Pick Your Poison: A Semester-Long Case Study for Undergraduate Toxicology

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Abstract

The ability to collate information from diverse scientific resources and effectively employ scientific writing is an essential skill for scientists. This lesson describes a semester-long project entitled "Pick Your Poison," which is designed for use in a one-semester Toxicology course. Students are each assigned to or choose their own individual toxicant as a case study from a pre-selected list of toxicants (poisons) that align with the theme of the course. As content is covered in the course, students complete ten scaffolded, low-stakes writing modules that are shared with groupmates of 4–5 students. Each module covers a major feature of the toxicant, such as chemical features, characteristics of absorption, distribution, metabolism, and elimination (ADME), and organ-specific toxicities. Students share their work with their group mates and the instructor, peer review one another's work, and then edit their original post as appropriate to produce a concise, 3–4 paragraph product. At the end of the course, students compile their writing modules into an article in the format of the Encyclopedia of Toxicology. This project can be adapted to any toxicology course through alteration of the content and number of modules and/or the type of final deliverable. Several evidence-based and inclusive teaching practices are included, such as writing-to-learn, peer review, and low-stakes assessments.

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Learning Goals

Students will:

◊ understand how to integrate a variety of scientific sources to create a toxicological assessment of a particular toxicant.

◊ condense scientific information for a generalist scientist audience with little expertise in a content area.

◊ value feedback and use it to enhance the quality of scientific writing.

◊ understand how scientific profiles of toxicants are generated from incomplete information and identify the gaps in knowledge.

◊ From the Toxicology Learning Framework at *CourseSource*, students will answer the following questions:

» How do cells respond to exposure to toxicants?

» How are organs affected by exposure to toxicants?

» How are body systems affected by exposure to toxicants?

» How do toxicants move through the environment to affect ecosystems?

» How is the science of toxicology applied to government regulations to ensure the protection of individuals and the environment?

Learning Objectives

Students will be able to:

◊ employ scientific writing to explain scientific concepts, supported by the scientific literature, to a generalist scientific audience.

◊ describe the mechanism of action of a toxicant at the cellular, organs, body system, individual, and ecological system levels.

◊ evaluate pharmacokinetics/toxicokinetics for a toxicant, including administration, distribution, metabolism, and elimination (ADME).

◊ synthesize current government regulatory information for their toxicant, including allowable exposure limits from a variety of government organizations.

◊ define the impact of a toxicant on ecosystems.

INTRODUCTION

Toxicants are chemicals that induce injury or dysfunction in living organisms through the alteration of biochemical pathways or by inducing physical injury, affecting the homeostasis of the organism (reviewed in [1]). Toxicants are formally assessed by regulatory agencies to determine their overall risk to human health or the environment. These assessments include both their chemical properties and their biological properties in terms of their impact on living organisms (see below for examples). Toxicants are described by their chemical structure and chemical properties. They are also characterized by their impact on living organisms through investigations of the toxic dose (the lowest dose that causes injury); their toxicokinetic properties, including how they are absorbed, distributed, metabolized, and eliminated (ADME); their organ-specific toxicities; and their ability to induce cancer. The environmental impact of toxicants is considered as well, assessing how toxicants affect other living organisms and how they enter, permeate, and are eliminated from the environment.

In the United States, the most basic assessment of toxicants may be found on Safety Data Sheets (formerly known as Material Safety Data Sheets [MSDS]). These sheets include basic chemical, toxicological, and ecological information in addition to other properties. Government agencies also produce comprehensive toxicological assessments for some chemicals; these agencies include the Occupational Safety and Health Administration (OSHA), the Agency for Toxic Substances and Disease Registry (ATSDR), and the National Toxicology Program (NTP). These reports draw directly from the primary scientific literature or may include actual studies performed by the government agency. Another comprehensive chemical overview is the Encyclopedia of Toxicology, a reference work that includes articles on toxicants in a standard format that discusses many of the features found in a toxicology course. The format of the writing of the articles is designed for a more general audience than the government agency reports described earlier.

Instead of following a case study approach, many undergraduate toxicology courses typically cover the aspects of toxicology from a more general perspective, one at a time (2). For example, the concept of chemical absorption might be discussed over the course of two lecture periods by covering all the various ways chemicals can be absorbed by the body, highlighting a few key examples of each type of way. Likewise, toxicant metabolism is discussed as a whole topic rather than focusing on how dozens of particular examples are covered.

This activity integrates a case study approach into the traditional undergraduate toxicology course framework, engaging students in active learning by having students identify a unique toxicant and analyze it through multiple learning modules over the course of the semester in real time as topics are covered in the course. In each of ten modules, students produce short written pieces associated with discrete topics and iteratively work to improve their writing and material understanding through asynchronous course management system discussion forums throughout the semester. These forums employ student and instructor feedback together with graded revisions.

This approach uses several evidence-based teaching practices. The writing assignments for each module are based on the "writing-to-learn" approach in which less formal writing is used to drive learning and comfort with the writing process in science (3-5). Highly scaffolded science writing approaches increase the quality of student writing, especially for students who struggle the most with scientific writing (6, 7). The assignments are iterative, providing students multiple chances for improvement over the course of the semester (8). Peer review for each module allows students to improve their writing and practice peer review skills essential for graduates, leading to higher quality writing (9). Use of a standard discussion format in which students provide their comments, evidence to support it, and suggestions for changes leads to more in-depth discussions and reflection (10). The final deliverable is a writing assignment in the format of an Encyclopedia of Toxicology article, which includes content from each of the modules previously produced in the course (11). Students integrate and condense their findings on toxicological agents into a format that a general scientific audience would understand.

Intended Audience

This lesson has been used in an upper-level toxicology course taught at a regional comprehensive college. While the course is taught face-to-face, the bulk of the assignment is performed using online discussion boards on a content management system. Students in these courses are Marine and Environmental Sciences majors who have taken Organic Chemistry and Biochemistry as prerequisites. This lesson could be adapted for use at the graduate level as well. Given its modular nature, aspects of the assignment can be added or removed to facilitate its use for other courses (see Potential Variations below).

Required Learning Time

The lesson is composed of ten modules delivered over the course of a 16-week academic semester. Each module requires approximately four hours of time outside of the classroom. The students spend up to three hours researching and writing for a module, followed by about one hour reading and reviewing modules produced by some fellow students. The number of modules used is flexible, but as written, the anticipated time of the entire lesson is 40 hours.

Prerequisite Student Knowledge

This lesson is a semester-long writing project employing "writing to learn" as the students progress through content in the course. The course has Organic Chemistry 1 and a single semester Biochemistry course as a prerequisite. PubChem provides basic information on most chemicals. An outstanding resource for toxicological principles is "ToxTutor", freely available at the Toxicology Mentoring and Skills Development Training website. Students should have familiarity with searching PubMed and similar academic resources. Governmental regulatory information for toxic chemicals is available at a variety of websites, and the instructor should ensure students are aware and comfortable with these sites prior to assigning modules focused on permissible exposures. Finally, the Undergraduate Toxicology Learning Framework available at *CourseSource* provides resources for lessons.

Prerequisite Teacher Knowledge

In this lesson, students select a toxic substance to work with over the course of a semester. A pre-selected list is provided to students, and they select their top three choices (S1. Pick Your Poison – Student Assignment). Depending on the instructor's comfort level with various toxicants, they may add or remove toxicants from the list. The instructor will need to evaluate the work of each student, and, therefore, if they are unfamiliar with a given toxicant, they will need to review each unknown toxicant. Thus, it is recommended that instructors limit the number of toxicants they are completely unfamiliar with to a number that is manageable. The instructor may also remove modules they do not need for their course or add new modules reflecting different course content. A very useful reference for teachers is *Casarett and Doull's Toxicology: The Basic Science of Poisons*, a principal reference source for professional toxicologists in the field of toxicology (1).

SCIENTIFIC TEACHING THEMES

Active Learning

Students are actively engaged in applying content covered in the classroom to a particular toxicant that they were assigned to at the beginning of the semester. After covering a given content area in the classroom, students search for authoritative sources applying that content area to their assigned toxicant. For example, after learning about ecological toxicology, the students would search for studies related to their particular toxicant being an environmental toxicant. The writing output is generally short, 2–4 paragraphs, and accomplishable in no more than three hours of research. Peer review is performed in an online discussion board format with a pre-assigned group of 3–4 students. Following peer review, students edit their own work, reflecting on the quality of their research and sources as well as lessons learned from their peers. This type of scaffolded approach improves writing communication competency and synthesis of material from the primary scientific literature and government resources (12).

Assessment

Assessment is conducted for each module, including evaluation of the writing itself, the quality of the citations used to support the writing, and the interaction of the student with their peer cohorts. An example assessment rubric is provided in the Supporting Materials section. Frequent formative assessments scaffold the assignment and allow students to improve over the course of the semester (8).

Inclusive Teaching

This lesson emphasizes application of classroom content to a toxicant that students are unfamiliar with, rather than memorization of content. It provides an alternative assessment to high-stakes exams by relying more on research and application and less on rote memorization. It is also composed of discrete modules and multiple low-stakes assessments that allow for iterative improvement rather than a single large assessment at the end of the project. Finally, the use of peer review in a low-stakes environment has been shown to reinforce a sense of scientific identity in all students (13).

LESSON PLAN

Pre-Lesson Activities:

The instructor should create a list of toxicants for each class member to choose from. Instructors may wish to constrain the list of toxicants to those they are familiar with or include a limited number of unfamiliar toxicants. It is recommended that the professor have some familiarity with most of the toxicants offered so that they can provide feedback without extensive review of the literature. The instructor may also wish to constrain the toxicant list to those with particular properties depending on the needs of the course; for example, an ecotoxicology course may want to focus primarily on those toxicants which impact the environment. An example list is found in the Supporting Materials. The instructor should read one or more articles from the Encyclopedia of Toxicology focused on single toxicants to familiarize themselves with the structure and layout of these articles. Alternatively, the instructor could create their own format based on their own modules. The article created by the instructor will be presented as an example to the class to help them create their own articles.

The instructor should select which modules they want to include in the course and space them appropriately throughout the semester. Each module consists of approximately four hours of work for a student, including peer interaction. The instructor should also prepare an online learning environment. A suggested approach are discussion boards embedded within a content management system, such as Blackboard or Desire2Learn. Instructors should recognize that students may download copies of Encyclopedia of Toxicology articles on their topics and may therefore obfuscate the source of the original article.

"At Home" Work:

The modules are spaced approximately one or two weeks apart and are based on the topic order of the syllabus. In the first week, students are provided a list of toxicants and asked to rank order their top three choices. If students are allowed to choose toxicants not on the list, careful consideration should be made to ensure enough scientific literature exists to make the assignment interesting. Likewise, the instructor should be knowledgeable enough about those toxicants to provide valuable feedback to the students.

In week 1, students are assigned into groups of 3–4 so that students who have chosen similar toxicants are not placed into the same group. For example, students working on the nerve agents soman and sarin should not be placed into the same group due to similarities of mechanism of action of these toxicants. Considerations about inclusivity might be made for group makeup as well. The first module asks students to identify chemical information for their compound including chemical structure, CAS number, molecular mass, and other basic chemical information. This information is posted in a discussion thread that other students and the instructor may access and provide comments, identify missing information, ask questions, and provide supplemental information. Students then modify their original postings to reflect the comments.

Subsequent weekly modules draw on material that was taught in the course over the previous lessons. For example, in the course at the CGA, week 2 discusses the cellular target(s) for the toxicants. Students are asked to identify the biochemical target, explain how that target's biochemical pathway performs under normal circumstances, explain how the toxicant disrupts that normal signaling pathway, and finally explain the consequence to the cell. If the chemical is also a pharmacological agent, the students are asked to provide a similar analysis for the pharmacological target. Since the final product for this semester-long assignment is an encyclopedia chapter, the information is provided in a few paragraphs, typically no more than five paragraphs for a given topic. The post is provided in a discussion board area available to members of their group, and peers read one another's work, make comments, ask questions, identify missing information, and provide additional sources if needed. The original authors then modify their work appropriately using the Encyclopedia of Toxicology template provided as an example.

In subsequent weeks, the same process is repeated: original post, feedback, and revision. These topics are spaced no closer than one week apart. The modules covered at the CGA are shown in Table 1. Importantly, not every topic is applicable to every toxicant. For example, most toxicants are not carcinogens.

Source materials for these assignments are expected to be peer reviewed primary literature, review articles, government websites, and, at times, commercial companies providing items such as Material Safety Data Sheets. Students often have difficulty recognizing authoritative sources of information; this represents an ideal point in which peer review and instructor feedback is critical to guide them to the right sources of information.

In addition, students must include at least three scientific figures that reinforce interesting points for their toxicant. These might include dose response curves, pictures of damaged tissues resultant from experimentation or injury, or schematic diagrams representative of the pathway of toxicity. The best figures augment their writing and make it more interesting for a reader.

The final assignment consists of compiling the work into a single document in the style of an Encyclopedia of Toxicology article. Students are provided at least two weeks at the end of the semester to accomplish this task. The work from each complete module can be inserted into the document, and any missing components can be added at this time. An example grading rubric is provided in the Supporting Materials.

Grading Notes

The overall assignment is worth 20% of the final grade in the course as an alternative significant assessment to complement exams. The overall grade values the average score from the modules at 80% and the final product at 20% of the total "Pick Your Poison" grade. For grading, each module is broken down into three components: the original post (50%), discussion (30%), and response to the discussion (20%). The grade for the original post considers content, length, style, and citation quality. Follow-on discussion by the instructor and groupmates provides the student ideas for improvement; even if the student earned the highest possible score on the original post, it is useful to provide some comments for improvement so that the students become accustomed to receiving and responding to constructive feedback. The best results occur when the instructor models appropriate responses early in the review cycle, especially for the first few modules, so that students know what kind of feedback is appropriate. Finally, the response assessment focuses on how students responded to the feedback. This works best if students are also asked to indicate which content was changed and why, because it allows the instructor to quickly determine what was changed. Another way to accomplish this would be to have the students highlight which sections were changed. The iterative nature of the assignment helps students improve as they continue through the course if the instructor provides timely feedback; in past experience, grades have risen over the course of the semester on this portion of the assignment.

Evaluation of the final report considers content for each of the modules used in the assignment formatted in the style of an Encyclopedia of Toxicology article. It also includes evaluation of three figures taken from published primary literature articles to augment the article. Assessment considers whether the students had skillfully homogenized the style and language so that the article became a single coherent work written in a consistent voice. Feedback is given prior to the deadline for the assignment for those students who have completed the work earlier, giving them a chance to revise their work.

TEACHING DISCUSSION

General Observations

This assignment has been taught twice to classes of 20 and 14 students. This assignment was rated well in free-form responses, but individual comments are not provided because an IRB was not able to be obtained after the course had been taught. Finding high quality scientific sources is the most difficult aspect of this assignment for the students. In addition to providing assistance as the instructor, group members are encouraged to help their classmates find appropriate sources and are rewarded as part of each module's grade for doing so. It is recommended that the professor provides search strategies and helpful resources in which to find information, such as governmental databases to which students may not have been exposed. Basic chemical information can be found at the National Library of Medicine's PubChem page. Other information may be found at supplier websites that post Safety Data Sheets. Helpful government websites include the Occupational Safety and Health Administration's Occupational Chemical Database, the Agency for Toxic Substances and Disease Registry, and the National Toxicology Program. Instructors outside the United States may wish to use their own nation's databases.

Potential Variations

The number of modules can easily be modified if the instructor wishes to shorten the assignment. The order of topics is entirely dependent on the order of lecture topics and may be readily adapted to other topic orders or content. As shown in this exercise, the assignment is rather long and is meant to be an alternative assessment, replacing an exam. However, the instructor may wish to reduce the length, which might allow

the students to complete the same assignment for more than one chemical. It might also be adopted and used as a group assignment in its current form.

Providing a list of suggested toxicants is highly recommended to prevent students from choosing toxicants with a dearth of information (such as the chemical weapon novichok) or to encourage students to choose toxicants that the instructor is familiar with. The list of toxicants might also be adjusted to form a common theme for a course, such as "environmental toxicants" or "liver toxicants".

In the first two iterations of this course, a single discussion board for each week was created rather than broken down into groups. Students had difficulty offering advice to one another, and some students were not given any comments. To avoid this, using small groups and requiring posts on each group member alleviates this issue. Reading and assessing multiple discussion assignments is time-consuming, and the instructor may wish to reduce the importance of this component if time is a consideration.

The order and choice of modules for the assignment is flexible, as is the choice of the format for the final product. This assignment is completely conducted virtually but could be adapted to face-to-face learning by having the discussion and collaboration portions happen within the classroom. The instructor may also decide to forego the final assignment, just using the weekly modules without a formal written deliverable.

SUPPORTING MATERIALS

- S1. Pick Your Poison – Student Assignment

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Table 1. Example List of Modules Used in the Semester-Long Pick Your Poison Assignment

Module Number	Topic
1	Chemical Information
2	Cellular Target
3	Dose Response
4	Absorption, Distribution, and Elimination
5	Biotransformation
6	Organ-specific Toxicities
7	Developmental Toxicology
8	Carcinogenesis
9	Environmental Toxicology
10	Regulatory Information

Table 2. Teaching Timeline for the Pick Your Poison Semester-Long Assignment

Activity	Description	Estimated Time	Notes
Prior to Start of the Course			
Instructor: Choose modules to use in the course.	Choose up to ten modules to use throughout the semester.	1 hour	Example template assignment with ten example modules is available in S1. Pick Your Poison – Student Assignment.
Align modules with syllabus.	Align modules with the content being taught in the course and desired length/value of assignment.	30 min.	Example syllabus with aligned modules may be found in S1. Pick Your Poison – Student Assignment.
Choose poisons to include in the course.	Instructor should choose 'poisons' they know well or are comfortable researching.	1 hour	A reasonable mix of known and unknown poisons will make the material more interesting for the students and instructor. An example list is found in S1. Pick Your Poison – Student Assignment.
Class Session 1 – Introduction of Assignment			
Students select or are assigned their poison.	A list of poisons is provided to the students, and the students select their top three choices.	5 min.	Typically, no duplicates are allowed. A write-in option may be used to allow some student choice. An online quiz using Google Forms works well for this.
Practice observations.	Data collection.	15 min.	Instructed practice on quality of observations and basic identification.
Module Workflow ***This process is repeated for each module over the course of the semester.***			
Instructor: Module assignment.	The module is assigned at the beginning of the content delivery period.	5 min.	Early assignment allows students to think about how the content learned in the course applies to their poison as they learn about it.
Instructor: Content instruction.	Instructor provides content in preparation for each module using the teaching method of their choice.	1–6 class periods	
Student: Primary post.	Students write 3–4 paragraphs about their poison for each module and each individual posts in their group of 3–4 students on an online discussion board.	1–3 hours	Through their teaching, the instructor should introduce proper places to find content related to the students' posts. The instructor should provide a sample for students to work from; the Encyclopedia of Toxicology is recommended as one good example of a concise piece of writing in the style desired by this assignment.
Student: Response to classmates' posts.	Students read the posts from others in their group, comment, and ask questions about unclear items.	1 hour	Instructors should model this by reading and commenting on posts from each group.
Student: Response to queries by students and instructor.	Each student alters their primary post in response to comments and criticisms provided by classmates and the instructor.	30 min.	
Instructor: Assessment.	Instructor assesses the primary post, student responses, and final work.	Variable	50% of the grade is applied to the original post, 30% to interaction with classmates, and 20% to response to the criticisms and comments by each student.

Activity	Description	Estimated Time	Notes
Final Deliverable			
Instructor: Describe the final assignment.	Provide instructions for the final paper in the form of an Encyclopedia of Toxicology article.	10 min.	This should be done early to allow students to see the big picture for how their work should be combined into a final deliverable.
Student: Draft final project.	Using the modules from throughout the semester, the student assembles the final project.	3 hours	Most of the content for this final project is performed throughout the semester. Completing the final project requires putting the assembled writings into one voice in the appropriate style. An example Encyclopedia of Toxicology article is provided.