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Modeling for Ecological Engineering

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For the past 15 years, pine forests across the United States have experienced devastating mountain and southern pine beetle outbreaks (Rosner 2015). These outbreaks are not uncommon but have become increasingly severe. Due to the effects of global warming, pine beetles have been able to survive warmer winters in their native habitats, producing greater numbers of offspring (Strain 2012). Warming temperatures have also allowed pine beetles to migrate farther north into territories where they have never been seen on both the east and west coasts (Blake 2018; Rosner 2015; Schlossberg 2016).

Additionally, rising temperatures accompanied by droughts are stressing trees, making it harder for the trees to defend themselves and easier for the beetles to take over (Rosner 2015). As pine beetles have entered new regions of the United States, foresters have not been prepared to tackle the problem and lack the resources to protect their forests (Schlossberg 2016). University of Rhode Island researchers and the state's Department of Environmental Management are looking to neighboring states where pine beetles have already been encountered (Blake 2018). This collaboration will help the state develop a plan to help prevent a pine beetle attack from occurring.

Over the course of four weeks, in a 50-minute class period (Table 1), high school biology students engaged in understanding this phenomenon through various lessons aligned to the *Next Generation Science Standards* (NGSS Lead States 2013). Throughout the ecology unit, students were able to build a vast collection of knowledge to better understand the underlying mechanisms that drive pine beetle attacks and then apply this knowledge to an ecological engineering task.

This unit is based on the same phenomenon of Xiang and Mitchell (2019), who took middle school students on a field trip to ask experts questions about bark beetle outbreaks and modeled the phenomenon through a computer simulation. The unit we describe takes a different approach, providing teachers with an example of how students are able to develop models in science to drive and support their understanding of engineering.

Developing unit models

One of the core science and engineering practices in the *NGSS* is developing and using models (NGSS Lead States 2013). While modeling looks different in science and engineering, both disciplines aim to make simpler versions of existing systems (Crismond 2013). However, models in science are used more to foster questions and explanations, generate data, and communicate ideas, whereas models in engineering are used more frequently to analyze and test systems (NGSS Lead States 2013). Using the framework for developing, revising, and using models in science from Windschitl, Thompson, and Braaten's (2018) *Ambitious Science Teaching*, students created robust scientific models and explanations about the observable and unobservable characteristics of pine beetle outbreaks.

We spent the first day of the unit observing the phenomenon in the short film, *Life of Pine* (National Geographic 2018), recording observations, and creating initial models (Figure 1). Initial models created by students are critical in uncovering students' prior knowledge by showing their initial thinking about the event presented and how this event occurred (Windschitl, Thompson, and Braaten 2018). Students were allowed to pictorially represent the phenomenon in their models, making sure to include its observable and unobservable characteristics. Including what is seen and not seen may not initially be natural for students, so teachers need to take care to engage with students and ask questions as models are being developed. Having students describe unobservable

FIGURE 1

Initial model from day 1.

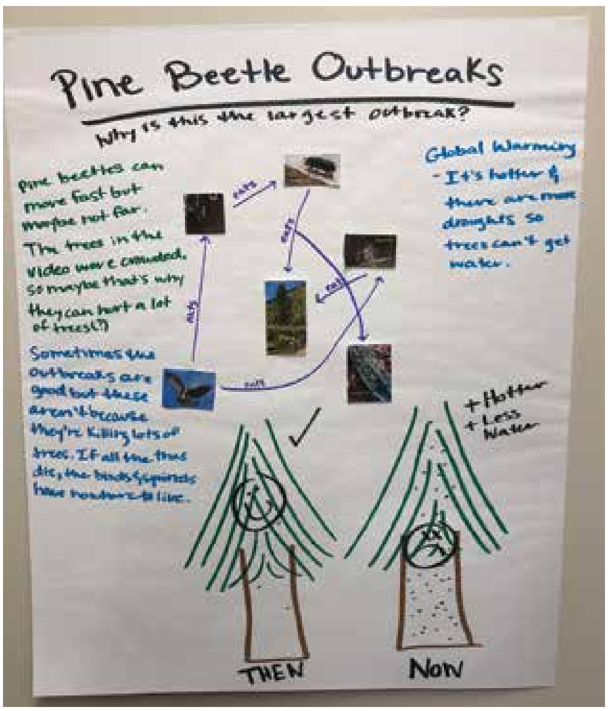
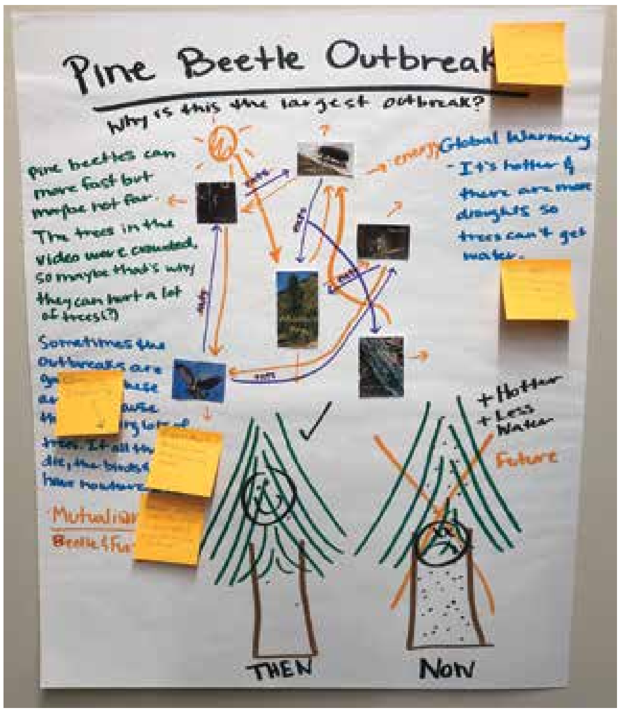


FIGURE 2

Revised model from day 9.



factors related to the phenomenon helped develop their conceptual understanding about why the observable events occur.

Because students developed models at the beginning of the unit, we provided them time on day 9 to revise their models as their learning and knowledge of the phenomenon increased. This was done only once during the unit because students can generate "model fatigue" if models are amended too often (Windschitl, Thompson, and Braaten 2018). Revision during the middle of the unit was important because students started to see how their ideas of the phenomenon were changing in light of new evidence accumulated on the class summary table and in their science journals.

TABLE 1

Unit calendar.

Day	**1**	**2**	**3**	**4**	**5**
Lesson Question	Why are recent pine beetle outbreaks worse than those of the past?	What is an ecosystem?	What happens to an organism's energy when it dies?	Do organisms in a population compete with one another?	How do limiting factors differently affect a population?
Main Activities	Initial Models	Ecosystem Card Sort	Carbon Cycle Role-Play	Comprehensive Cycles of Matter Models	SEPUP Fishery Simulation
Day	**6**	**7**	**8**	**9**	**10**
Lesson Question	How do limiting factors affect a population differently?	How do organisms interact with one another?	Can more than one species occupy the same niche?	How has our thinking changed in light of new evidence?	How can introduction of a species affect an ecosystem?
Main Activities	Group Interactive Frayer Models	*Ghost Moose* Reading & Symbiosis Notes	Virtual Paramecium Lab	Revise Models	Invasive Species Anticipation Guide & Video Introduce Engineering Task
Day	**11**	**12**	**13**	**14**	**15**
Lesson Question	Are forest fires and flooding bad?	Can we trust everything we read?	What scientific data is relevant for describing global warming?	What effect does global warming have on the environment?	Why are recent pine beetle outbreaks worse than those of the past?
Main Activities	Jigsaw: Pros & Cons of Ecological Succession	Case Study: Rising Temperatures, Differing Viewpoints	"What Are the Signs of Global Warming?" Probe Sort and Analyze Climate Data	Jigsaw: What are the effects of climate change on ecosystems?	Final Models & Explanations
Day	**16**	**17**	**18**	**19**	**20**
Lesson Question	How can we help prevent further devastation?	How can we help prevent further devastation?	How can we help prevent further devastation?	How can we help prevent further devastation?	How can we help prevent further devastation?
Main Activities	Research Solutions and Prevention Strategies	Finish Research and Write Proposals	Peer Review	Collaborate With Peers and Revise Proposals	Finalize Proposals and Submit for Review

Windschitl and colleagues (2018) suggest two ways of revising original models. One way is to revise student hypotheses as a class. The other option, which we chose for this unit, was to add sticky notes to their original models (Figure 2, p. 32) with evidence from lessons as well as questions and comments about parts that still need evidence.

Up to this point, students had gathered information about ecosystem relationships (populations, communities, symbiotic, coevolutionary) and competition for resources among various organisms. Students used this information to make stronger connections in their models about how specific organisms were connected and how pine beetles affect the stability and sustainability of the ecosystem where outbreaks occur.

On day 15, students were done with learning content and ready to finalize their models with all the evidence they collected from various activities, discussions, and investigations from previous days. To help students sort through the information they accumulated, we provided students with a Gotta-have checklist (Figure 3). The checklist included ideas we decided as a class would be necessary to include and expand upon in their final models (Windschitl Thompson, and Braaten 2018). Functioning as a grading checklist for students' models, it was made clear that each point of the checklist was expected to be included in their final models. This checklist acted as an outline for students, but students could elaborate more on a specific point if they felt some held more importance than others.

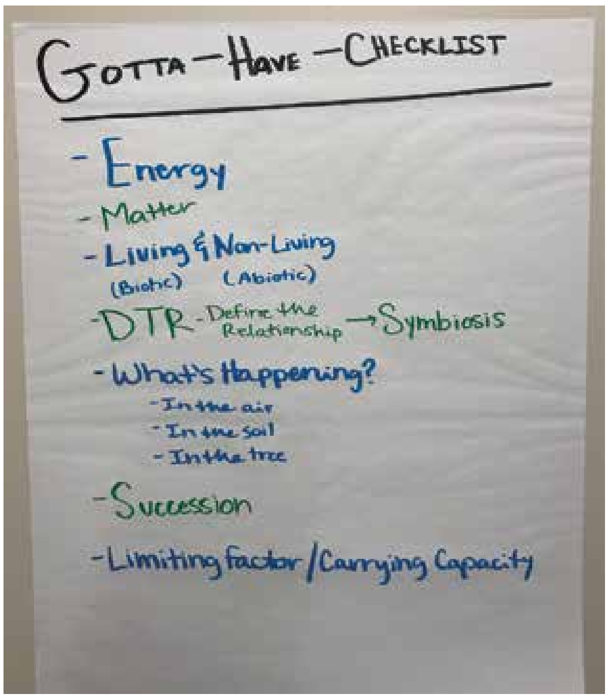
As students developed their final models (Figure 4, p. 36) and explanations, we pressed them to go further during the explanation process by allowing them to have access to accumulated resources (e.g., summary tables, class charts, readings, science journals) and asking specific questions. Allowing students to have access to these resources helps them develop more robust explanations, while also showing the teacher how they are able to sort through large amounts of information and choose what is critical in developing an evidence-based explanation (Windschitl Thompson, and Braaten 2018). The information did not provide an explanation of how the phenomenon worked, but rather gave students evidence to support their hypotheses and explanations, which they were able to cite in their finished products.

Students developed explanations in a claim–evidence–reasoning (CER) format to provide structure and were assessed individually (Table 2). Assessing explanations separately from the models allowed us to see what students were able to do apart from their group. Having students create individual explanations was also necessary because some students created models that were more pictorial than explanatory. The explanations in conjunction with the models allowed students to elaborate on portions of the model that did not fit on the poster and ensured that all students were able to make sense of the information they had accumulated.

The models students created were a critical component in developing their conceptual understanding of ecology, necessary for taking on the role of an ecological engineer. Students' models and conversations in class allowed them to see how pine beetle outbreaks can either be beneficial to the health of an ecosystem or devastating, like those in the short film. In order to get students thinking about intervening and developing solutions

FIGURE 3

Gotta-have checklist.



to the problem, we directed our discussion to the pine beetle problem as we learned about invasive species. Students began to wonder, "Should we intervene, or should we leave the forests alone?" They were starting to think like ecological engineers.

Ecological engineering task

Ecological engineering defined by Mitsch (1996) is a field of both ecology and engineering that includes the "designing and restoring of ecosystems according to ecological principles" (p. 112) with the goals of restoring ecosystems and creating new sustainable ecosystems. Over the course of five days, students took on the role of ecological engineers by thoroughly researching and proposing a solution to help states unfamiliar with pine beetles alleviate the outbreaks of their region (Figure 5, p. 37).

This task aligns with the characteristics of engineering proposed by Whitworth and Wheeler (2017): designing a solution to a problem, working under constraints, and not having step-by-step instructions. While this task is conceptual in nature, students

TABLE 2

Rubric for models and explanations.

Criteria	Advanced 4	Meets Expectations 3	Approaches Expectations 2	Not Yet 1
Explains Phenomena: Did I completely answer the driving question, "Why are current mountain pine beetle outbreaks worse than those of the past?"	Explanation includes the full causal story of the phenomenon including the unobservable components as well as additional components and relationships that fit the scientific explanation.	Explanation connects all relevant components and relationships (observable and unobservable) to explain what caused the mountain pine beetle migration and outbreaks.	Explanation includes some of the relevant parts that explain how mountain pine beetle outbreaks occur but does not include the cause of the migration and outbreaks.	Explanation does not explain the phenomena or only describes what happened. Explanation does not answer the driving question.
Evidence-Based: Is my explanation supported by evidence from class activities?	Explanation includes all of the evidence collected and included in the class summary table and correctly justifies why it is evidence.	Explanation refers to a sufficient amount of relevant evidence collected through the investigations to be compelling and justifies why it is evidence.	Explanation correctly incorporates some of the evidence collected through the investigations.	Evidence is not correctly related to the explanation or not included.
Building Science Ideas: Does my explanation include science concepts and crosscutting concepts?	Explanation includes essential science concepts included in Gotta-have-checklist and other relevant science ideas and crosscutting concepts (e.g., cause and effect, stability and change).	Explanation includes some essential disciplinary science concepts AND crosscutting concepts needed to explain the phenomena.	Explanation includes some of the essential concepts to explain the phenomena—but not all that are needed.	Explanation does not include relevant science ideas.
Clarity of Communication: Would someone else be able to understand my explanation?	Explanation is clearly written, and additional communication or educational pieces are included for the audience (e.g., pictures, diagrams, footnotes, etc.).	Explanation is clearly written in a way that allows others to understand how and why pine beetles are migrating and causing devastating outbreaks.	Explanation is somewhat clearly written.	Explanation is not clearly written.

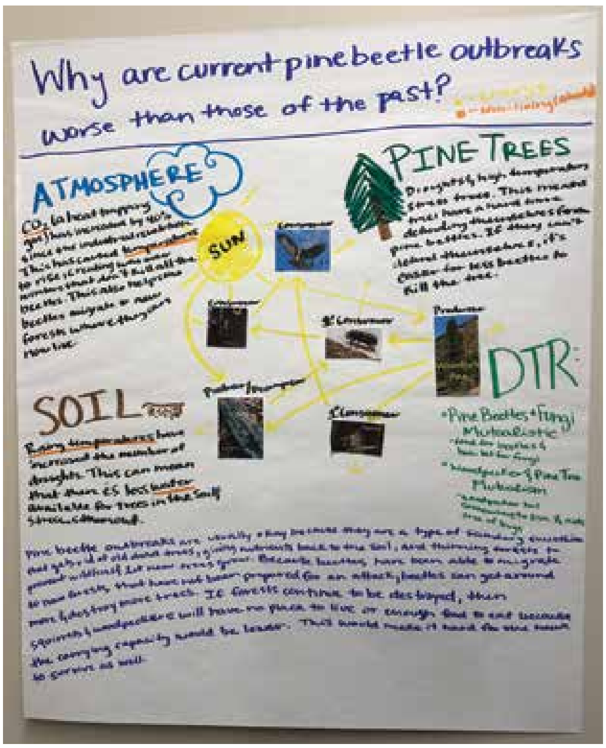
were able to model the process ecological engineers engage in by diagnosing the current state of an ecosystem and deciding what steps should be taken for maintaining a healthy (i.e., stable and sustainable) ecosystem (Costanza 2012).

Before we officially began our engineering task, we encouraged students to read about the different ways researchers and scientists manage pine beetle outbreaks across the United States. We made resources available for students to read on their own time, which allowed them to get a general overview of commonly used solutions and methods for managing forests and outbreaks. Once the project officially started and their models were complete, students discussed solutions with their groups and decided which solution or solutions would be most beneficial for the forests.

Students then began conducting their own research to find ecological maintenance strategies that engineers, ecologists, and foresters use or could use that align with the solution they have chosen. However, engaging in argument from evidence is not limited to only strengthening one side of an argument (NGSS Lead States 2013). Students should also be able to listen to opposing arguments and recognize their validity, while also acknowledging the weaknesses of their own. This type of thinking promotes students' problem solving and decision-making abilities in engineering, even though nothing is being built (Crismond 2013). Instead, students work as a group to piece together large amounts of information to determine what is useful and what is not.

FIGURE 4

Final model from day 15.



The final part of the task was for students to write a two- to three-page proposal outlining the suggested solution, alternative solutions, and justification for the solution or combination of solutions they chose as a group. Scientific writing can be hard for students who are not familiar with it, so I provided a RAFT template (Table 3) to help get their ideas onto paper. This allowed students to have a clearer understanding of the purpose of their writing.

Finished with their initial proposals, students conducted a double-blind peer review to practice giving and receiving feedback to one another (Sampson, Grooms, and Walker 2009). Students also had time to collaborate with their classmates and ask questions about the decisions made in the proposal. This allowed students to develop stronger arguments and provided guidance for making revisions to their proposals. Students then submitted the final draft of their proposal to the teacher for a final review and, if satisfactory, acceptance. If student proposals did not meet the minimum requirements in the engineering rubric, proposals were sent back for further revision and resubmission.

Once accepted, we assessed the proposals for grading purposes according to the engineering proposal rubric (Table 4, p. 38) given to students at the beginning of the task. We assessed students on their ability to develop an argument, collect and analyze sources, and propose a reasonable solution to a real-world problem. The proposal acted as an additional summative assessment, revealing how students were able to apply their scientific knowledge to a real-world situation. By completing an ecological engineering task, students were able to find purpose in their learning and be exposed to a new STEM career.

Conclusion

Engineering can be hard to include in the science classroom. Some science educators lack the training to successfully incorporate engineering activities into the classroom, and some feel like they do

TABLE 3

RAFT template.

RAFT is writing strategy meant to assist in clarifying students' role and purpose in writing by addressing the four core writing elements (Holston and Santa, 1985).

Role: Ecological Engineer
Audience: Researchers, scientists, other engineers, and foresters
Format: Proposal
Topic: Propose a solution or solutions for controlling pine beetle outbreaks and maintaining a healthy forest ecosystem to someone who is encountering pine beetles for the first time and does not know which strategy is best for protecting and recovering their forest.

FIGURE 5

Ecological engineering design brief for pine beetle outbreak proposal.

Context/Challenge:

The mountain pine beetle is a native species of the southwestern United States. As temperatures have increased globally, the mountain pine beetle has begun to migrate into northern U.S. states and even into Canada. The same phenomenon is happening in the eastern United States as the Southern Pine Beetle is migrating into Rhode Island. This migration means the insect is an invasive species to these new territories. Because the pine beetle is not new, some regions know how to rid forests of the beetle and prevent further occurrences of pine beetle infestations. This being said, regions where the beetle is new lack the resources and experience to maintain their forests and prepare them for the beetle.

Engineers who work with these types of problems are ecological engineers. A specific role of ecological engineers is to protect the environment through analyzing ecosystems experiencing ecological distress in order to create solutions that maintain the health of the ecosystem. You will take on this role to research and design a solution to help prevent severe pine beetle outbreaks in the northern United States and Canada, which may be experiencing the beetles for the first time.

Criteria/Specification:

Your task is to research various ways that current ecologists, environmental engineers, and foresters work to control pine beetle outbreaks in North America. Using this information along with your models, your group will write a proposal to states or territories encountering the beetles for the first time on which solution or combination of solutions is most effective at preventing pine beetle outbreaks.

The solution(s) must:

- Be realistic—a state could actually use your proposal as a resource,
- Be supported by evidence with proper documentation—we need to know the information is real,
- Be supported with sufficient justification for why it is the best solution (see rubric), and
- Maintain biodiversity of the ecosystem—we don't want to make things worse.

Evaluation:

CRITERIA	ADVANCED (4)	PROFICIENT (3)	DEVELOPING (2)	BEGINNING (1)
Solution and Plan	Student provided a thought-out solution and plan that is realistic and maintains biodiversity of the ecosystem.	Student provides a solution to the problem along with a plan.	Student did not outline a plan, the solution was not realistic, or the solution puts other members of the ecosystem at risk.	Student provides no solution to the problem and no plan for implementation.
Alternative Solutions	Student addresses at least 2 alternative solutions to the problem along with justification for why they were not chosen.	Student addresses 1 alternative solution to the problem along with justification for why it was not chosen.	Student addresses 1 or 2 alternative solutions but provides no explanation or justification as to why they were not chosen.	Student addresses no alternative solutions.
Sources	Student provides at least 2 credible sources to support their proposed solution.	Student provides 1 credible source to support their proposed solution.	Student provides 1 source, which is not credible.	Student provides no source of information or data to back up their solution.
Justification	Student's justification is clearly reasoned and based on evidence.	Student's justification is based on evidence.	Student's justification is not clear or is not based on evidence.	Student provides no justification for their proposed solution.
Teacher Comments:				

TABLE 4

Engineering proposal rubric.

Criteria	Advanced (4)	Proficient (3)	Developing (2)	Beginning (1)
Solution	Student provides a solution that is thoughtful, rooted in evidence, and maintains the health of the ecosystem.	Student provides a solution to the problem but lacks strong or clear evidence.	Student's solution was not realistic, or the solution puts other members of the ecosystem at risk.	Student provides no solution to the problem.
Alternate Arguments (Solutions)	Student addresses at least 2 alternate arguments to the problem along with justification for why they could have been chosen but were not.	Student addresses 1 or 2 alternate solutions to the problem along with justification for why it was not chosen. Does not address strengths of alternate arguments.	Student addresses 1 or 2 alternate solutions but provides no explanation or justification as to why they were not chosen. Does not address strengths of alternate arguments.	Student addresses no alternate solutions.
Justification	Student justification is clearly reasoned and based on evidence. Student mentions the strengths and weaknesses of the proposed argument.	Student's justification is clearly reasoned or based on evidence but does not mention the weaknesses of the proposed argument.	Student's justification is not clear or is not based on evidence.	Student provides no justification for their proposed solution.
Sources	Student provides at least 5 credible sources to support their solution.	Student provides less than 5 credible sources to support their solution.	Student provides sources, but none are credible.	Student provides no source of information or data to back up their solution.

not have time (Crismond 2013). Modeling complex phenomena related to real-world problems can be one way for teachers and students to bridge the gap between science and engineering. ■

REFERENCES

Blake, T. 2018. Southern pine beetle makes its way to RI. The Public's Radio. *https://thepublicsradio.org/post/southern-pine-beetle-makes-its-way-ri# stream/0*.

Costanza, R. 2012. Ecosystem health and ecological engineering. *Ecological Engineering* 45: 24–29. *https://doi.org/10.1016/j.ecoleng.2012.03.023*.

Crismond, D. 2013. Design practices and misconceptions. *The Science Teacher* 80 (1): 50–54.

Holston, V., and C. Santa. 1985. RAFT: A method of writing across the curriculum that works. *Journal of Reading* 28 (5): 456–457.

Mitsch, W.J. 1996. Ecological engineering: A new paradigm for engineers and ecologists. In *Engineering within ecological constraints*, ed. 111–128. Washington, DC: National Academies Press.

National Geographic. 2018. Life of pine. *www.youtube.com/watch?v=vR30qIK0-Cw&t=1s*.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards*.

Rosner, H. 2015. The bug that's eating the woods. *National Geographic*. *www.nationalgeographic.com/magazine/2015/04/pine-beetles-forest-destruction-canada-rockies*.

Sampson, V., J. Grooms, and J. Walker. 2009. Argument-driven inquiry. *The Science Teacher* 76 (8): 42–47.

Schlossberg, T. 2016. Warmer Winter Brings Forest-Threatening Beetles North. *New York Times*, March 22. *www.nytimes.com/2016/03/22/science/southern-pine-beetles-new-england-forests.html*.

Strain, D. 2012. Climate change sends beetles into overdrive. *Science*. *www.sciencemag.org/news/2012/03/climate-change-sends-beetles-overdrive*.

Whitworth, B.A. and L.B. Wheeler. 2017. Is it engineering or not? *The Science Teacher* 84 (5): 25–29.

Windschitl, M., J. Thompson, and M. Braaten. 2018. *Ambitious science teaching*. Cambridge, MA: Harvard Education Press.

Xiang, L., and A. Mitchell. 2019. Investigating bark beetle outbreaks. *Science Scope* 42 (6): 65–76.

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standard

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics

Performance Expectations

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

HS-LS2-6. Evaluate claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.

HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Engaging in Argument From Evidence Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments.	Students research various methods of forest preservation and restoration and evaluate the sources for an engineering proposal.
Constructing Explanations and Designing Solutions Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade-off considerations.	Students propose a solution to the growing pine beetle epidemic that will maintain and preserve healthy forests.
Disciplinary Core Ideas	
LS2.C: Ecosystem Dynamics, Functioning, and Resilience A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions.	Students develop models describing pine beetle outbreaks to help explain past, present, and future statuses of the forest ecosystem.
LS4.D: Biodiversity and Humans Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change.	Students examine climate data and sources on the effects of climate change to determine how humans have an effect on climate, which also affects the severity of pine beetle outbreaks.
EST1.B: Developing Possible Solutions When evaluating solutions, it is important to take into account a range of constraints including cost, safety, reliability, and aesthetics and to consider social, cultural, and environmental impacts.	Students propose an ecological engineering solution, addressing potential loss of biodiversity and solutions to maintain stable and sustainable ecosystems. Students complete an ecological engineering task to determine the risks and benefits associated with solutions to pine beetle outbreaks, selecting those best for preventing outbreaks.
Crosscutting Concepts	
Stability and Change Much of science deals with constructing explanations of how things change and how they remain stable.	Students create models and explanations to describe how the forest ecosystem has changed from the past and could change in the future due to pine beetle outbreaks.

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