological data, which is not clearly shown in textbook examples, and because we wanted students to appreciate that real data can be challenging. This paper underscores the importance and concern for metals (17, 18), exposes students to a biological model which is typically not discussed in academic classes and it contextualizes the data with the One Environmental Health approach.

Intended Audience

This case study is intended for and tested within an upper-level juniors/seniors introductory toxicology course. It has also been used as an Active Learning Exercise for approximately 40 upper-level undergraduates at the Society of Toxicology 2021 Virtual Meeting in which students all had varying levels of science background but had all completed at least the introductory sequences of biology and chemistry. This case study has also been tested within an AP High School Biology class where the students had prior knowledge of environmental science, but not all questions were used.

Required Learning Time

This exercise can be adapted for the needs of the students, instructor, and class. A minimum requirement would be 90 minutes, but it could be stretched into a three-hour lab period. The goals and objectives can be met if spread over several different meeting times.

Prerequisite Student Knowledge

Students should have basic knowledge for the principles of toxicology, including exposure, absorption, distribution, biotransformation, and excretion. Prior to the exercise, students can complete the "Principles of Toxicology" module available through ToxMSDT. Students should review sections 1-4, 10-13, and 16, specifically.

Prerequisite Teacher Knowledge

In addition to the prerequisite student knowledge, the instructors are expected to understand the One Environmental Health Approach (10, 12, 13), as well as basic information about metals and their role in the induction of toxicity (10, 11, 14–17). Instructors should read the Wise et al. paper which contains the original data used in the case study (11).

SCIENTIFIC TEACHING THEMES

Active Learning

Active learning is a student-centered instructional strategy where small groups of students can collaborate on solving questions. This can promote content knowledge while also engaging the students in problems that will allow them to think critically and creatively. This approach allows students to take control of developing their own conceptual understanding (8, 19). This case study involves three major activities.

- Students work collaboratively in groups to answer questions allowing them to share their knowledge and discover new understandings together.
- Students work together to interpret data from the primary literature. This allows them to understand data analysis and data presentation, and to think collaboratively about the scientific process.
- Through the presentation of group answers, students not only build their communication skills but they also dialogue with one another. They share ideas, build confidence, and take ownership of the learning process.

Assessment

- In-class discussions led by the instructor will provide formative assessments of student understanding with the goal of identifying gaps in learning and guiding the learning process (20).
- Matched questions illustrating related or similar skills to those in the case study allow for assessment. These questions require students to apply the knowledge and skills they have gained from the case study to a new situation.

Inclusive Teaching

This activity involves cooperative group work and implements inclusive teaching strategies in the classroom. Since this is an activity for small groups, the instructor has several choices on how to sort students in the class. Students could be allowed to individually select groups, or the instructor could pre-assign groups to encourage students to interact with individuals with whom they normally do not work, enabling students to learn the value of diverse perspectives and opinions. As instructors, we ensure that every group member is engaged in the entire discussion, and we discourage student isolation. We recommend that the instructor have each group determine roles such as facilitator, recorder, presenter, and timekeeper. This will encourage individual accountability. The positions can rotate as students transition from one question to the next. In doing this, it ensures that each student takes a different role at some point during the process and encourages participation of students who may struggle with the questions.

LESSON PLAN

This lesson was designed for a 90-minute period but can be extended depending on the prior knowledge of the students and the goal for the class. This lesson is best designed for a classroom that allows the students to easily gather in groups and in which the data can be projected onto a screen. A suggested timeline is provided in Table 1.

Pre-Class Preparation

This lesson is intended to be used after the introduction of basic toxicological principles of exposure, absorption, distribution, biotransformation, and excretion. If these are not primary topics for the class, then extra time can be used at the beginning to review these concepts but it is encouraged for students to complete the "Principles of Toxicology" module available through ToxMSDT. More specifically, students should review sections 1-4, 10-13, and 16 which should take approximately 1 hour. It is not necessary for students to be familiar with the One Environmental Health Approach but instructors many find it helpful to refer to the suggested instructor resources for basic understanding. Before class, the instructor will need to print and distribute copies of the case study which can be printed in color or black and white (S1. Environmental Health - Student Data Set). Instructors should also provide students with a copy of the Wise et al. article (11). Alternatively, the case study and article could be posted to a course LMS, and students could read from there. In this case, the internet would be needed in the classroom for the students to refer to the case student and the data set questions.

Review by instructor

The class should begin with a brief review of the basic principles of toxicology by the instructor, with students actively listening and discussing them. A review of the basic principles can be found through ToxMSDT.

Case Study

The instructor should organize the class into small groups of approximately 4-6 students and ensure everyone has a copy of the case study and questions. Beyond basic instructions, the instructor does not need to intervene. The groups should discuss each Data Sets for approximately 10 minutes and then reconvene to share their responses to each question for 10 minutes. The instructor should let the students discuss the data set and serve as a moderator, walking and checking on each of the groups. Each data set could have several answers, and the instructor should guide the students if necessary to come up with all possibilities and in the end summarize the important points. The whole class discussion of each data set serves as a formative assessment for the students and the instructor. As the students move through the case study, the instructor can use the time to reinforce basic principles of toxicology and relate the data to other biological models as relevant.

Data Set 1 of the case study, requires students to critically analyze data from Table 1 and Figure 1C from the Wise et al. paper (11). Students should discuss the importance of sample size and why obtaining adequate sample size can be more difficult with biological/ecological models. Though not a learning objective for this activity, instructors could use the data set to discuss statistical analysis and statistical significance. Additionally, metals can originate from several anthropogenic sources, and a discussion of how these data may vary if taken from different locations can be conducted.

The case study's second and third Data Sets have students looking more critically at the data from Figures 2, 3 and Table 2 from Wise et al. paper (11) and identifying trends depending on year, sex, and type of metal. Students are asked to consider how metals may accumulate in one type of whale species as opposed to another. Additionally, students are required to think about how these data can relate to human exposure and health. As students discuss the movement of metals through whales and human, the instructor can bring up the principles of exposure, absorption, distribution, biotransformation, and excretion.

Data Set 4 asks the students to discuss sources of environmental metal contamination and create a trophic pyramid combining all the information obtained throughout the discussion. Students are asked to think critically about sources of metals and how this would be disbursed throughout the food chain from smaller organisms to whales. At the conclusion of the discussion for all the data sets, the instructor should discuss how the data can be applied to human or other biological models and reiterate the importance for the One Environmental Health Approach. Potential answers to all questions can be found in instructor notes (S2. Environmental Health - Instructor Notes).

Out-of-Class assignment

Students may need to review basic toxicological principles prior to completing the case study, but no formal assignment following the case study is necessary.

Assessment

During the in-class exercises, students' answers and the subsequent discussion of the questions will provide feedback on student learning and meeting the set objectives for the exercise. The questions in the case study are designed to have students look at real data and learn to analyze tables and figures. Students may be given an additional opportunity to practice and apply these stills by analyzing a separate data set (S3. Environmental Health - Matched Student Questions). The matched questions are not required to meet the learning objectives for the case study. Instructor notes are provided in S4. Environmental Health - Matched Student Questions-Instructor Notes.

TEACHING DISCUSSION

Using case studies through a PBL approach has many advantages in the classroom. When applied correctly, case studies can increase student motivation. Use of case studies promotes a deeper understanding of the material and enables students to see the applicability and in some instances allows for cross-disciplinary connections (21). Case studies should be self-directed allowing students to take control of the process and figure out independently where they may need more information or knowledge on a particular topic. The overall goals for the case study focuses less on material retention and more on the development of skills.

Activity's effectiveness at achieving the stated learning goals and objectives.

This activity was effective in helping students draw conclusions about the impact of metals on biological systems using data from a primary paper, making predictions about overall human health, and understanding the One Environmental Health approach. Additionally, students examine how individual populations were affected by exposure to toxicants and how toxicants move through the environment into the ecosystem. These are goals for the Society of Toxicology Learning Framework. Since the instructor acts mainly as a moderator, students have ownership of the knowledge, and their level of understanding is evident in their confidence while presenting answers during the class discussion. Groups who do not complete questions, or who do not have the correct answer, have the opportunity to hear from their classmates. The students can practice similar skills by completing the matched questions (S3. Environmental Health - Matched Student Questions).

Reactions to the activity

This module has been implemented successfully within an AP High School Biology class, a sophomore/junior 300 level Introductory Toxicology course, and as an Active Learning Exercise for upper-level undergraduates at the Society of

Toxicology 2021 Virtual Meeting. In all instances, the responses have been very positive and following this interaction several students followed up with additional questions. Using real-world data and allowing the students to discuss it on their own led to lively discussions and excitement from the students. Students appreciated the opportunity to learn about the collection of samples and understand a different biological model which has an impact on human health. Each time the case study was run, students had several questions about the use of whales as a biological model, the extrapolation to human data, and the use of it as a predictor for overall human health. From the students who participated in the virtual Society of Toxicology presentation of this case study, 80% either strongly agreed or agreed that this case study provided useful and new information. Approximately 87% felt that the case study was understandable in the manner in which it was delivered. 84% of students in the 300-level Introduction to Toxicology course felt that this activity enhanced their interpretation of data, and they liked the ability to work independently and then share their ideas with the class.

While most responses to the activity were positive, we did receive some constructive comments from students collected anonymously. Most of the comments were in reference to wanting to have more background information on the collection methods for the samples. Though neither of these impacted the interpretation of the results, students felt it would have enhanced their experience. Some students also wished that there was more time to examine the data. For students who have little to no experience with data analysis, it is important to allot enough time at the beginning to explain the figures and answer any basic questions students may have. During the activity, the instructor should monitor the groups and sometimes apply a little encouragement to ensure engagement with classmates.

Adaptations

We have done this activity in a 90-minute session, spread over two 45-minute sessions, as well as a 2.5-hour session. If the activity is broken up into smaller sessions, the instructor may want to ask students to review the data and questions first on their own and then come together as a group to answer the questions. Students would then work collaboratively within their groups to answer questions.

SUPPORTING MATERIALS

- S1. Environmental Health - Student Data Set
- S2. Environmental Health - Instructor Notes
- S3. Environmental Health - Matched Student Questions
- S4. Environmental Health - Matched Student Questions-Instructor Notes

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REFERENCES

1. Wolff M, Wagner MJ, Poznanski S, Schiller J, Santen S. 2015. Not Another Boring Lecture: Engaging Learners with Active Learning Techniques. J Emerg Med 48(1):85–93. doi:10.1016/j.jemermed.2014.09.010
2. Michael J. 2006. Where's the evidence that active learning works? Adv Physiol Educ 30(4):159–167. doi:10.1152/advan.00053.2006
3. Duncan RG, Rivet AE. 2013. Science Learning Progressions. Science 339(6118):396–397. doi:10.1126/science.1228692
4. Tytler R. 2007. Re-imagining science education: Engaging students in science for Australia's future. ACER Press, Camberwell, Victoria.
5. Dolmans DHJM, Loyens SMM, Marcq H, Gijbels D. 2016. Deep and surface learning in problem-based learning: A review of the literature. Adv in Health Sci Educ 21(5):1087–1112. doi:10.1007/s10459-015-9645-6
6. Goodnough K, Cashion M. 2006. Exploring Problem-Based Learning in the Context of High School Science: Design and Implementation Issues. Sch Sci Math 106(7):280–295. doi:10.1111/j.1949-8594.2006.tb17919.x
7. Bonney KM. 2015. Case Study Teaching Method Improves Student Performance and Perceptions of Learning Gains. J Microbiol Biol Educ 16(1):21–28. doi:10.1128/jmbe.v16i1.846
8. Herreid C. 1994. Case studies in science—a novel method of science education. J Col Sci Teach 23(4):221–229.
9. Adams NE. 2015. Bloom's taxonomy of cognitive learning objectives. J Med Libr Assoc 103(3):152–153. doi:10.3163/1536-5050.103.3.010
10. Pérez A, Wise JP. 2018. One Environmental Health: An emerging perspective in toxicology. F1000Res 7:918. doi:10.12688/f1000research.14233.1
11. Wise JP, Wise JTF, Wise CF, Wise SS, Zhu C, Browning CL, Zheng T, Perkins C, Gianios C, Xie H, Wise JP. 2019. Metal Levels in Whales from the Gulf of Maine: A One Environmental Health approach. Chemosphere 216:653–660. doi:10.1016/j.chemosphere.2018.10.120
12. Atlas RM. 2012. One Health: Its Origins and Future, p. 1–13. In Mackenzie JS, Jeggo M, Daszak P, Richt JA (ed), One Health: The Human-Animal-Environment Interfaces in Emerging Infectious Diseases. Springer Berlin Heidelberg, Berlin, Heidelberg.
13. Lebov J, Grieger K, Womack D, Zaccaro D, Whitehead N, Kowalcyk B, MacDonald PDM. 2017. A framework for One Health research. One Health 3:44–50. doi:10.1016/j.onehlt.2017.03.004
14. Rehman K, Fatima F, Waheed I, Akash MSH. 2018. Prevalence of exposure of heavy metals and their impact on health consequences. J Cell Biochem 119(1):157–184. doi:10.1002/jcb.26234
15. Verma R, Dwivedi P. 2013. Heavy metal water pollution- A case study. Recent Research in Science and Technology 5(5):98-99.
16. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. 2005. ATSDR (Agency for Toxic Substances and Disease Registry). Toxicological profile for nickel. Atlanta, GA: U.S.
17. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. 2012. ATSDR (Agency for Toxic Substances and Disease Registry), Toxicological profile for chromium. Atlanta, GA: U.S.
18. Hayes RB. 1997. The Carcinogenicity of Metals in Humans. Cancer Causes Control 8(3):371–385. doi:10.1023/A:1018457305212
19. Andrews TM, Leonard MJ, Colgrove CA, Kalinowski ST. 2011. Active Learning Not Associated with Student Learning in a Random Sample of College Biology Courses. CBE Life Sci Educ 10(4):394–405. doi:10.1187/cbe.11-07-0061
20. Evans DJR, Zeun P, Stanier RA. 2014. Motivating student learning using a formative assessment journey. J Anat 224(3):296–303. doi:10.1111/joa.12117
21. Kulak V, Newton G. 2014. A guide to using case-based learning in biochemistry education. Biochem Mol Biol Educ 42(6):457–473. doi:10.1002/bmb.20823

Table 1. One Environmental Health Approach Timeline

Activity	Description	Estimated Time	Notes
Review	The instructor should review general toxicological principles	10 minutes	Students should have prior knowledge on the material and if not, this section can be extended or the students could be required to read these topics prior to the session
Case Study: Data Sets 1-4	Groups should analyze each data set and answer the provided questions	10 minutes each (40 minutes total)	Text of case study in S1. Environmental Health - Student Data Set Instructor notes can be found in S2. Environmental Health - Instructor Notes
Class Discussions	After each data set, students should share their answers with the class with the instructor acting as a moderator. If the students are unclear of the answers, the instructor can step in to provide clarifications.	10 minutes each (40 minutes total)	It is encouraged that the instructor not provide the answers but instead allow the students to have a discussion and to act as a guide in the learning process.