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Authors
Santiago, Nicholas A
Glasenapp, Matthew R
Howard, Shanna L

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Dose-Response in Context: A Backward Design, Inquiry Activity Workshop for College Transfer Students

Nicholas A. Santiago[*1], Matthew R. Glasenapp[2], Shanna L. Howard[1]

[1] Department of Microbiology & Environmental Toxicology, University of California Santa Cruz, Santa Cruz, CA, USA
[2] Department of Ecology & Evolutionary Biology, University of California Santa Cruz, Santa Cruz, CA, USA
[*] Corresponding author, nisantia@ucsc.edu

Abstract

The Workshops for Engineering and Science Transfers (WEST) program was designed to foster critical-thinking skills and develop a supportive community for new Science, Technology, Engineering, and Mathematics (STEM) community college transfer students at the University of California, Santa Cruz, with the ultimate goal of improving student retention and persistence in STEM. All learners in the program participate in inquiry activities devised to incorporate elements of backward design and equity and inclusion. Here we discuss our 2019 Toxicology WEST workshop activity, an in-depth exploration of dose-response relationships created to provide an overview of the field of toxicology and clarify common misconceptions. To reflect authentic research design, we had learners assume the roles of Environmental Protection Agency (EPA) scientists tasked with investigating the effects of environmental toxicants on the model organisms *Caenorhabditis elegans* and *Daphnia magna*. Learners were asked to design and conduct experiments to explore the dose-response relationship and report their results in a culminating poster symposium. We assessed learning by evaluating their performance on two tasks: an individual written response and a group poster presentation. Our activity gave learners an opportunity to practice experimental design, data analysis, and science communication before beginning UCSC STEM courses. Practicing these skills early is essential for student retention in STEM, as many students find the experimental process challenging. Here, we describe details of our inquiry workshop activity, reflect on the effectiveness of the activity and our assessment of student learning, and offer suggestions for facilitation and adaptation of our activity to additional educational contexts.

Keywords: activity design, designing investigations, dose-response, inquiry, toxicology

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1. Introduction

1.1 ISEE, PDP, and WEST venue overview

During the Spring of 2019, we participated in the Professional Development Program (PDP) organized by the UCSC Institute for Scientist and Engineer Educators (ISEE). In this program, we received experiential training in pedagogy through collaboratively designing an inquiry activity that we later taught at an ISEE-affiliated educational program. In an inquiry activity, students learn about concepts by figuring them out rather than by being given the answers in a lecture.

To design our inquiry activity, we implemented the backward design framework of Wiggins and McTighe (1998). We began by defining learning goals and acceptable evidence of understanding, then created prompts to elicit this evidence of understanding from learners, and finally devised instruction components. Two critical components of our inquiry activity design were incorporating research-based teaching strategies and providing opportunities for learners to experience authentic research design. During this process, we produced a teaching plan document that describes our design choices and provides instructions for teaching the activity in the classroom. To conclude the PDP program, we taught our inquiry activity during the 2019 UCSC Workshops for Engineering and Science Transfers (WEST) program (Figure 1) and formally assessed its effectiveness. UCSC WEST is a multi-day program designed to help community college transfer students transition into UCSC science and engineering majors through hands-on workshops that promote research-based critical thinking skills and help build community. Here, we

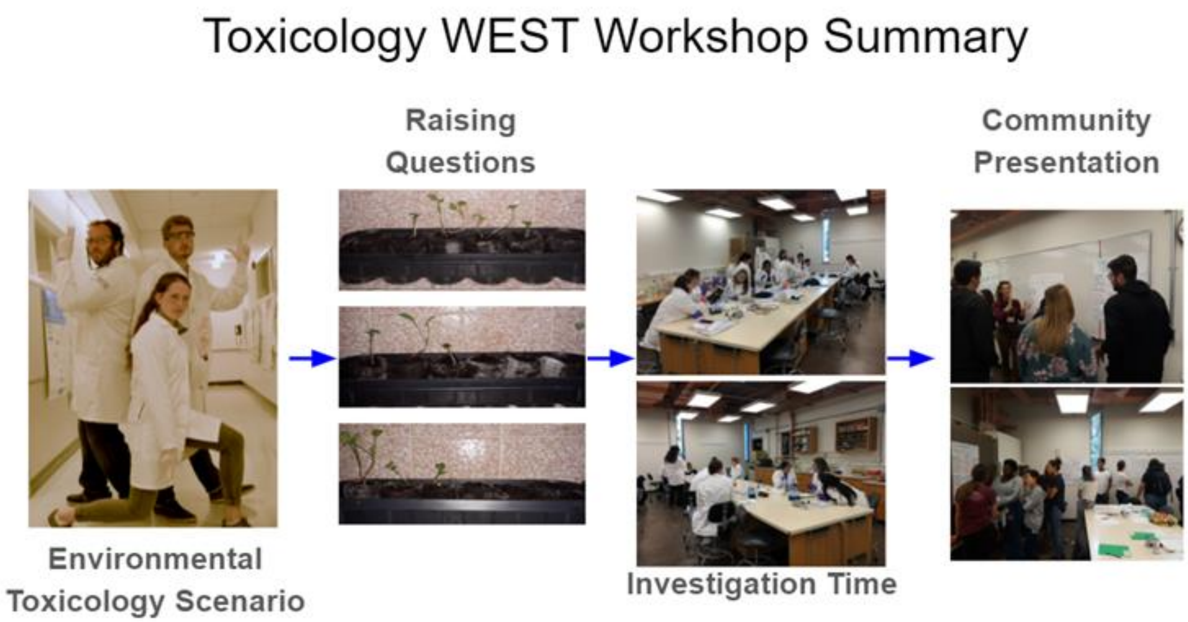

Figure 1: A visual overview of the Toxicology WEST 2019 Workshop main activities. The program began by introducing the learners to an environmental toxicology role-playing scenario where scientists discovered a river with plant death and obtained three unidentified chemical samples. During the Raising Questions portion of the activity, learners made observations of how these unidentified chemicals affected plant growth. Learners developed hypotheses based on these observations, and then performed an experiment to test their hypotheses in the Investigation Time portion of the activity. They collaborated with their team and shared their findings with the students that investigated the other chemicals in different model organisms, and then presented their findings and policy recommendations to relevant parties at a Community Member Presentation.

describe our activity, reflect on its effectiveness, and provide suggestions for adapting it to be taught in a college-level curriculum.

2. Activity Goals

2.1 Overview of dose-response topic and design process

We created our inquiry activity for the subject of environmental toxicology. The inspiration for our activity was an adage in the field of toxicology — "The dose makes the poison." This idea was popularized by Paracelsus, a 16th-century Swiss physician and alchemist who is considered the father of toxicology. He introduced the idea of dose-response in his Third Defense, where he wrote, "All things are poison, and nothing is without poison; the dosage alone makes it so a thing is not a poison." Although true in many cases, this notion is overly simplistic, does not necessarily reflect all biological processes, and has led to the common misconception that dosage and toxicity have a relationship of direct proportionality.

Following ISEE's assessment-driven design framework, we began with a content learning outcome based on a foundational STEM concept that learners often have difficulties understanding. Our content learning outcome was for learners to understand the intricacies of the dose-response relationship in ecologically relevant study systems and appreciate that the relationship may not always be linear. The dose-response relationship is a core concept in a broad range of environmental toxicology and medical fields, and learners often have difficulty understanding dose-response curves. Often, learners assume the relationship between dose and toxicity to be linear, failing to consider the possibility of nonlinear relationships and important biological thresholds. Other common pitfalls include failing to recognize that different organisms may have different responses to doses of the same toxicant and that other variables that may influence the dose-response relationship. We enumerated the important dimensions of the concept and created a content rubric to evaluate learner understanding. Our main learning dimensions, the core toxicology concepts we wanted learners to understand following the activity, were:

1. The dose-response relationship has important thresholds, and toxicity does not always increase linearly with dosage.
2. The dose-response relationship may vary among taxa or substances.
3. Important factors outside of exposure level influence dose-response, such as age, exposure time, and exposure route.

To guide learners towards an understanding of these learning dimensions, we designed a role-playing activity where learners assumed the roles of Environmental Protection Agency (EPA) scientists tasked with investigating the toxicity of mystery chemicals on model organisms. In small groups, learners were asked to design and conduct experiments to evaluate the dose-response relationship. We offered learners the choice of designing experiments with either the water flea *Daphnia magna* (*Daphnia*) or the nematode *Caenorhabditis elegans* (*C. elegans*). Learners chose one of three compounds - sodium chloride (NaCl), dimethyl sulfoxide (DMSO), and ethanol (EtOH) - to assess the dose-response relationship, but they did not know the identity of their chosen compound until the conclusion of the activity. In groups, we instructed learners to form testable hypotheses and design an experimental protocol. We were ultimately guiding them to be able to respond to our content prompt: "Based on your experimental results and the results of the other groups, describe your understanding of the dose-response relationships that may occur in the different organisms of an environment."

We created a culminating assessment task (CAT) to allow learners to respond to the content prompt in a way that mirrored authentic science practices. Our CAT had two parts, an individual written response, and a group poster. Using a predefined rubric, we assessed learners on their understanding of our learning dimensions through their performance on their individual written responses and group poster presentations.

2.2 STEM practice

Along with our content goals, we also built in a core STEM practice learning outcome, "Designing and carrying out investigations." This practice is relevant to any scientific field, and thus is a critical practice for learners who wish to pursue a career in STEM. We defined the dimensions of this learning outcome, which included:

1. Develop a testable hypothesis and control groups to investigate a scientific question
2. Perform experimental procedures with the available tools/technology
3. Interpret results and plan follow-up experiments to confirm results

Involving learners in the experimental design process is a current educational priority (Dasgupta et al., 2014). Although a major goal of STEM education is to develop students' abilities to reason scientifically, students' lab experiences are often "cookbook" labs that provide step-by-step instruction for learners on how to engage in scientific practices. These labs do not develop learners' critical thinking skills or allow them to experience the authentic scientific process of designing an experiment. Undergraduate learners experience many difficulties with the experimental design process, such as arranging treatment and control groups within testable hypotheses, interpreting their findings and understanding the limitations of their experiment, and communicating their findings in ways that incorporate the measures used in their experiments (Dasgupta et al., 2014). Therefore, we wanted to provide our students with an opportunity to practice these skills authentically.

2.3 Equity and inclusion focus area

Our activity design approach incorporated equity and inclusion principles. We specifically focused on developing our learners' identities in STEM through competence, performance, and recognition. Developing a STEM identity is critical for success and retention in STEM fields (Carlone & Johnson, 2007; Perez et al., 2014). Many of the students we worked with at our UCSC WEST venue identified with historically excluded groups. Students from marginalized groups have a more difficult time developing STEM identities because of, among many factors, stereotype threat (Steele & Aronson, 1995) and gendered learning and cultural examples (Hazari et al., 2010). The threat of affirming or perpetuating negative stereotypes can interfere with students' thought processes, motivation, and performance. Students often believe their race prevents peers from recognizing them for their accomplishments (Carlone & Johnson, 2007).

To promote STEM identity during our activity, our design tapped into learners' interests and featured frequent, built-in recognition. Making use of learners' interests is an important way to engage learners and help them persist in STEM, and recognition is a key factor in how learners perceive themselves as scientists (Carlone & Johnson, 2007; Hazari et al., 2010). To encourage learners to pursue their interests, our activity had multiple entry paths and investigation routes. Learners chose their own chemical, organism of interest, and dependent variable to measure, and designed their own protocol. We also made the activity relatable for them by creating an EPA role-playing scenario conveyed through a video we filmed ourselves. The role-playing scenario also simulated authentic science, as the learners' investigation paths represented what a real environmental toxicologist may do to test their hypotheses. Our activity had built-in interventions where learners could give and receive feedback on their progress. We reminded learners that there were no right or wrong answers in their investigations. Facilitators also checked in on learners' progress throughout the activity and provided targeted feedback and positive recognition when appropriate. At the end of our activity, we invited guest graduate students from the UCSC Microbiology and Environment Toxicology Department to listen to learners' poster talks and provide feedback, allowing them to practice their science communication skills. This was also an important moment for promoting STEM identity in the learners.

3. Activity timeline

Here we outline our workshop activity timeline (Figure 2) to provide a general overview of each aspect of our design and the necessary context for understanding our reflections and future design applications.

3.1 Introduction (25 minutes)

We began the activity by playing a video that introduced the topic of our inquiry activity. In our video, we posed as three Environmental Protection Agency (EPA) scientists that stumbled upon significant plant death along the banks of the San Lorenzo River in Santa Cruz, California. We took water and soil samples back to the lab to isolate the responsible pollutants. The video concludes with the three of us recruiting our new UCSC students as interns to help study the effect of the three isolated pollutants on biological organisms and report their findings to the community. After the video ended, we introduced ourselves and the key features of inquiry activities.

3.2 Raising Questions (30 minutes)

The purpose of the Raising Questions component of an inquiry activity is to define the scope and encourage learners to generate questions about a phenomenon that they can pursue later during their investigations. A well-designed Raising Questions activity engages learners' interests and accommodates multiple entry points to the Investigations component. In our Raising Questions activity, we used radish seedlings and three mystery substances to demonstrate three different dose-response outcomes (Figure 3 and Supplemental Document): (i) a nutritional curve where negative health effects can occur when an organism is either deficient or has excess levels of certain nutrients; (ii) hormesis, where low doses of toxicants are beneficial for an organism's growth or survival; and (iii) the traditional threshold dose-response where toxicity increases linearly with dose. However, we did not define these dose-response relationships for the learners.

As new environmental toxicologists, the learners were encouraged to discuss how the dose of different chemicals affects different biological processes of humans and model organisms and the kinds of questions that environmental toxicologists must ask to evaluate a chemical's effect on the environment. Individually, learners wrote down questions and predictions while observing the plant growth pilot study. Learners were then placed into small groups to discuss the questions warranting further investigation. Examples of questions we were expecting learners to ask included:

1. How will different doses of *x* influence the growth/survival of model organism *y*?
2. Will chemical *x* produce the same dose-response relationship in different species?
3. What should the exposure limit of chemical *x* be?
4. Is there a dose of chemical *x* that is beneficial for model organism *y*?
5. Does chemical *x* affect *Daphnia*/*C. elegans* and plants in the same way?

We guided learners away from questions that they would not be able to investigate in the timeframe of the activity with the available resources. We focused group discussion on the role of an environmental toxicologist to prompt learners to think about how these chemicals may affect other organisms. We organized learners into groups of 3–4 based on similarities in their questions.

Inquiry Component	Time (min)	Participant Structure(s)	Leader	If possible: ***"Prompt given to learners that drives this component"***. **Otherwise: What is happening? What are learners doing?**
Introduction	5	Large Group	All	Play video setting up EPA role-playing scenario (research opportunity to figure out the effects of a toxin on the San Lorenzo River ecosystem)
	5-10	Large Group	All	Introduce ourselves/students introduce themselves
	10	Large Group	All	Establish role of facilitators/role of learners in an inquiry activity/lay E&I ground rules/growth mindset, lab safety
Raising Questions	5	Large Group	All	Present plants exposed to unknown chemicals demo and give model organism background of C. elegans/Daphnia.
	15	Small Groups	All	Learners individually write questions for investigation, and then get in small groups to discuss
	10	Small Groups	All	Small group - What does a toxicologist do? What questions are important to answer? What are the first steps in investigating these unknown compounds?
Investigation	30	Team	All	Get learners into small groups and plan experiments.
	20	Small Group	All	Small group - Present experimental plans to other learners and get feedback. Give learners SOP/Practice Rubric.
	25 /15	Team	All	Give students time to revise hypotheses and experimental design and then check in with facilitators.
	60	Team	All	**D1 End:** Daphnia - Run full experiment and collect data C. elegans - Dose and transfer to well plates
	60	Team	All	**D2 Beg**: Daphnia - Analyze data/run additional experiment C. elegans - Well plate counts, analyze data
Culminating Assessment Task	15	Small Group	All	Small Group Jigsaw - Collaborate with other groups to discuss findings, and explore the implications of different curves that were generated
	15	Team	All	With team, accept or reject hypotheses and discuss broader implications, limitations, and other variables not tested. Write Individual Responses (CAT) and break for **Lunch**.
	25	Team	All	Prompt learners to produce poster (CAT), including data, interpretation, and "future studies" component/Make Poster
	40	Large Group	All	Community Member Poster Session--real world application to inform "community members" of tox. findings/implications
Synthesis	10	Large Group	All	Show group results compared to ours. Discuss the names of the different curves, dose doesn't always make the poison, mechanisms of the toxins we used.
	10	Large Group	All	Reinforce experimental design techniques and authentic science approaches learners completed. Future applications of toxicology in different fields/broader implications.

Figure 2: An overview of each component completed in the Toxicology WEST 2019 Workshop. The overview is broken up by task, time allotment, and participant structure for each segment of the workshop. All three of our facilitators participated in each task by either presenting a portion of each large group activity, leading their own small group jigsaw discussion, or checking in with each individual team.

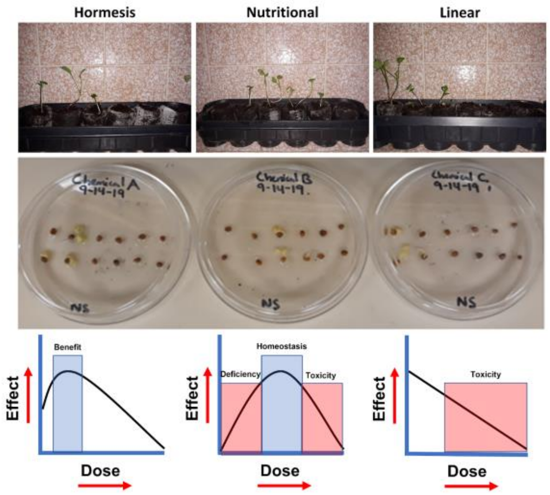

Figure 3: The three main dose-response curves from our Raising Questions component, shown using radish plants and seed germination. Instructors provided a demonstration using the relationship between dose and plant growth to illustrate the dose-response phenomena. The chemicals in the plant growth demonstration achieved three important dose-response curves: hormesis, nutritional, and traditional-threshold. Graphical representation of each curve is depicted with each plant growth outcome.

3.3 Investigations (3.5 hours)

In the Investigations component of the inquiry activity, learners designed and carried out their own experiments to investigate the effect of a mystery chemical on either *Daphnia* or *C. elegans*. Learners began planning experiments in small groups by formulating hypotheses, determining a toxicant treatment regimen, assigning control and treatment groups, and determining how to collect and analyze data. They then participated in a jigsaw activity (Figure 4) where they presented their group's experimental plan to members of other groups to receive feedback. Following the jigsaw activity, learners returned to their original groups, where they revised their experimental plan based on feedback from other groups. Facilitators circulated between groups during this experimental design phase to ask targeted questions and ensure learners were on track. Learners then began their experiments.

3.4 Assessment (95 minutes)

After completing their experiments, students participated in another jigsaw activity in which they shared their findings and discussed the different dose-response curves they had generated. They then returned to their original groups and decided whether to accept or reject their original hypotheses. They also discussed the implications of their results, limitations of their experimental design, and other variables that they could measure in future studies. We had multiple opportunities to check in with our learners and adjusted our facilitation when learners were not making efficient progress towards our workshop goals (Figures 6,7).

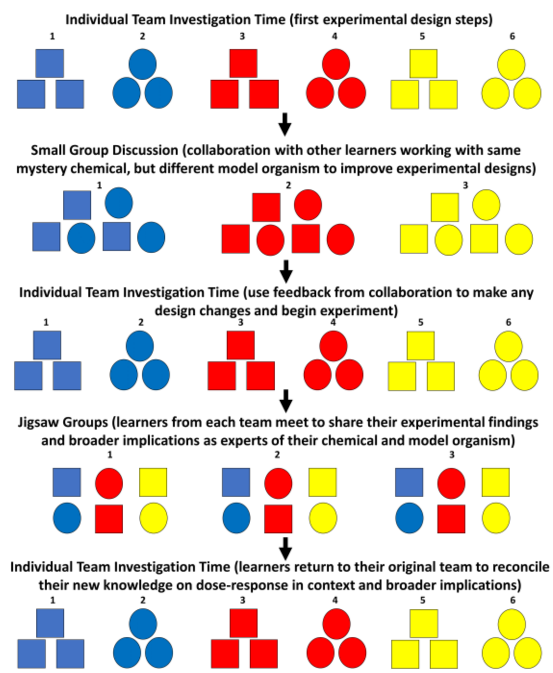

Figure 4: An overview of our jigsaw expert group strategy. Each shape represents a learner based on their chosen chemical and model organism. Each number represents an independent jigsaw discussion group. Square = *Daphnia*, Circle = *C. elegans*. Blue = Chemical A, Red = Chemical B, Yellow = Chemical C.

We developed a rubric to assess our learners' understanding of the content and practice goals. We asked students to complete an individual written Culminating Assessment Task (CAT) and a group community poster presentation to demonstrate their understanding (Figure 5), which we assessed using the rubric.

3.5 Synthesis (20 minutes)

Our final activity was a synthesis presentation. We summarized the dose-response concepts from the activity, identified the mystery toxicants that the learners had been working with, and described how concepts and skills from this activity might be used by learners in the future. The two main goals of the synthesis portion of the activity were to (i) summarize our core content to our learners to clarify any remaining misconceptions on dose-response outcomes and (ii) provide our learners with recognition for the authentic STEM practices that they had engaged with. We also wanted to leave our learners with ideas about applying the content and practice principles they learned in our activity to other aspects of their studies at UCSC. At the end of this presentation, we had a final community-building effort by answering their questions on our research, graduate school, and the UCSC community.

4. Workshop Reflection

4.1 Overview

Overall, we had an excellent experience leading this activity and believe that the learners gained both a peer community and experience with authentic STEM practices. We found that this toxicology role-playing scenario was a great context for learners to practice designing experiments in, and they challenged their previously held toxicology misconceptions.

The WEST 2019 program began with a welcome event where we were able to meet our learners and establish a supportive community. Since we knew that this event would be one of the first times our learners were on campus, we began introductions

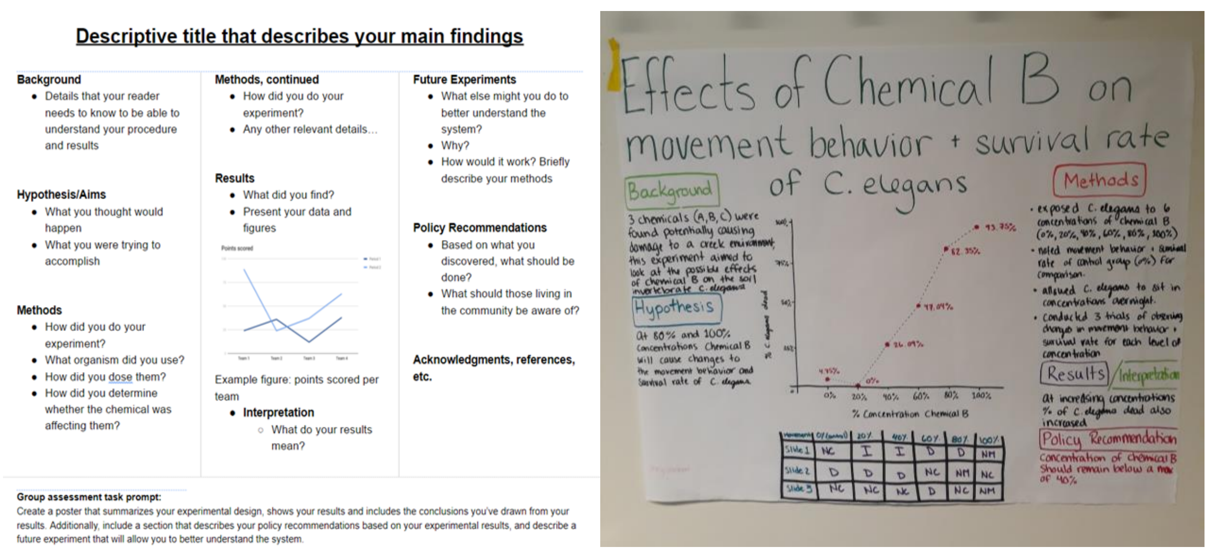

Figure 5: Community Poster Session Examples. On the left is an example poster given to learners illustrating the main components necessary for a scientific poster presentation (Background, Hypothesis/Aims, Methods, Results/Interpretations, and Future Experiments). In our activity, we also asked learners to provide policy recommendations. On the right is an example poster with the experimental findings created by one of our learner teams.

with the ice breaker prompt: “What am I excited about transferring to UCSC, and what am I nervous about?” The students seemed to respond well to this discussion and came away realizing that they had a lot in common with one another. Many stated that they were excited to live away from home, take classes in their major, enjoy the nature surrounding Santa Cruz, be closer to graduating with a degree, and explore academic research opportunities. Many students indicated that they were nervous about living away from home for the first time, switching to the fast-paced quarter system, finding a new social support system on campus, and navigating jobs while having class and research responsibilities. We emphasized that the lessons learned, and the critical thinking skills developed in our Toxicology WEST activity would apply to the learners’ majors, future research experiences, and everyday life. We also emphasized that our learners should use this experience to build a support network with their peers, as a support network is vital for academic success and navigating the transition from community college to a four-year university.

The following day, we began our activity with an introductory film depicting the environmental toxicologist role-playing scenario that we would be working with in our activity. The learners seemed very engaged with our film and clapped and cheered afterward. From their reactions and comments, we believe our initial film was a great way to break the ice and get our learners comfortable with the context of our workshop. In addition to the video, we discussed ground rules to ensure that everyone's opinions would be respected throughout the workshop. We also discussed the concept of growth mindset and emphasized that intelligence is malleable.

For the poster presentation portion of our activity (Figure 5), we had graduate students come to listen to each groups’ presentation and to ask questions about how the learners’ findings could inform policy recommendations for the community. The learners seemed to find this aspect of the workshop exciting based on their enthusiasm to report their findings and policy recommendations during their presentations. Based on the learners’ reactions, they seemed surprised at how well we were able to establish an authentic conference-like experience for the workshop. At the presentation, the learners were able to recommend acceptable low and high concentration level boundaries to minimize environmental harm, identify the chemicals that had beneficial environmental outcomes at particular dose ranges, and brainstorm ways to engage with local government and community members.

Our experience facilitating this workshop and the overall feedback from the learners suggested that our workshop successfully clarified content misconceptions with dose-response outcomes, promoted authentic STEM practices, and built a supportive community for newly transferred students.

4.2 Content goal reflection and assessment

Despite observing examples of non-linear dose-response outcomes during the Raising Questions portion of our activity, some learners still formulated hypotheses based on the simplistic assumption that their chemical would always produce a linear dose-response. At this stage of the activity, learners did not consider that their response outcomes may differ depending on the model organism used, the analysis metric (i.e., mortality or behavior), or other contextual factors (i.e., age or sex). Evidence of this oversimplification of dose-response outcomes were expected and further emphasized the importance of our content learning outcomes.

Since we expected that students would hold these common misconceptions, we used our first pre-designed jigsaw group discussion (Figure 4) to prompt students to discuss the questions they were going to investigate with one another. In later jigsaws, we facilitated learners to discuss how different experiments produced different dose-response outcomes.

During the Investigation portion of our activity, many learners explored pathways that we did not anticipate but were welcomed. Some groups investigated variation in dose-response with age, measured how the chemicals influenced organism behavior (i.e., movement or activity level), and evaluated whether an acute vs. chronic exposure regime influenced the outcome. We had groups achieve hormesis dose-response curves that we ourselves had struggled to generate when designing the activity. For the substance that produced the hormetic dose-response (Chemical A), learners identified the range where the substance had beneficial effects on activity level or survival rate, recognized that higher doses had detrimental effects, and recommended the following policies at the community presentation:

- "Monitor in excess dosage"
- "Stop the release of this chemical [A] in the environment"
- "Don't consume the water or anything else from this water source"
- "Talk to the local government (city council, mayor, parks & rec)"

For the substance that produced the nutritional dose-response (Chemical B), learners identified a range of doses that were beneficial to their model organisms. Some examples of their conclusions and recommendations include:

- "Concentration [Chemical B] remain lower than 40%" to prevent environmental harm
- "*C. elegans* perform the best in 0-20% concentrations"
- "Based on our discoveries I believe the community should be aware of Chemical B in the stream...the source of the chemical should be identified to see if it can be restricted from the environment."

For the traditional dose-response curve (Chemical C), our learners successfully concluded that this chemical would produce more harmful effects as exposure increased in their organisms:

- "The data supports our hypothesis that the larger concentration of Chemical C negatively affects the survival rate of *C. elegans* in their environment."

The learners also successfully recognized that their chosen model organism experienced different outcomes depending on the chemical used:

- "Not all unknowns [Chemicals] produced the same results and trends as the chemical my group had used."
- "Some chemicals are not as toxic in a certain range of 20-60% concentration while others can have a harmful effect."

Learners identified cases where *C. elegans* seemed hardier than *Daphnia* for a particular chemical and vise-versa:

- "I would like to see more about different life stages for these organisms since it had different effects. For example the *C. elegans* were more likely to die if they were bigger rather than smaller and the *Daphnia* it was the opposite, the larger ones survived whereas the smaller ones didn't."
- "*C. elegans* did seem to hold up better than *Daphnia*, not dying off as quickly, and at higher concentrations."

When comparing the organismal responses to the three chemicals, learners said:

- "Chemical C seemed to be slightly more toxic"
- "A + B had similar death tolls at the same concentration (60% +) while C seemed to be more toxic (40% +)."

Finally, learners made suggestions for future experiments to better understand the complexity of how the unknown chemicals may be affecting the environment. The learners suggested:

- "In future experiments, it would be beneficial to obtain more quantitative data and have more controlled variables such as age in *C. elegans*."
- "Same population size, better way to accurately count *C. elegans*, more precise measurements, and more time intervals"
- "Longer [chemical] exposure with more observations"
- "Smaller increments of [Chemical] concentrations to find lethal concentration between 0%-40%"
- "Observe the difference between *Daphnia* living in an environment polluted with Chemical C versus ingesting food polluted with Chemical C."
- "Focus testing aquatic plants and animals" and "Different organisms with varying sensitivity"

We developed a content rubric (Figure 6) to evaluate how well our learners understood our content goals. Our levels of understanding were (i) missing evidence of understanding, (ii) evidence of misunderstanding or incomplete understanding, and (iii) evidence for proficient understanding. We scored students using this rubric after they completed both an individual response (see supplemental page 8) and a group poster presentation. Both forms of assessment were necessary to determine whether our learners reached our content goals.

Overall, we succeeded in guiding most students to a sufficient level of understanding of our content goals. Evaluation of the individual written responses and the group posters allowed us to give most of the students scores of proficient understanding in all three dimensions. We did not receive adequate evidence of understanding in our individual assessment prompts from several students, indicating that our assessment questions could have been more exhaustive. During evaluation, we noticed that the language of our assessment task prompts may have been too vague, leading some students to misunderstand what we expected of them. These students did not necessarily provide incorrect responses; they just failed to address one or more of the three dimensions of our content goal. Evidence from observing each team discussion and reviewing each poster presentation supported this notion as learners verbally articulated their understanding of the core content. If we had to teach this activity again, we would likely adjust the wording of our assessment task prompts to be more specific, to guide the students to draw comparisons between the different organisms and chemicals (see supplemental page 8 for suggested wording). Our shortcoming was not in our ability to guide learners to the content goal but in prompting them to put what they had learned into writing for a fair evaluation.

In the synthesis presentation and culminating discussion, we summarized our content goal and revealed the identity of the three mystery chemicals. We provided real-world examples of the use of *C. elegans* and *Daphnia* in important toxicological assays for environmental and human health. We discussed the three main dose-response relationships examined and important factors influencing the relationship, such as age, sex, exposure time, and exposure route. By the end of the synthesis, we felt that each learner understood our main content goals and achieved them through personal inquiry rather than through a traditional lecture format.

Content rubric: Dose-Response in Context

Dimensions:	**M** **Missing Evidence**	**0** **Evidence that learner has misunderstanding or incomplete understanding**	**1** **Evidence that learner has sufficient understanding**	**Score**
Dosing with a toxin has important thresholds and toxicity doesn't always increase linearly with dosage.	- Learner does not plot the experimental data. - Learner does not offer an interpretation.	- Incorrect interpretation of the dose-response curve, such as attributing results to experimental design flaws or failures - "Our curve doesn't represent the curve we saw during raising questions, so something we did failed." - The curve was plotted incorrectly, does not reflect the data recorded (ie incorrect relationship, incorrect axes, scales, etc.)	- Graphs are correct and interpreted to demonstrate the relationship between dose and toxic effects for a given chemical. - Learner identifies important thresholds if present, such as a beneficial response dose range vs. when a toxin dose starts having a negative response outcome.	
Doses in different systems (taxa & compound) could produce differently shaped dose- response curves	- Does not consider different systems may have different responses with the same chemical and dose	- Generalizes one dose-response paradigm to all systems or other toxins with the same system - "My experiment results showed that low and high doses of our chemical produced negative effects in my organism. I am sure this relationship would be the same in another organism."	- Recognizes that their dose-response results are dependent on the biological system they investigated and may not always have the same response in other biological systems. - "My experiment results showed that a low dose of our chemical produced a negative effect, and a high dose also produced a negative effect. I wonder if I conducted another experiment with this same dose in another organism if it would work the same?"	
Factors outside level of exposure influence dose-response	- Learners do not discuss whether other factors would play a role in altering response outcomes	- Learners don't recognize there are other factors that may alter dose-response outcomes. - "I gave X dose and Y effect happened, so this same effect will always happen at this dose (regardless of other variables)"	- Learners recognize other variables that influences dose-response are important to consider (sexes, ages, body sizes, habitat environment, previous exposure level, co-exposures) - "If we gave this dose over a different time period (or life stage, etc.) it might have a different response"	
Total score				

Figure 6: Content Rubric. This rubric was created for the facilitators to assess learners' understanding of our core content goals at the end of the activity. Each learner was assessed on their individual response to the Culminating Assessment Task prompt, their poster and presentation, and our notes from facilitation throughout the activity. Examples of demonstrated evidence are included for each dimension.

4.3 STEM practice goal reflection and assessment

The learners successfully reached our practice goals, aided by the role-playing scenario that allowed the learners to view the scientific process in the context of a real-world problem. All students made testable hypotheses based on our Raising Questions activity, designed their own experiments using one of the unknown chemicals and model organisms, interpreted their results, and communicated their findings during the group poster session. We designed check-ins throughout the activity for learners to collaborate on how to (i) troubleshoot experimental design and (ii) relate their findings to public and environmental health. By asking them to collaborate, they were forced to work through these issues together in an inquiry format without the facilitators providing answers.

It was difficult to balance giving learners ownership of their experimental design decisions while also ensuring they employed scientifically appropriate approaches in the amount of time we had available for the inquiry activity. For instance, some students were interested in analyzing how the toxicants influenced behavioral characteristics of *Daphnia* and *C. elegans* (i.e., activity levels, abnormal movement), but struggled to generate unbiased metrics to quantify these behaviors.

Although the facilitators discussed important experimental design features, we do not believe the students would have defined proper dependent variables or included appropriate sample sizes without us providing a detailed lecture and deciding these aspects for them.

Scientific accuracy was a limitation of our activity because we had limited time and wanted to promote learners' ownership of their experimental design decisions. However, by promoting discussion of potential quantification methods rather than providing the learners with the answer, learners were forced to think critically about the important aspects of experimental design. Additionally, we had a breakthrough with all the groups about the notion of how to quantify organism behavior in non-biased ways. Although the scientific accuracy of the experiments the students designed could have been better, we believe that the learners strengthened their critical thinking skills.

We developed a practice rubric (Figure 7) to assess our learners' understanding of the three learning dimensions of our practice goal. We used a rubric to score individuals based on their content prompts and group posters. We found evidence that students created appropriate hypotheses, designed and performed experiments, recognized important limitations, accepted/rejected their hypothesis, and considered future experiments and broader implications.

In the Synthesis portion of our activity, we emphasized the authentic scientific practices that the learners performed throughout, such as making observations of real-life phenomena, forming hypotheses based on these observations and prior knowledge, developing an experiment using proper controls, and collecting and analyzing data. Furthermore, we stressed the importance of collaborating with other scientists and communicating findings to relevant parties, which learners practiced during the individual team and jigsaw discussions and poster presentation. After examining our learners' practice rubric scores and delivering the synthesis presentation, we concluded that our learners came away with an appreciation of the value of our STEM practice goals and additional contexts in which they may continue developing these skills.

STEM practice rubric: Designing and carrying out investigations

Dimensions:	M Missing Evidence	0 Evidence that learner has misunderstanding or incomplete understanding	1 Evidence that learner has sufficient understanding	Score
Develop a testable hypothesis and appropriate control groups to investigate a scientific question	- Learner did not form a hypothesis - Learner did not include appropriate controls	- Hypotheses were arbitrary and not based on observations - Hypothesis could not be tested (ie did not choose measurable variables) - Appropriate controls and variables were not properly identified/rationalized	- Hypotheses were based on observations made during Raising Questions component - Hypotheses were testable (appropriate explanatory variable(s) that could be manipulated; response variable was measurable) - Design included appropriate control groups and rationale for each	
Perform experimental procedures with available tools and understand the limitations	- Learner did not propose an experimental procedure - Learner is unaware of the available resources and limitations	- Chosen protocol did not provide a way to evaluate hypothesis - Proposed experiment required methods or tools not available - Did not identify potential limitations of experimental design	- Experiment proposed can be done within the time frame and with available resources - Recognizes and reports limitations present in experimental design and interpretations (ie dose regime, timescale, lab setting, etc.)	
Interpret results and plan follow-up procedures to confirm results	- Learner did not interpret results - Learner did not propose follow-up procedures	-Learner is hesitant to believe their data and reject/revise their hypothesis (because of prior knowledge, or fear that experiment was flawed) - Learner incorrectly interprets the experimental data -Learner revises their hypothesis but does not provide rationale	- Learner interpreted data in the context of the variables that were manipulated - Learner accepted or rejected hypothesis with appropriate rationale - Learner used their experimental results to propose future experiments - Learner revises hypothesis (if needed) and describes how it could be tested.	
Total score				

Figure 7: STEM Practice rubric. This rubric was created for the facilitators to assess learners' understanding of our core STEM practice goals at the end of the activity. Each learner was assessed on their individual response to the Culminating Assessment Task prompt, their poster and presentation, and our notes from facilitation throughout the activity. Examples of demonstrated evidence are included for each dimension.

5. Strategies to implement and adapt our workshop

5.1 Overview

We have described our activity in detail, including key goals for learners and assessment methods. Here we outline some strategies for those who wish to implement or adapt this lesson for different learning contexts. The content focus of our activity was toxicology, the different types of dose-response relationships, and the factors that influence these relationships. This activity would be appropriate for any context in which students may be learning about toxicology. Our STEM practice goal was for students to design and carry out experiments. Effectively designing, conducting, and interpreting an experiment is critical to all STEM-related fields. Thus, this activity would be an excellent introduction to these practices in any context.

5.2 Implementing and facilitating

Here, we describe strategies for implementing this activity, and specific facilitation notes that may be helpful. These strategies are derived from research-based teaching techniques and the experience of the authors in conducting this activity.

1. Schedule multiple points for facilitators to check in with learners to ensure that progress towards content goals is being made. Multiple check-ins allow for interventions in later portions of the activity if you realize that learners are not progressing towards the content goals (or if it is unclear whether they are meeting content goals).
2. If you have more than one activity leader, assign groups of students to each leader. This will allow leaders to work more closely with the groups they have been assigned and prevent doubling up on efforts to support each group.
3. It may be helpful to discuss or have a list of specific points for students to consider during small group discussions to allow for more focused and effective facilitation. During our activity, we gave each group a sheet with general information about their model organism (either *Daphnia* or *C. elegans*) to support their experimental design (see Supplemental Document). After reflection, we thought that including an info sheet or mini lecture on experimental design may have helped guide our facilitation and supported students who were not yet familiar with the process. This would allow facilitators to ensure that the groups have a scientific rationale behind their experimental decisions. Points could include:
    a. Sample sizes (with biological and technical replicates)
    b. Defining, measuring, and interpreting a dependent variable (i.e., death, activity level, growth, etc.)
    c. Confounding variables such as age/life stage, sex, route of exposure, acute vs. long-term exposure, etc.
    d. Analysis and interpretation of results (i.e., will decreased activity be interpreted as a sign of toxicity? How will you compare different groups?)
4. Some students may be hesitant to reject their original hypothesis based on contradictory data, even if the data they collected is correct and successfully accomplishes our goal of challenging content misconceptions. Students may feel, due to their inexperience or other societal factors, that their data was collected sub-optimally or that their experiment did not work. It is important to check in with all groups to ensure that they have a solid experimental protocol prepared before data collection to minimize this risk. Additionally, facilitation time can be used to question students about why they might see unexpected results.
    a. Keep in mind that the goal is not for the students to design the experiment that you

think is best. Instead, the goal is for them to design an experiment with a testable hypothesis and a rationale for each design choice/component. The synthesis portion can be used to emphasize components of optimal experiments if the activity would be done a second time. Facilitation time should be used to ask students to think deeply about the choices they are making but not to steer them in one direction or another experimentally.

5. Our main goal for this activity was for learners to design an experiment. However, emphasis can be placed on other portions of the activity (such as forming hypotheses, communicating scientific findings with the public, etc.) depending on your learning goals.

5.3 Adapting to other educational contexts

Here we discuss how our activity might be adapted to be taught at the local community, high school, and college-level:

Role-playing scenario: The role-playing scenario can easily be adapted to fit your local community. We selected an aquatic exposure scenario because our community has a large river that feeds into the ocean. However, you may include a different scenario, such as pollutants being released from a factory or chemicals found in well water or a reservoir.

Model organisms: Different model organisms can be used depending on supplies available and the time frame of the activity. Plants could be used for a longer (1–2 week) activity. The choice of model organisms can also relate to role-playing (for instance, if there is an organism found in your local community). However, it is ideal if there is more than one model organism so students can select the one they are most interested in and compare the organism dose-response outcomes.

Chemicals/toxicants used: Although learners will not know the identity of their chemicals until the end of the activity, you can choose chemicals that may be more relevant to your learners. For instance, specific chemicals that are actually present in a local waterway or neurotoxicant chemicals for a neuro-focused group could be chosen. This will allow learners to connect more with the material and think about how their activity outcome relates to their studies or community.

Age groups: This activity was originally run with community college-aged transfer students. However, it could be adapted to fit learners of different age groups. With younger students, more facilitation and preliminary information could be provided to promote learning and success. This information could include key considerations for designing experiments (such as including controls, how data is collected/analyzed/graphed, interpreting results, etc.), how to use scientific tools such as pipettes and microscopes, and/or how to communicate scientific findings to the public.

Time Frame: The activity could be shortened, but most likely needs at least one full day for raising questions, experimental design, conducting experiments, analyzing/interpreting data, and presenting results. As noted earlier, we put the emphasis on designing effective experiments; however, emphasis can be put on other outcomes as well (forming hypotheses, use of scientific tools, scientific communication, etc.). This may allow for the activity to be shortened, but be mindful of taking away too much ownership from the students (such as just providing them with an experimental protocol rather than having them work on one themselves). If the activity will be longer than two full days, you might consider having learners design a revised experiment based on the outcomes of the experiment they already conducted. This will allow them to take into consideration what they learned from the first experiment to learn and grow and become more effective researchers. It also allows learners to incorporate other factors of interest (such as how chemicals may affect organisms differently depending on sex, age/life stage, route of exposure, timeframe of exposure, etc.). Additionally, you may include supplemental jigsaw rounds of collaboration throughout the process to give learners more time to discuss their experimental design and outcomes with others. This is an excellent way to get them to consider their experimental design more carefully and provide an opportunity for targeted feedback.

We used an introductory video and live plants for the Raising Questions portion of the experiment. To save time, the video could instead be written as an introductory speech. A graphic could be designed to represent the plants if live ones are not available or are able to be grown ahead of time. The live plants did contribute to making the work feel more authentic but may also be a bit more difficult for learners to interpret.

High school or college-level class: The activity can be adapted for a variety of classroom settings and structures, including a high school or college-level introductory lab. For a class that meets several times a week (such as high school biology classes), we suggest a structure similar to the outline below:

- Day one: establish the role-playing background and the Raising Questions portion of the activity. Assign students to formulate official questions that can become testable experimental hypotheses, which may be done for homework.
- Day two: Conduct the first jigsaw group discussion based on the types of questions students focused on, and establish investigation pathway groups. Groups begin their experimental plans in class with some facilitator feedback and then continue working on them as a group for homework.
- Day three: Implement jigsaw groups for groups to revise and finalize experimental plans. Groups may begin their experiments.
- Day four: Complete experiment investigation time, and begin discussing interpretations of results.
- Day five: Implement the final jigsaw group discussions on results and interpretations. Students then complete individual CAT, and plan and give presentations. Finally, the facilitator will present the synthesis.

For college-level classes that may not meet as frequently, more of the in-between homework assignments can be modified as group work, and the majority of class time can be spent with the lab work and final presentation. For instance, online group class discussion boards could be used as homework assignments to spark intergroup jigsaw discussion on experimental design and findings. Even final poster presentations can be shared via online platforms. Students can be required to comment and discuss before submitting a final lab report detailing their results and conclusions of how their findings on dose-response relate to other contexts investigated by other groups (chemicals and model organisms).

6. Conclusion

Overall, we believe our Toxicology WEST workshop achieved its goals of (i) clarifying misconceptions about the core Toxicology concept of dose-response and (ii) providing learners experience with authentic STEM practices and designing experiments. We prompted our learners to think more broadly about the significance of toxicological research, such as how their experiments could inform public policy recommendations had this role-playing scenario been real and how toxicology concepts can apply to their everyday lives. Importantly, we also made strides to build a supportive community for each learner's initial first-year transition to the University of California, Santa Cruz. We believe that our reflections and ideas for further adaptation and implementation of our activity will be useful to support other facilitators in designing similar inquiry activities in other academic environments.

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Appendix A

We included a supplemental document at https://escholarship.org/uc/item/28r6g3kf#supplemental with additional information, which may be helpful when leading this activity. It includes information on *Daphnia* and *C. elegans*, scripts and prompts for assessment, and example handouts.