**Making Sense of Monarchs: Toward Linking Phenomena & Scientific Argumentation with Cultural Relevance**

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**Abstract**

We use the population decline of the monarch butterfly as a central phenomenon to support data analysis and scientific argumentation skills and to motivate inquiry and content learning in intermediate college-level biology courses. Students practice analyzing population trends, critically evaluate scientific articles that debate the causes and implications of those trends, and interpret data using key biological concepts in evolution and ecology. Students learn how to evaluate and reconcile conflicting information and use evidence and scientific reasoning to develop arguments about how communities should respond to the decline. Many of our students find the phenomenon engaging, probably because many of them come from the Upper Midwest and have witnessed or even reared monarch butterflies at home or in previous schooling. However, we draw upon ideas from culturally relevant science teaching to engage more of our students in critical analysis about the relevance of these topics to their communities, and we propose strategies for teaching about the monarch decline phenomenon in diverse contexts.

**Key Words:** culturally relevant science teaching; inquiry; monarch butterfly; phenomena; scientific argumentation.

**Introduction**

Recent movements in science education, especially at the K–12 level, advocate the use of a phenomenon, a natural event that science can explain or predict, to anchor and motivate instruction in science classes (NGSS Lead States, 2013). When instruction is centered around explaining and predicting phenomena, students are challenged to reason with the content they are learning as they engage in core science and engineering practices, such as evaluating evidence and scientific argumentation (NGSS Lead States, 2013). As phenomena play an increasingly central role in curriculum design, educators must carefully identify phenomena that are engaging and relevant to all.

For example, phenomena can be embedded in culturally relevant science teaching (CRST), which emphasizes the goals of academic excellence, cultural competence, and critical sociopolitical awareness for students (Ladson-Billings, 1995; Mensah, 2011). The practices of constructing explanations for phenomena and designing solutions are among the most common inquiry practices used in culturally relevant science teaching (Brown, 2017). To facilitate this discourse, the Claim-Evidence-Reasoning framework offers a structure that makes explicit some of the academic language demands, including evaluating data to determine whether they provide appropriate and sufficient evidence to support a claim and articulating logical reasoning to justify the support (McNeill & Krajcik, 2012). These critical thinking skills are part of the academic excellence pillar of CRST (Ladson-Billings, 1995). At the same time, cultural competence can be equally important for crafting effective arguments, which must draw upon the experiences and values of their audience to persuade them. Finally, when students critically apply scientific argumentation to sociopolitical issues, they can engage in the third pillar of CRST (Ladson-Billings, 1995).

We propose that the decline of the iconic migrating population of the monarch butterfly (Figure 1) is a powerful, complex phenomenon that supports the development of scientific argumentation skills and content learning related to evolution, ecology, conservation, ecological restoration, and the biological impacts of climate change, and we describe our efforts to increase the cultural relevance of our teaching by using this phenomenon. The annual monarch migration between Mexico, the United States, and Canada is a culturally significant phenomenon poised to capture the attention of many students: “The monarch migration between Mexico, the United States, and Canada is a culturally significant phenomenon poised to capture the attention of many students.”
finally, the souls returning to Michoacán on the Day of the Dead” (Gustafsson et al., 2015). In one specific example, the visual awe of the monarch migration has been described, in a New York Times Bestseller, as a “forest blazed with its own internal flame” (Kingsolver, 2012), an image that contrasts markedly with the graphs showing population declines (Figure 1). In another, the suspected murder of Homero Gómez González, an environmental activist and director of the El Rosario monarch preserve in Mexico, made international news, highlighting tensions over land rights. Because different parties will interpret information about an icon like the monarch butterfly in different ways (Gustafsson et al., 2015), studying the population fluctuations of these magnificent creatures can generate productive dialogue. We use the monarch decline phenomenon to motivate instruction about key course concepts in a variety of classes. To highlight the relevance of course content to the community and to improve students’ abilities to critically apply their learning, we designed, tested, and modified an assessment inviting students to propose a community response to the monarch decline.

Specific aspects of the monarch decline phenomenon support the culturally relevant pedagogical pillars of academic achievement, cultural competence, and critical sociopolitical awareness (Ladson-Billings, 1995). First, scientists disagree about the primary causes of monarch population trends, citing factors ranging from climate change to loss of overwintering habitat in Mexico to declines in milkweed abundance or nectar resources (Brower et al., 2012; Pleasants & Oberhauser, 2013; Inamine et al., 2016; Boyle et al., 2018). This disagreement compels students to engage their own reasoning rather than try to identify the “right answer.” Additionally, when students generate their own ideas about how society should respond to the monarch decline phenomenon, they critically apply science learning and argumentation skills to a context relevant to their community (Rodriguez & Barryman, 2002; Mensah, 2011). Here, we describe our moves to utilize these aspects of the phenomenon to teach scientific argumentation in a way that increasingly draws upon culturally relevant teaching practices.

**Implementation**

Students come to our residential, liberal arts college from all over the world, but more than half of the student population comes from the Upper Midwest. Consequently, we expected monarchs to be familiar to many but not all students, and we expected the migratory and iconic nature of the population to be of broad interest because of heightened and well-publicized regional conservation efforts (Oberhauser et al., 2017). We used the monarch decline phenomenon to motivate instruction in two courses designed for biology majors: a 200-level required ecology course (hereafter “Ecology”), and a 200-level invertebrate biology course (hereafter “Invertebrate Biology”) that meets the organismal biology requirement for the major. All students entered these classes having completed a 100-level biology course that introduced them to reading scientific literature, data analysis and scientific writing skills, and content related to evolution and genetics; otherwise, they represented a range of experience from sophomore to senior biology majors. However, the Claim-Evidence-Reasoning structure is not widely used at our institution and was new to many students. The same instructor taught both courses in different years, no students were enrolled in both classes. We describe both courses to illustrate how the monarch phenomenon may be used with different content learning goals, and to demonstrate the modifications we made to align instruction more with culturally relevant science teaching.

In Ecology, the conceptual focus of the unit was evolution and local adaptation. The 50 students (33 female, 17 male) in the course began by discussing the monarch population graph (Figure 1) in small groups, orally answering two questions: (1) What can you infer from these data? (2) What questions do you have about them? As we returned to full class discussion, students noticed the downward trend and interpreted that monarch populations were declining, though they also noticed the year-to-year variability. They asked about the y-axis measurement of area occupied, which led well into the next segment of the lesson in which the instructor reviewed what is known about the monarch life cycles and migration, especially focusing on the eastern monarch population that overwinters in Mexico. Students were assigned to read for homework one of four scientific papers (Table 1) that hypothesize different causes of the monarch decline. They spent an entire class period in jigsaw groups with their peers identifying the key claim, evidence, and reasoning articulated in each of the four papers. Then they read a local newspaper article about state department of transportation plans to promote Interstate 35, which passes near campus and continues all the way to Texas, as the “Monarch Highway” by planting milkweeds and other nectar sources along it. Students drafted individual essays making an argument about whether and how milkweed should be planted along the Monarch Highway (Table 1). These drafts were used to record and organize students’ initial ideas, based on their reading and discussions; they did not receive feedback on these drafts.

At this point, students understood the importance of milkweed to monarchs, but they probably had not thought much about adaptation in milkweed plants. We spent two class periods learning about evolutionary processes that can lead to, or disrupt, patterns of local adaptation in which plants perform better at home than in distant sites, and discussing the implications of local adaptation for habitat restoration. Students gained hands-on experience measuring milkweed plants from different origins transplanted on our campus and analyzed their data to test for patterns of local adaptation in milkweeds. Finally, they revised their Monarch Highway essay. At this point, students should have been able to make arguments with much richer reasoning about the risks and benefits of planting milkweed along the “Monarch Highway,” and they should have been primed by reading about prior scientific disagreements to acknowledge viable counterarguments.

**Figure 1.** The area of forest in Mexico occupied by the overwintering migratory monarch population, estimated annually between 1993 and 2018. (Photo credit: Avi Dolgan, Flickr. Data source: USFWS.)
In Invertebrate Biology, we used the monarch phenomenon to highlight complex life cycles, population dynamics, and species interactions. Instruction for this unit was structured similarly, but we shifted the introduction to highlight the connection between social and science issues. On the first day of class, we displayed a picture of Homero Gómez González. Although the 19 students (9 male, 10 female) readily recognized the monarch butterflies in the photo, no students expressed prior knowledge about Mr. Gómez González, so brief details of his life were shared. He grew up in Rosario, Mexico, as a logger on communal land. Though he loved monarchs, he initially fought against conservation efforts until he came around to the idea that tourism could replace logging revenue for the community. After logging was outlawed, he organized patrols to protect the preserve from illegal loggers, whom many suspect may have taken González's life (Sieff, 2020). Students individually considered the importance of land-use issues in society and contemplated the question “Could you imagine giving your life for invertebrates?” in their notes. Later in the class, students were graded using the version provided in class; we present here the latest updated version, used to analyze student work in Invertebrate Biology. In particular, we assessed the degree to which students extended their reasoning by addressing counterarguments, and wrote persuasive essays targeted to student environmental groups on campus, making arguments about what they should be doing to support monarch butterfly populations (Table 1). We constructed this essay prompt so that students could draw upon common knowledge of the campus community as they applied their science learning to solve problems.

○ Assessment of Scientific Argumentation

We developed and revised a rubric (Table 2) to assess scientific argumentation related to the monarch decline, largely centered on the core structures of Claim-Evidence-Reasoning developed by McNeill and Krajcik (2012). The rubric retained this core but went through multiple iterations as our teaching of the unit developed. Students were graded on the core structures of Claim-Evidence-Reasoning developed by McNeill and Krajcik (2012) original criteria are meant to assess the way students use the CRST pillars of cultural competence and critical awareness of broader narratives to make their case. We scored initial and final assessments in Invertebrate Biology using the rubric (Table 2) and

| Course          | Papers Read for Jigsaw                                                                                          | Assessment Prompts                                                                                     |
|-----------------|------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| Ecology         | Flockhart et al., 2015: Unravelling the annual cycle in a migratory animal: breeding-season habitat loss drives population declines of monarch butterflies. *Journal of Animal Ecology.*<br>Brower et al., 2012: Decline of monarch butterflies overwintering in Mexico: is the migratory phenomenon at risk? *Insect Conservation and Diversity.*<br>Pleasant & Oberhauser, 2013: Milkweed loss in agricultural fields because of herbicide use: effect on the monarch butterfly population. *Insect Conservation and Diversity.*<br>Inamine et al., 2016: Linking the continental migratory cycle of the monarch butterfly to understand its population decline. *Oikos.* | Should the I-35 corridor be planted with milkweed? If so, how should the project be carried out? If not, why not? |
| Invertebrate Biology | Boyle et al., 2018: Monarch butterfly and milkweed declines substantially predate the use of genetically modified crops. *PNAS.*<br>Stenoien et al., 2018: Monarchs in decline: a collateral landscape-level effect of modern agriculture. *Insect Science.*<br>Inamine et al., 2016: Linking the continental migratory cycle of the monarch butterfly to understand its population decline. *Oikos.* | Preliminary: Are monarch butterflies at risk of extinction? Make a claim and use evidence and reasoning to support it.<br>Final: What should student environmental groups be doing in response to the decline of monarch butterflies? Think about your target audience and how you will use evidence and scientific reasoning to support your claim to this audience. Communicate effectively without overstating or oversimplifying your case. Specifically address monarch food supply and habitat. |
compared performance using paired, one-sided t-tests. In Ecology, we recorded whether each initial and final essay used specific evidence, referenced the concept of local adaptation, addressed counterarguments, and cited sources, and we compared class outcomes using a one-sided chi-square test of proportions. We also tracked the degree to which students change their claims after being exposed to new evidence. Finally, we use course evaluation data to provide some evidence about the degree to which students found the phenomenon engaging.

**Claims:** In both classes, students were able to make clear and bounded claims both before and after instruction. All but two students in Ecology made an identifiable claim, and the average score for making a claim in Invertebrate Biology increased only slightly, from 2.4 to 2.6 on a three-point scale \( t = -1.5588, df = 12, p = 0.0725 \); Figure 2), indicating that this is a skill most students developed prior to our class. Claims on final essays were more sophisticated; for example, a straightforward preliminary claim like “Monarch butterflies are facing extinction” was not uncommon. However, final claims were more complex, often embedding some reasoning and integrating multiple ideas; for example, “due to the variety of scientific perspectives that exist, the best solution … is to educate the public on what information is out there and what they can do in their daily lives.” In addition to developing more complex claims, many students also demonstrated a willingness to change their claims as they encounter and make sense of new data. For example, after lessons on evolution and a lab collecting and analyzing data about local adaptation of milkweed plants in the field, about 30% of students in Ecology changed their claim between their initial and final drafts of the Monarch Highway essay.

**Table 2. Rubric for assessing student arguments.**

| Criteria                        | 1                                                                 | 2                                                                 | 3                                                                 |
|---------------------------------|------------------------------------------------------------------|------------------------------------------------------------------|------------------------------------------------------------------|
| **Core Argument**               |                                                                  |                                                                  |                                                                  |
| Claim                           | Claim is absent.                                                 | Claim is present and answers prompt.                             | Claim is provocative; appropriately nuanced/bounded.             |
| Evidence                        | References to data/evidence are absent or unclear.               | Refers to appropriate data/evidence.                             | Data are described clearly and are sufficient to support claim.   |
| Reasoning (with course concepts)| Vague or absent reasoning without relevant vocabulary. Reasoning is inappropriate or not scientific. | Uses relevant vocabulary or concepts.                             | Explains the reasoning using relevant vocabulary. Explanation connects to the claim. |
| **Extensions to Reasoning**     |                                                                  |                                                                  |                                                                  |
| Counterargument                 | Counterargument is absent.                                       | Acknowledges gaps or holes in your argument; acknowledges other claims. | Level 2+: Discusses validity or confidence in the data and/or compares the weight of data supporting various claims. |
| Sources/citations               | Sources are absent or irrelevant.                                | Uses 1 or 2 appropriate sources. Link between sources and argument may not be articulated completely. | Uses 3+ sources. Sources are explicitly integrated/link to argument. |
| Relevance                       | Personal connection is absent or irrelevant.                     | Reflects on personal/community/cultural connection to topic; for example, Experience/History, Prior Knowledge, Opinions, Values. | Uses personal/community/cultural connections as evidence to support argument. |
| **Broader Implications**        |                                                                  |                                                                  |                                                                  |
| Significance                    | Does not articulate aspects of significance.                     | Reflects on the significance of the claim to self or community. | Uses an argument about significance of the claim to persuade reader. |

In Invertebrate Biology, 100% of students made an identifiable claim, and the average score for making a claim increased from 2.3 to 2.7 on a three-point scale \( t = -1.4292, df = 11, p = 0.0787 \); Figure 2), indicating that this is a skill most students developed prior to our class. Claims on final essays were more sophisticated; for example, a straightforward preliminary claim like “Monarch butterflies are facing extinction” was not uncommon. However, final claims were more complex, often embedding some reasoning and integrating multiple ideas; for example, “due to the variety of scientific perspectives that exist, the best solution … is to educate the public on what information is out there and what they can do in their daily lives.” In addition to developing more complex claims, many students also demonstrated a willingness to change their claims as they encounter and make sense of new data. For example, after lessons on evolution and a lab collecting and analyzing data about local adaptation of milkweed plants in the field, about 30% of students in Ecology changed their claim between their initial and final drafts of the Monarch Highway essay. Although the Invertebrate Biology class initially tended to somewhat agree that monarchs were declining, nearly every student changed their response after looking at data, but not all in the same
adaptation was central to the learning goals. After instruction, we varied with context. For example, in Ecology, the concept of local category measured, the magnitude of improvement in each category exhibited skepticism about drawing strong conclusions from citi...argument that “genetically modified herbicide resistant crops … are the main factor to blame for monarch decline.” Some students, however, still did not describe the strength or magnitude of the evidence that indicate a moderate effect. In the post-assessment, the same student described how mathematical models incorporating fertility hypotheses and rule out competing theories. However, the student rates and milkweed searching behaviors were used to test different strategies, including using specific data points as evidence, addressing counterarguments, and using sources to support their reasoning. Each strategy was more frequently used in the final essays, with the biggest improvement in students’ ability to reason with the concept of local adaptation.

way. Since there is not a current consensus among monarch biologists about many issues, it is perhaps unsurprising that students generated a diversity of claims.

Evidence: Students were less likely to use evidence effectively, though they made dramatic gains in their use of evidence in both classes (Figures 2 and 3). In Ecology, students regularly used citations as evidence to support their reasoning, but even though the fraction of students using specific data nearly doubled between the initial and final drafts ($\chi^2 = 6.23$, df = 1, $p = 0.0063$; Figure 3), more than 40% of students failed to use specific evidence to support their claims. Thus, even though we highlighted the importance of specific evidence in instruction, more practice with this strategy is required for mastery. In Invertebrate Biology, most students vaguely referred to evidence in the pre-assessment; for example, one student argued that conservation efforts had “moderate effects” without describing the source of data or the patterns in the graph that indicate a moderate effect. In the post-assessment, the same student described how mathematical models incorporating fertility rates and milkweed searching behaviors were used to test different hypotheses and rule out competing theories. However, the student still did not describe the strength or magnitude of the evidence that “genetically modified herbicide resistant crops … are the main factor to blame for monarch decline.” Some students, however, were careful to evaluate the quality of evidence – for example, by exhibiting skepticism about drawing strong conclusions from citizen science data. Overall, Invertebrate Biology students improved their scores by almost three-fourths of a point ($t = -4.20$, df = 13, $p = 0.00052$; Figure 2).

Reasoning: Although student reasoning improved in each category measured, the magnitude of improvement in each category varied with context. For example, in Ecology, the concept of local adaptation was central to the learning goals. After instruction, we saw more than three times as many students use this concept correctly in their essays; nevertheless, more than one-third of students failed to either mention or explain this concept in their final essays, suggesting the need for further scaffolding ($\chi^2 = 17.53$, df = 1, $p < 0.0001$; Figure 3). In Invertebrate Biology, students were more likely to reason with biological concepts like the monarch life cycle in both their drafts and their final essays; nevertheless, they still made improvements ($t = -2.19$, df = 13, $p = 0.024$; Figure 2). For example, a student who used reasoning to connect conservation efforts to increased monarch survival on the monarch extinction pre-assessment was able to more effectively flush out a chain of events that impact the availability of milkweed in the final essay. This student’s reasoning goes beyond references to provide a causal explanation and uses relevant vocabulary in the process.

Students in both classes showed improved use of sources in their final drafts (Invertebrate Biology: $t = -8.27$, df = 13, $p < 0.0001$; Figure 2; Ecology: $\chi^2 = 16.95$, df = 1, $p < 0.0001$; Figure 3), probably because they had more time and motivation to find support for their arguments. However, Invertebrate Biology students made more dramatic improvements in their attention to counterarguments ($t = -3.6667$, df = 13, $p = 0.0014$; Figure 2) than did students in Ecology ($\chi^2 = 1.58$, df = 1, $p = 0.10$; Figure 3), probably because the jigsaw paper discussion, which provided models to support this kind of reasoning, was introduced prior to the pre-assessment in Ecology but after the pre-assessment in Invertebrate Biology. After the jigsaw activity, many students referred to “disagreement” or “a lack of consensus” among scientists, and some used specific evidence from one source to counter an argument posed in another source.

Cultural Competence and Critical Sociopolitical Awareness. We assessed students’ reasoning about the relevance and significance of their claims only in Invertebrate Biology, where students did show improvement but still needed additional support. In the monarch extinction pre-assessment, only one student addressed relevance by referring to experiences with monarchs in the classroom; however,
since the persuasive essay specified a target audience on campus, students drew upon values, experiences, and rhetorical patterns appropriate for that audience. For example, one essay referenced the academic calendar, arguing that student groups should provide interested students with milkweed seeds before spring break, and another referenced familiar spaces around campus, arguing that the organization should plant local milkweeds on campus land and reach out to area farmers to do the same. Because they are so relevant to the target audience, such proposals provide a rich opportunity for debate about the scientific and ethical support for different plans. Despite better use of relevance ($t = -4.19, df = 13, p = 0.00053$; Figure 2), students especially struggled to articulate the significance of their claims, and their attention to this factor did not improve significantly ($t = -1.59, df = 13, p = 0.068$; Figure 2). When students did address the significance of the monarch butterfly, they often referred to its cultural significance in either the introduction or conclusion. For example, one student argued that monarchs are one of the “most beloved insects in America” and another referred to their use in many science classrooms. Many students discussed land-use patterns that threaten monarchs, but they did not critically evaluate the relationships between land-use patterns and the cultural and ecological significance of monarchs. Thus, additional support may be necessary to help students better articulate the significance of their claims, which is an important aspect of culturally relevant science teaching.

 Extensions to Enhance CRST

Although we did not formally assess the monarch lessons in the Ecology class, responses were generally positive in Invertebrate Biology, where students’ anonymous feedback indicated that most found the initial monarch extinction activity engaging (average $= 4$ on a five-point scale), and the discussion of articles that disagree about the cause of the decline slightly less so (average $= 3.8$). Although our goal with the persuasive essay was to increase the relevance of the monarch decline phenomenon to students’ experiences on campus, students ranked this activity as less engaging than the others (average $= 3.2$). One student commented that the assignment was “rudimentary,” while another commented that it was helpful practice in communicating scientific articles with general audiences. We interpret both of these responses as indications that students in our classes will benefit from more attention to the cultural relevance of their learning. Since most biology classes at our institution focus on helping students develop communication skills targeted to the scientific community, such as posters, presentations, and scientific papers, students have less experience rigorously articulating the applications of science in their communities. Here, we explain how the changes we made toward CRST in Invertebrate Biology helped improve student engagement and learning, and we identify additional opportunities to enhance CRST.

The monarch decline phenomenon supports academic achievement, the first pillar of culturally relevant science teaching, by helping students practice and grow in both their use of data and their reasoning skills. Many students benefit from more scaffolding, for example, when the Invertebrate Biology assignment specifically prompted students to “address monarch food supply and habitat,” every student did so, although some reasoned with these ideas more clearly and effectively than others. We plan to add additional reminders to scaffold our prompts, and to help students identify models of key reasoning strategies in assigned readings. The choice of readings is also important: by exposing students to sources that disagree, we support them to address counterarguments and to evaluate the quality and relevance of data as they construct their own arguments. We believe that introducing Homero Gómez González’s story in advance of the scientific articles helped increase the cultural relevance and student engagement with scientific arguments about land use that followed because they could relate the more abstract hypotheses with impacts on a real person’s life and death. Although some Ecology student evaluations complained that the course afforded too much attention to monarchs and milkweeds, we did not receive similar feedback from students in Invertebrate Biology. We aim to continue to identify and include more diverse sources that contribute to the rich dialogue of disagreement, as well as sources that model different ways to use relevance and significance to support a claim. For example, Agrawal (2019) argued that studying the monarch decline is important because “monarchs are sentinels… [and] to understand what is happening to environmental health more generally, monarchs may be a source of information for both our own population and biodiversity writ large.”

In support of the second pillar of culturally relevant science teaching, cultural competency, we found it helpful to specify an audience for student work. We believe that the decision to specify student groups as the target audience motivated students to explain their reasoning clearly (because they could not assume prior knowledge), but this may have pushed them to include qualitative rather than specific quantitative evidence to support their ideas. Additionally, with a target audience, students were better able to make connections about the relevance of their argument. In the future, we plan to offer students more choices about their target audience as well as the type of product they create. For example, students might choose to write a letter to their family, to the editor of a local paper, or to food services. Alternatively, they could craft an essay, video, or podcast to distribute to a student organization or other target group of peers.

Finally, we suggest a revised prompt to allow students greater freedom in their critical sociopolitical analysis: “Explain and interpret the monarch population data to your audience. Then propose and justify an appropriate response.” This prompt does not imply a decline and therefore a particular response; it leaves students free to argue what an appropriate response is in the context of the community they choose to engage. Students should draw upon the evidence from the literature to analyze social and structural forces that have affected the distribution of monarchs, analyze who in their target community has the power to make changes, and use specific evidence and reasoning to support those arguments. While we anticipate that generating one or more consensus proposals to act on with a community partner would improve student engagement and solidify science learning, such activities would demand a significant investment of time toward using scientific knowledge as a social actor that could come at a cost of further learning about science ideas and practices (see Dimick, 2012).

 Adaptations for Diverse Contexts

The particular learning objectives, student population, and nature of the course will drive instructional decisions about learning activities and ways to engage students in inquiry between the initial engagement with the monarch decline phenomenon and the final assessment with a community response proposal. Although our work focused on college undergraduates in a more rural setting, we share resources and approaches to adapt instruction about the monarch decline phenomenon for different age groups and in urban
settings, and we link these to disciplinary core ideas and the science and engineering practices in life and earth sciences from the Next Generation Science Standards (Table 3; NGSS Lead States, 2013).

Engaging students in argumentation about the monarch decline phenomenon is appropriate for students at many levels and aligns with NGSS (Table 3). We focus on middle and high school standards, where connections to population dynamics and designing solutions align well with our experience. Because milkweed is a critical food source for monarch caterpillars, and because milkweed declines are one of the leading hypotheses to explain the monarch decline, planting milkweed is a commonly suggested solution. The Milkweed Adaptation Curriculum (available at https://pages.stolaf.edu/milkweed/) offers resources to support course connections with evolution and ecology and investigations about the impacts of the phenology, or timing of milkweed emergence and flowering, on monarchs and other herbivores (Table 4). Many of the inquiry activities can take place anywhere common milkweed plants are growing. At the middle school level, addressing the monarch decline phenomenon is a way for students to practice analyzing data, evaluating a limited range of proposed solutions, and making claims in response to simple prompts with yes/no answers. At the high school level, students can articulate mathematical relationships present in data to support claims and explore multiple types of evidence that might be contradictory, to develop more complex reasoning that includes acknowledging counterarguments (McNeill & Krajcik, 2012). The Monarch Decline Debate lesson (Table 4) offers summaries of different scientific papers that students can grapple with as their reasoning skills develop. High school students can also tackle more open-ended prompts where the class brainstorms proposals that can be implemented in the community and groups or individuals work to evaluate and refine these ideas.

It may not seem as if the monarch decline phenomenon is very applicable to urban areas; however, scientists argue that urban areas are actually quite critical to conservation efforts, with "myriad" monarch gardens planted in schools, backyards, parks, and other urban areas that are accessed and utilized by monarchs (Baker & Potter, 2018). Estimates based on sampling in Chicago, Minneapolis-St. Paul, Kansas City, and Austin suggest that up to 30% of all milkweed stems needed to save monarchs from their decline can be added in cities (Johnston et al., 2019). Many types of urban areas, including residential areas, open areas, and road sides, have the potential to contribute important monarch habitat (Johnston et al., 2019). Perhaps as part of a “crosstown walk” (Middendorf & Nilon, 2005), students could investigate the degree to which green spaces in their city contain milkweed, they could critically evaluate who has access to green spaces and monarchs

Table 3. NGSS standards relevant to the monarch decline phenomenon.

| Middle School Standards |
|-------------------------|
| Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems. MS-LS2-2 |
| Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations. MS-LS2-4 |
| Evaluate competing design solutions for maintaining biodiversity and ecosystem services. MS-LS2-5 |

| High School Standards |
|-----------------------|
| Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales. HS-LS2-2 |
| Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. HS-LS2-7 |
| Evaluate or refine a technological solution that reduces impacts of human activities on natural systems. HS-ESS3-4 |

Table 4. Summary of investigations and lessons from the Milkweed Adaptation Research and Education Network (https://pages.stolaf.edu/milkweed/).

| Investigations | Lessons |
|---------------|---------|
| • Phenology and Herbivory Survey – Students quantify the developmental stages of milkweed and characterize herbivore damage at specific times during the growing season. | • Monarchs and Their Decline – Students interpret a graph of the monarch overwintering population size over time. They generate hypotheses to explain the pattern. |
| • Herbivory Bioassay – An experiment that tracks the abundance of different types of herbivory on milkweed at a site at a given time. | • Monarch Decline Debate – Students read, discuss, and compare articles (or summaries) that provide conflicting evidence about the primary cause of the monarch population decline. |
| • Pollination Project – Select one of two protocols to record or survey pollinator activity on milkweeds at a site. | • Milkweed: A Critical Food Source for Monarchs – A series of stations introduce students to milkweeds and their relationship to monarch butterflies. |
| • Seed Collection – Record data about plants, collect seed pods, prepare seeds, and submit them to a library for future study. | • Evolutionary Principles – A series of activities introduce students to the concept of local adaptation and give them practice predicting the implications of local adaptation for milkweed populations. |
| • Phenylography and Phenology. | • Picking Plants for the Monarch Highway – Students analyze preliminary data to determine whether existing evidence is consistent with local adaptation or population differences in phenology. |
in their communities, and they could investigate the optimal configuration for planting milkweed to support monarchs in urban gardens (Baker & Potter, 2018).

The literature is full of other extensions to learning about the monarch decline, ranging from the precipitous decline of western monarch populations (Pelton et al., 2019) in addition to that of the eastern population (Figure 1) to the potential role of introduced plants that may facilitate the spread of diseases among monarchs (see Agrawal, 2019). Thus, there is rich potential for the monarch decline phenomenon to motivate students with diverse interests and backgrounds to engage in rigorous scientific argumentation. As a bonus, students are likely to remember the lesson again and again as monarchs cycle through their annual migration.

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