Environmental Injustice: When the Grass is Greener on the Other Side

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Abstract

Environmental pollution is a global threat that is especially prevalent in heavily industrialized and urbanized areas. Pollution can be found in many forms, such as natural and synthetic pollutants from natural and anthropogenic processes. These impact individual, population, and ecosystem health. Additionally, urbanization and industrialization create landscape heterogeneity, which alters socioecological dynamics within environments—often through intentional and systematic processes. For humans, the subjection to and impacts of both pollution and land distribution have disproportionate effects on members of low-income and marginalized communities. Environmental injustice occurs when systemic biases like racism and classism fuel inequalities and inequities among individuals and their communities. The current activity combines predictive graphing and group discussions to help reinforce basic principles of environmental pollution and the sociocultural underpinnings that increase risks of exposure and impacts, using real-life examples of environmental injustice such as the Flint Water Crisis and Cancer Alley Louisiana. Utilizing the "Mapping for Environmental Justice" website, students will predict the cumulative environmental injustice burden across the State of Virginia, resulting from imbalanced land distribution, and compare public health data to examine those to be considered "at risk" based on various demographic characteristics. Students will then think critically and discuss the decision-making behind societal pollution and land management, which influence the presence and intensity of environmental injustices.

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Learning Goals

Students will:

◊ understand that environmental and human health are interconnected, especially when considering pollution.

◊ explore the intersection of science and society through the concept of environmental injustice.

◊ become aware of systemic biases that create structural inequalities for some communities.

◊ recognize and critically analyze cases of environmental injustice outside of the classroom.

◊ value environmental health and justice in their decision-making.

◊ hone science process skills.

◊ From the Science Process Skills Learning Framework:

- » Interpret, evaluate, and draw conclusions from data
- » Consider interdisciplinary solutions to real-world problems
- » Demonstrate the ability to critically analyze ethical issues in the conduct of science
- » Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practice

Learning Objectives

Students will be able to:

◊ explain the types, sources, and impacts of environmental pollution.

◊ define environmental injustice.

◊ critique systemic structural inequalities that lead to environmental injustice.

◊ evaluate and predict cases of environmental injustice.

◊ reflect on ways to improve environmental health and justice.

◊ consider interdisciplinary solutions to real-world problems.

◊ From the Science Process Skills Framework: Students will be able to describe examples of real-world problems that are too complex to be solved by applying biological approaches alone.

Learning Goals

◊ From the Ecology Learning Framework:
  - » What impacts do humans have on ecosystems?
  - » How do humans depend on ecosystems for their health and well-being?

◊ From the Toxicology's Learning Framework:
  - » Why are certain populations at greater risk from exposure to toxicants?
  - » How are organisms living in the natural environment affected by natural and anthropogenic toxicants?
  - » How have historical incidents impacted the development of regulatory laws concerning toxicology?
  - » How do toxicants affect an organism's development and reproduction?
  - » How do toxicants move through the environment to affect ecosystems?

INTRODUCTION

Environmental health and human health are undeniably interconnected. Pollution, the unwanted introduction or excess concentration of a substance or form of energy added to the environment at rates faster than can be dispersed or stored, may prove to be one of the most influential drivers of change in environmental health. Pollution exposure is responsible for approximately 9 million deaths per year and a plethora of human health problems (1). Pollution results from both natural processes like volcanic eruptions, as well as anthropogenic (human-induced) processes like burning fossil fuels, agricultural fertilizer runoff, and wastewater runoff. An example of natural air pollution results from a volcanic eruption, which releases natural pollutants such as sulfur dioxide that can lead to acid rain lower in the atmosphere and can reflect sunlight when higher in the atmosphere which cools the planet (2). The production of synthetic, single-use plastics, that enter and persist in the environment are one of the pressing human-mediated pollutants impacting the planet (3). In addition to environmental impact, anthropogenic pollutants affect organisms and move through ecological food webs through the processes of bioaccumulation and biomagnification. Bioaccumulation is the accumulation of a pollutant or contaminant in an organism over time, while biomagnification is the increasing concentration of contaminants as they are passed along through trophic interactions.

Air pollution can have widespread effects but is particularly concentrated around highly industrialized and urbanized settings with well-documented individual, societal, and environmental health impacts (4, 5). Globally, poor air quality reduces life expectancy by ~20 months, leading poor air quality to be the fifth highest cause of death in the world (6, 7). For instance, human exposure to ozone (O_3) impacts the respiratory, cardiovascular, and central nervous systems. Ozone exposure can be especially dangerous for certain populations (children, people 65 years and older, people who work outside, and people with lung and cardiovascular diseases) and is correlated with higher rates of pregnancy complications, asthma, and cardiovascular and respiratory-related mortality (8, 9). Unfortunately, exposure to pollutants and the subsequent negative health impacts are not spread evenly across populations or the planet and often are concentrated in dense pockets adjacent to urban areas, navigation waterways, ports, and industrial areas (10).

Urbanized areas hardly reflect their historic wild landscape, as humans have reduced the amount of natural vegetation, forests, streams, and rivers and replaced them with human-made concrete structures (gray spaces) including roads, parking lots, concrete-lined stream channels, and buildings (11). Urbanized areas with excess concrete structures pose significant problems for human health, as concrete structures absorb and retain more heat relative to areas of natural vegetation, leading to an 'urban heat island' effect in addition to concentrating pollution effects (12–14). In the United States, a strong relationship between socioeconomic status and race/ethnicity, and residential location leads to socioeconomic and racial disparities in health driven in part by differential exposure to environmental pollution. While urbanization has exposed people from all populations to increased pollution and environmental hazards, several policies have made this exposure unequal across demographic trends.

Urban development, both current and historical, has involved planning and zoning practices that are exclusionary and unsustainable (15). Affluent white communities have traditionally been more equipped to mount opposition, and more likely to be heard, to the placement of hazardous facilities and were enticed by suburbanization, which together, decentralized cities leaving behind disadvantaged communities, predominantly low-income and people of color, who were then subjected to the placement of these facilities and the accompanying pollution burden (16–18). Further, the practice of "redlining" withheld loan services to residents in areas deemed hazardous to investment and functionally segregated communities based on ethnicity, race, and socioeconomic status. The historical legacy of redlining resulted in present-day landscape heterogeneity that maintains patterns of social and environmental amenities and disamenities, with direct impacts on health (15, 19, 20). For instance, legacies of historic redlining practices of the 1940s in Richmond, Virginia were strongly correlated with contemporary urban heat island effects, as historically redlined neighborhoods are on average three degrees Celsius warmer compared to non-redlined neighborhoods, due to lower tree canopy cover and greater impervious surface area (13, 14). These discriminatory systemic biases of racism and classism in urban development produce environmental inequalities by restricting access to green spaces, which are urban areas that have been explicitly designed with grass, trees, and vegetation for recreation and aesthetic value (21). Simultaneously, these residential areas may also be near brownfields—formerly developed urban areas that have been abandoned and not redeveloped due to environmental contamination (22). Brownfields are especially problematic as pollution or potential for pollution can pose severe health risks and obstacles to development (23). The combined effects of which have contributed to health disparities, loss of biodiversity, and loss of ecosystem services felt by underserved, non-white, and low socioeconomic class communities, is referred to as environmental injustice (15, 17, 19, 20).

Previous studies have shown the extent of the inequitable effects of pollution on affected communities, showing racial-ethnic and socioeconomic disparities (17, 24–26). Some prominent examples of environmental injustice across the United States include Flint, Michigan (27), Cancer Alley, Louisiana (28), Salt Chuck Mine, Alaska (29) and Uniontown, Alabama (30). For instance, in Flint, Michigan ~100,000 residents, mostly low-income people of color, were exposed to high levels of lead when city officials shifted the city water supply from Detroit city water supply to water supplies from the Flint River. Because city officials did not apply corrosion inhibitors to the water supply, lead from aging infrastructure polluted the water supply. While fifteen city and state officials were charged with numerous felony and misdemeanor crimes, most of the charges have been dropped or dismissed, although citizens of the water crisis were awarded $641 million (31).

As another example, Cancer Alley is an 85-mile stretch of the Mississippi River stretching between New Orleans and Baton Rouge, Louisiana. Cancer Alley processes ~25% of the US's petrochemicals and is home to over 200 chemical plants. Cancer Alley is termed the 'frontline example of environmental racism' and is home to adverse birth outcomes (including low birthweight and preterm birth that is triple the national average) and cancer rates upwards of seven times the national average, all of which disproportionally impacting both low-income families and Black/African American citizens who make up over 40% of the population in the region (32–34). Despite the clear evidence of health disparities in Cancer Alley, adverse health outcomes including cancer risks have continued to climb in the region over the last several decades (34).

As another example, in Coastal Alaska, the Salt Chuck Mine operated as a gold, silver, and palladium mine from 1905 to 1941, processing over 326,000 tons of ore during that time (29, 35, 36). Waste tailings were distributed on state-owned land in the intertidal zone, over a 10-hectare region that served as sustenance crabbing, shrimping, and fishing area of members of the Organized Village of Kasaan, a federally recognized indigenous tribe. Members of the community were unaware of the decades of exposure to high levels of polychlorinated biphenyls (PCBs), arsenic, copper, and vanadium through bivalves, crabs, shrimp, and fish, as the historic mine operated and closed during a time prior to federal permitting, oversight, and remediation plans. The United States Bureau of Land Management began investigating the pollution effects around the mine in 1995 and the site was designated as a priority Superfund site in 2010 by the United States Environmental Protection Agency (37, 38). This action dedicated federal funds for the cleanup of the site nearly 70 years following the end of mining at the site and is still ongoing.

Finally, Uniontown, Alabama provides an interesting case study on how federal and state policies and regulations surrounding disposal of hazardous waste can have lasting impacts on communities geographically separated from waste generation (30, 39). In Uniontown, Alabama, 4 million cubic yards of coal ash cleanup from the Tennessee Valley Authority in Kingston, Tennessee were transported and dumped within this small, predominantly Black/African American town in South Central Alabama in 2010. Regulatory loopholes allowed the Tennessee Valley Authority to transport the toxic coal ash cleanup from Tennessee to the Alabama landfill where it was then considered non-toxic industrial waste. While dozens of examples exist and impact various marginalized communities (40, 41), the Flint Water Crisis, Cancer Alley, and Uniontown, Alabama are just three that have received a lot of notoriety over the last two decades, while showcasing the systemic forces that can combat clean-up and improving the health outcomes for all citizens.

While goals of sustainable urban development include increasing green spaces and remediating brownfields to restore ecosystem services within cities, these efforts may paradoxically stimulate gentrification as well as green gentrification. Gentrification is the influx of wealthier, privileged, and typically white individuals into poor, working-class neighborhoods predominantly populated by people of color that leads to displacement or increased living costs for existing residents. Green gentrification is similar, it arises as a result of environmental sustainability improvements like the addition of greenspaces at the expense of affordable housing (42, 43). Therefore, to be truly sustainable, social equity and environmental justice must be integral in efforts to improve ecological integrity and economic development within urban settings (38, 42). Brownfield redevelopment has been aided by brownfield legislation that explicitly calls for greater community involvement. By linking site cleanup and redevelopment plans with educational opportunities for youth and promoting employment opportunities for impacted communities, state and local governments can strengthen community involvement, engagement, and empowerment within the redevelopment process (37). An often-cited brownfield development success occurred in Belcourt, North Dakota within the Turtle Mountain Band of Chippewa community. Redevelopment of an initial brownfield site was aided by EPA investment into the tribal community college to develop training programs in brownfield redevelopment, which provided career opportunities across the region on various brownfield projects and helped revitalize the tourism industry. Through tourism, the tribe shares cultural history and values with the general public, and tribal leaders can maintain control of the types of redevelopment projects across the region (37). Sustainable urban and brownfield development requires policy decisions that focus on just development, community empowerment, and regulations on polluting industrial activities.

To help students explore the intersectional and complex interactions occurring within environmental policy, Mapping for Environmental Justice (MEJ) has developed an interactive mapping activity that allows users to explore cumulative environmental justice impacts. This is accomplished in association with demographic measures of human communities, public health data, and contributions of various pollution burdens from ozone, lead, traffic, to hazardous waste facilities. MEJ developed the interactive maps as a team of policy, data science, and community engagement experts to empower communities to end environmental injustices. Our lesson draws upon these interactive maps and guides students to explore these maps while also reflecting on what environmental justice/ injustice means for them and their communities. This lesson enables educators to integrate socioculturally-relevant teaching into their classrooms, which allows students to consider how systemic biases affect both environmental health and justice. This practice, known as ideological awareness, acknowledges ideological biases and emphasizes how they influence the generation and application of knowledge (44–46). This activity invites students to use scientific practices, like making observations and interpreting data based on prior research yet transcends traditional approaches to biology education by challenging students to reflect upon, question, and critique existing structural inequality and inequity in the sociocultural landscape (46, 47). In providing awareness of environmental injustices, students can begin to recognize systemic issues like the distribution of land and pollution burden, while positioning themselves as social and environmental activists who employ scientific ideas and processes to better address problems that affect society (48–50). It is critical that future citizens, scientists, and policymakers understand the complex ties between environmental and human health to promote a more sustainable and equitable future.

Intended Audience

This lesson was designed for use in lower-level, introductory biology major's courses at the university level, but is appropriate for students of any major and non-majors' level courses. Suggested courses for implementation include similar introductory courses at universities that deal with ecology, human health, global change, and urban ecology. We also invite the application of this lesson to advanced high school biology courses (*e.g.,* AP, IB, etc.).

Required Learning Time

Based on our experience, the required learning time to complete this activity is approximately 60 minutes. Time may vary depending on the adaptation of slides and assessment, the option of in-class literature review and video resources, online activity setup, as well as inclusion of open-ended questions and opportunities for discussion. We acknowledge this activity has a lot of important information that could be covered during the lecture, in discussions, and in time for students to reflect on the personal impact of this activity. Some students may find this material to be emotionally challenging. For these reasons, this activity could also be split into multiple lessons.

Prerequisite Student Knowledge

Students should have some prior knowledge of ecological systems (*e.g.,* trophic interactions and levels), human influences on natural systems (*e.g.,* agriculture, burning fossil fuels), and human-induced environmental effects (*e.g.,* eutrophication, climate change) that lead to biodiversity loss and altered biogeochemical processes.

Prerequisite Teacher Knowledge

To implement this lesson, instructors should be familiar with ecological systems, the types, sources, and impacts of pollution on human and environmental health, and understand how suburbanization, redlining, and gentrification have caused disparities that lead to environmental injustice. Before any lesson that involves the inclusion of sensitive topics, such as systemic and structural inequalities, we recommend that instructors create a safe learning environment that encourages participation but is based on established norms and mutually respective and reflective conversations (51). Topics that integrate scientific and sociocultural considerations can engender meaningful outcomes for students and the classroom environment (45, 52). However, instructors may be hesitant to implement socioculturally relevant lessons for various reasons, such as having little experience with these topics or feelings of time and content constraints (53–55). Nonetheless, instructors should be prepared to engage in potentially difficult discussions that surround racism, classism, and human health when implementing the current or similar lessons. Instructors should be able to navigate these conversations to facilitate an enriched conceptual understanding of environmental issues without the expense of context. Instructors should seek resources to become familiar with discussing these topics and reflect upon their practices, curricular materials, and ideologies. To read more about teaching ideological awareness in biology classrooms, we recommend (45, 46, 49, 52, 55).

SCIENTIFIC TEACHING THEMES

Active Learning

This lesson promotes the use of active learning throughout the lesson and activity. This activity engages students by allowing them to make observations, and evaluate data via predictive mapping, followed by evidence-based interpretation and reflection. Students will use the knowledge gained in the opening lecture on pollution, environmental injustice, and the impact of environmental injustice on public health to make predictions of drivers and consequences of environmental injustice within two specific examples (Virginia or Colorado). By working within teams, students discuss their predictions with peers, can work together to generate and test those predictions with the interactive map and model, and can then interpret the model output. If done in small groups or teams, the instructor should have groups report their findings following the activity, using a think-pair-share model to provide some structure to facilitate discussion, reflection, and the sharing of ideas surrounding environmental injustices (51). If done as a solo exercise (in-person or asynchronously), the activity still provides an authentic learning experience that reinforces topics of environmental injustice and the instructor could ask open-ended reflection questions within the assessment to promote student reflection on these topics. In providing students with authentic ways to explore data from scientific research, instructors can support improved data literacy and understanding of the nature of science (56, 57), as well as increase self-efficacy and interest in STEM careers (58).

Assessment

The assessment within this lesson provides flexibility for instructors to adapt it to both formative or summative assessment formats. For example, instructors are encouraged to employ audience response systems, such as electronic voting or clicker questions, to actively engage students and formatively assess teaching and learning of material throughout the lesson (59). In addition to this, the questions can be incorporated into summative assessments, such as unit quizzes or exams, to determine students' knowledge gain and retention (60). Instructors may also choose to rely entirely on the student handout as a source of evaluation following the lesson and activity. The included assessment covers the types, sources, and impacts of environmental pollution, as well as the causes of and contributions to environmental injustice within urban landscapes. To support sociocultural dimensions that are often neglected within assessments and scientific learning outcomes, our assessment asks students to define environmental injustice within their own words, describe the foundation for environmental injustice, and to hit higher-level Bloom's taxonomy, we ask students to highlight some of the similarities and differences in well-known environmental injustice cases—Flint Water Crisis and Louisiana Cancer Alley and to synthesize lecture and activity material to discuss why low-income and minority communities are exposed to more pollution compared to other groups. To aid instructors in assessing responses, we provide criteria that should be covered within each question.

Inclusive Teaching

Ideological awareness as pedagogy is committed to diversity, equity, and inclusion initiatives by creating socioculturally relevant learning experiences within science education. Stemming from culturally relevant pedagogy, ideological awareness holds the potential of validating student identities and promoting an inclusive, equitable classroom (46, 50, 61). This lesson in particular examines biological and environmental issues of pollution through a social justice lens, exposing students to underlying systemic biases, diverse perspectives, and encouraging students to problem-solve solutions to mitigate and address those that lead to marginalization (47, 62). Instructors should employ various strategies that broaden student participation and ensure classroom equity throughout the lesson. For instance, the multiple hands, multiple voices approach is recommended to broaden participation of students and provide an equitable influx of novel ideas in the classroom discussion (51). This strategy allows students to feel included, engaged, and that they have contributed to the lesson.

LESSON PLAN

Components

Introductory Lecture

The lecture (Supporting File S1) provides the necessary background information for the students to understand and engage with the activity. The instructor should begin with the introductory lecture (Table 1), which introduces the various types, sources, and impacts of environmental pollution affecting both environmental and human health. Then, the topic of environmental injustice is presented regarding pollution burden, followed by causation (*e.g.,* suburbanization, redlining), a spotlight on those disproportionately impacted (*i.e.,* low-income, and marginalized communities), and specific examples around the United States (*e.g.,* Cancer Alley). The instructor should then introduce students to the activity, where they will use an interactive, online map to predict pollution burden based on resident population characteristics to determine those considered to be at risk. The lecture concludes by discussing improvements to environmental injustices by stressing the importance of urban development that integrates sustainability and environmental justice to tie in the goal of achieving equitable, resilient cities and promote group reflection.

Student Handout

Mapping for Environmental Justice Setup

To help students explore the intersectional and complex interactions occurring within environmental policy decision-making, Mapping for Environmental Justice (MEJ) developed a web-based interactive map that allows users to explore cumulative environmental injustice impacts in association with several demographic measures of human communities, public health data, and contributions of various pollution burdens from ozone, lead, traffic, to hazardous waste facilities. MEJ is a team of policy, data science, and community engagement experts to empower communities to end environmental injustices. MEJ interactive maps merge demographic data from the 2014–2018 American Communities Survey and 2013–2017 Comprehensive Housing Affordability Strategy (CHAS) data, pollutant data from the Environmental Justice (EJ) Screen produced by the United States Environmental Protection Agency, and public health data from the Virginia Centers for Disease Control and Colorado Department of Public Health and Environment. Links to the various datasets are available on the MEJ interactive map webpage.

This activity is flexible in its implementation and is a great in-class small group activity for students to conduct as a team-based learning activity and can also be implemented easily within an asynchronous online course as a solo project. Instructors should provide students with the handout (Supporting File S2), following the introductory lecture (Table 1), that details instructions for the activity and a series of conceptual and reflective questions. The first portion of the handout orients students with the online, interactive map by asking several questions regarding the items found on the legend of the map and how they were generated. Students will then choose a map that displays environmental injustice impact to manipulate and use as a reference throughout the rest of the activity.

Mapping for Environmental Injustice Activity

Once the online activity is set up, students are encouraged to explore the layering options within their map and manipulate the visible layers to predict pollution burden (Table 1). For example, the activity requires students to choose a layer that depicts the environmental injustice impact as it relates to people of color or those in poverty. Students can also view certain health effects and conditions such as asthma and heart disease as it relates to environmental injustice impact. Following each alteration to their map of choice, students are prompted to reflect on how the environmental injustice impact changes based on their chosen layers with questions like "What did you notice about the layer and how it relates to the impact score and other characteristics?" Finally, students are encouraged to choose a storybook link that details a specific instance of environmental injustice within a county that highlights the pollution impacts and stories of those who were impacted.

Wrap-Up and Reflection

To conclude the activity, students are asked to reflect on the lecture and activity by answering a few questions that assess their understanding of populations that are overburdened by pollution and challenge them to consider systemic biases' influences on people's lives (Table 1). Instructors are encouraged to ask questions that enable students to ponder the societal and environmental implications, how to address issues of environmental injustice using science, and any additional questions that arise. Instructors might encourage students to discuss their responses with a partner or share their thoughts with the class. Reflective questions throughout and especially at the end of a lesson are vital to allow students the time and space to consider what they have learned and how they may apply or consider this knowledge in their daily lives. The instructor may then choose to revisit the lecture slides to promote further reflection through a cautionary statement that centers goals of adequately improving environmental injustices within urban areas.

Assessment

The assessment included within this lesson can be incorporated throughout the lesson or completed at the end of the class period (Table 1). The assessment (Supporting File S3) adequately complements the lecture materials with questions covering types, sources, and impacts of environmental pollution, as well as causes of and contributions to environmental injustice within urban landscapes. These multiple-choice, true or false, and short-response questions serve as a way for students to apply newfound knowledge and reflect on important concepts from the lesson while allowing educators a way to assess student learning. The assessment answer key (Supporting File S4) is included to provide the instructor with the correct responses or examples of responses for questions within the student assessment.

TEACHING DISCUSSION

The goal of this lesson and its accompanying activity is to provide educators with an accessible way to discuss environmental and human health issues surrounding environmental injustice. This lesson is suitable for both online and in-person teaching formats due to the electronic shareability of its materials, and its modular nature allows for adaptability to shorter or longer class periods as components can be distributed before, during, or after class. Through the practice of ideological awareness (44–46), educators can situate science within a socioculturally relevant context. This ideological awareness lesson reveals systemic biases that lead to disproportionate environmental and human health impacts of pollution, allowing students to actively explore the complex intersection of science and society, which is a core competency of *Vision and Change in Undergraduate Biology Education* (63). Previous research has shown that students and faculty have positive perceptions of ideologically aware teaching and that the practice can have valuable outcomes for science education. For instance, Beatty and colleagues (45) found that students who engaged with ideological awareness lessons preferred these materials over those used in a traditional biology curriculum. The study also found that persons excluded because of their ethnicity and race (PEERs) reported greater approval of the lessons than non-PEER students and that the lessons positively impacted students' perceptions of science and scientists. Further, implementing ideological awareness lessons impacts students' perceptions of sociocultural interactions with science. Adams and colleagues (52) found students exposed to ideological awareness lessons were better able to make connections between science and society compared to control sections in which ideologically aware resources were not implemented. Other studies have shown that biology instructors value ideologically aware practices within courses, noting that substantial class time should be devoted to these considerations (55). Research centering instructor implementation of ideological awareness has confirmed the value and motivation behind this practice, where innovation-experienced educators suggested that it is vital for future scientists and citizens to receive this exposure (Caudle *et al.,* in preparation). For an additional ideological awareness *CourseSource* article and activity centering representation in science, technology, engineering, and mathematics (STEM) disciplines, see (64).

Successful implementation of this lesson and its activity will likely involve critical reflection on personal biases found in oneself and one's instructional practices in combination with personal research and interaction with the content that is to be covered (65, 66). The activity lends itself to plenty of opportunities for educators to include structured facilitation that is inclusive and equitable, allowing students to actively engage in their learning (see [46] for several examples). This includes carving out class time for discussion and formative assessment, as well as employing strategies that broaden student participation. We also encourage instructors to communicate with other instructors who are implementing similar modules. Sharing resources and promoting cooperative reflection and evaluation of instructional practices can ultimately enhance teaching and learning (67–69). Instructors play a critical role in providing the necessary context surrounding science lessons, and science classrooms may be the only opportunity for students to gain experience with these topics (45, 70). Introductory biology courses are inaugural and represent foundational science experiences for students in higher education. Ideologically aware lessons, such as this one, have the potential to produce meaningful student learning outcomes among both biology major and non-major audiences. This lesson and activity attempted to accomplish this by allowing students to engage with a topic that encompasses environmental and biological sciences, in addition to sociopolitical processes and impacts on human health. Exposing students to topics of environmental injustice within science education will highlight systemic biases that lead to inequality. These issues may generate new perspectives and impact decisions in their lives. Ideologically aware lessons are invaluable to science education, as they can be critical for both future scientists and citizens. We hope that educators are challenged to become agents of change that adopt this practice and explicitly link science and its sociocultural dimensions within their courses.

Effectiveness in Meeting Learning Objectives and Student Reactions

Our group implemented the activity within an introductory, non-major biology course at Saint Mary's College of Maryland during the Spring of 2024 that was taught by AEB. We assessed student learning using author-generated summative assessment asking an open-ended question asking students to summarize what they learned completing the environmental injustice activity. Students were asked "Please provide a 200–250 word summary/discussion of today's lesson. You can write about whatever you would like, as long as it shows your understanding of the materials." Next, JAH thematically analyzed open-response learning summaries to investigate the alignment of student reactions to our stated Lesson Learning Goals. We mapped student themes onto Lesson Learning Goals and JAH calculated the frequencies of each theme from student responses (Table 2).

Overall, our analysis revealed a strong alignment between student responses and our stated learning lesson goals (Table 2), which indicated that students grasped activity goals. For instance, 93% of students highlighted the relationship between environmental injustice impacts and documented health disparities, including adult asthma and heart disease as frequent examples, which corresponded to our first major Lesson Learning Goal. Similarly, our second Lesson Learning Goal was to 'explore the intersection of science and society through the concept of environmental injustice', and 65% of our student summaries included a formal definition of the cumulative environmental injustice impact score used in the activity and defined all the components of the impact score. 57% of student summaries explicitly highlighted the relationship between environmental impact and areas that were associated with increased populations of marginalized communities, and 64% highlighted the linkage between environmental impact with areas of lower socioeconomic opportunities. Taking that one step further, 36% of student responses defined the historic policies (*e.g.,* redlining) and 21% of student responses defined contemporary policies that are exacerbating environmental injustices, which ties to our 3rd Lesson Learning Goal—to become aware of systemic biases that create structural inequalities for some communities. Linking to our fourth Lesson Learning Goal—recognize and critically analyze cases of environmental injustice outside of the classroom—50% of student responses applied the environmental injustice framework to places and situations beyond the Virginia classroom examples or explicitly mentioned interest in completing the assessment in their hometown or state. Mapping on our fifth Lesson Learning Goal—value environmental health and injustice in their decision-making. Finally, 14% of students explicitly stated that this activity provided their first knowledge of environmental injustice. While not every student addressed every Lesson Learning Goal, each student's response addressed multiple learning goals within their open-ended responses asking them to summarize their learning experience. Focused questions on each learning goal or objective may have revealed more nuanced student responses. However, here we demonstrate the initial implementation led to an improved understanding of historic and contemporary biases and policy failures, like redlining, brownfields, and green spaces. Highlighting these examples supported stronger connections for students on the systemic biases that generate and maintain structural inequalities.

SUPPORTING MATERIALS

- S1. Environmental Injustice – Introductory Lecture Slides
- S2. Environmental Injustice – Student Handout and Activity
- S3. Environmental Injustice – Student Assessment
- S4. Environmental Injustice – Student Assessment Answer Key

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Table 1. Lesson timeline. The timeline consists of a 60-minute guide including the lecture, activity, and assessment that can be adapted to various course formats.

Activity	Description	Estimated Time	Notes
Introductory Lecture			
Environmental Injustice	The instructor describes the types, sources, and impacts of environmental pollution, introduces environmental injustice, and highlights disparities resulting from systemic bias and structural inequalities.	25 minutes	The introductory lecture (Supporting File S1) provides the necessary background information for students to understand and engage with the activity.
Student Handout and Activity			
Mapping for Environmental Injustice Setup	Students are provided with a handout detailing instructions for the activity. Instructors should allow students individual or group time to load the activity on their electronic devices.	5 minutes	The student handout (Supporting File S2) is easy to navigate and self-explanatory, yet students could potentially need time to become oriented with the website.
Mapping for Environmental Injustice Activity	Students then begin to manipulate the online, interactive map layers, answering questions as they complete the handout.	20 minutes	Students can work individually, in pairs, or in small groups. Students may also choose to explore the other available maps if they finish early. Supporting File S2
Wrap-Up and Reflection			
Minimizing Injustices	Students are asked to reflect on the lecture and activity by answering a few questions on the handout. The instructor then can revisit the lecture slides to promote further reflection on minimizing environmental injustice.	5 minutes	Encourage students to discuss their perspectives among themselves. Ask them questions that make them think critically while allowing them to ask questions and share their ideas as well. Supporting Files S1 and S2
Assessment			
Environmental Injustice Lesson Assessment	The assessment consists of multiple-choice, true or false, and short-answer questions. It can be incorporated as a formative or summative assessment during or after the class period, respectively.	5 minutes	The assessment (Supporting File S3, S4) is meant to be adapted as needed. We recommend a combination of formative and summative approaches for the best outcome (*e.g.,* questions during the lecture via an audience response system and within unit quizzes or exams).

Table 2. Student reactions to the activity and alignment with Lesson Learning Goals. We coded student responses to the prompt “Please provide a 200–250 word summary/discussion of today’s lesson. You can write about whatever you would like, as long as it shows your understanding of the materials.”

Percent Response	Theme	Lesson Learning Goal
64%	Defining cumulative environmental justice impact and defining the components used to compute it	Explore the intersection of science and society through the concept of environmental injustice
36%	Defining the historic policies that have led to concentration of demographic groups into certain areas	Become aware of systemic biases that create structural inequalities for some communities
21%	Including contemporary examples of how and why environmental injustice are maintained	Become aware of systemic biases that create structural inequalities for some communities
57%	Highlight the relationship between environmental impact and areas with higher populations of marginalized individuals	Become aware of systemic biases that create structural inequalities for some communities
57%	Highlight the relationship between environmental impact and areas with higher poverty	Become aware of systemic biases that create structural inequalities for some communities
93%	Highlight the relationship between environmental impact and areas with health outcomes	Understand that environmental and human health are interconnected, especially when considering pollution
50%	Application of EJ framework beyond classroom activity example focused on Virginia	Recognized and critically analyze cases of environmental injustice outside of the classroom
43%	Using knowledge of environmental justice impact to structure more just societies	Value environmental health and justice in their decision-making
21%	Students provide examples of how to engage in social change	Value environmental health and justice in their decision-making
14%	Environmental justice as a new concept	Become aware of systemic biases that create structural inequalities for some communities

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