Alignment of *Engineering Design Inspired by Nature* with the NGSS

The following rubric form serves to document the fact that, and the manner in which, the *Engineering Design Inspired by Nature* curriculum is aligned with the Next Generation Science Standards, and follows the EQuIP Rubric for this documentation, as recommended by the authoring agents of the NGSS (e.g., Achieve.org).

The document evaluates several of the curriculum's lesson plans with respect to the NGSS, but not all of them. There are several reasons for this:

- Some of the lesson plans form sequences that support other lesson plans, and are not designed to be evaluated independently of the other lesson plans with which they form larger learning trajectories.
- Some lesson plans go beyond the parameters described in the EQuIP Rubric by design, to meet additional learning objectives not specified in the NGSS.
- The curriculum includes a sizable final student project in which many or all of the performance expectations can readily be included. Because of the open-ended nature of the final student project, it is left largely up to the teacher which performance expectation to include here.
- The representative sample of lesson plans evaluated should be sufficient to demonstrate that the curriculum is indeed aligned with the NGSS.

The main area of the NGSS addressed by the *Engineering Design Inspired by Nature* curriculum are the Engineering Design standards. Other areas include Life Sciences, Earth Sciences, and the Physical Sciences. Within Engineering Design, the lesson plan which address the main performance standards are provided in the table below:

Performance expectation	**Addressed in the following lesson plans**
HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.	LP 4, 5, 19, 20
HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.	LP 4, 5, 7, 8, 20
HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.	LP 5, 7, 8, 9, 13, 20
HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.	LP 9

The next 4 pages contain language from the EQuIP Rubric. The standards alignment analysis of the *Engineering Design Inspired by Nature* curriculum begins on page 5.

EQuIP Rubric for Lessons & Units: Science

Introduction

The Educators Evaluating the Quality of Instructional Products (EQuIP) Rubric for science provides criteria by which to measure the alignment and overall quality of lessons and units with respect to the Next Generation Science Standards (NGSS). The purposes of the rubric and review process are to: (1) review existing lessons and units to determine what revisions are needed; (2) provide constructive criterion-based feedback and suggestions for improvement to developers; (3) identify exemplars/models for teachers' use within and across states; and (4) to inform the development of new lessons and units.

To effectively apply this rubric, an understanding of the National Research Council's *A Framework for K–12 Science Education and the Next Generation Science Standards*, including the NGSS shifts (appendix A of the NGSS), is needed. Unlike the EQuIP Rubrics for mathematics and ELA, there is not a category in the science rubric for shifts. Over the course of the rubric development, writers and reviewers noted that the shifts fit naturally into the other three categories. For example, the blending of the three-dimensions, or three-dimensional learning, is addressed in each of the three categories; coherence is addressed in the first two categories; connections to the Common Core State Standards is addressed in the first category; etc. Each category includes criteria by which to evaluate the integration of engineering, when included in a lesson or unit, through practices or disciplinary core ideas. Another difference between the EQuIP Rubrics from mathematics and ELA is in the name of the categories; the rubric for science refers to them simply as *categories*, whereas the math and ELA rubrics refer to the categories as dimensions. This distinction was made because the Next Generation Science Standards already uses the term *dimensions* to refer to practices, disciplinary core ideas, and crosscutting concepts.

The architecture of the NGSS is significantly different from other sets of standards. The three dimensions, crafted into performance expectations, describe what is to be assessed following instruction and therefore are the measure of proficiency. A lesson or unit may provide opportunities for students to demonstrate performance of practices connected with their understanding of core ideas and crosscutting concepts as foundational pieces. This three-dimensional learning leads toward eventual mastery of performance expectations. In this scenario, quality materials should clearly describe or show how the lesson or unit works coherently with previous and following lessons or units to help build toward eventual mastery of performance expectations. The term *element* is used in the rubric to represent the relevant, bulleted practices, disciplinary core ideas, and crosscutting concepts that are articulated in the foundation boxes of the standards as well as the in the NGSS appendices on each dimension. Given the understanding that a lesson or unit may include the blending of practices, disciplinary core ideas, and crosscutting concepts that are not identical to the combination of practices, disciplinary core ideas, and crosscutting concepts in a performance expectation, the new term *elements* was needed to describe these smaller units of the three dimensions. Although it is unlikely that a single lesson would provide adequate opportunities for a student to demonstrate proficiency on every dimension of a performance expectation, high-quality units are more likely to provide these opportunities to demonstrate proficiency on one or more performances expectations.

There is a recognition among educators that curriculum and instruction will need to shift with the adoption of the NGSS, but there is currently a lack of NGSS-aligned materials. The power of the rubric is in the feedback and suggestions for improvement it provides curriculum developers and the productive conversations educators have while evaluating materials (i.e., the review process). For curriculum developers, the rubric and review process provide evidence on the quality and alignment of a lesson or unit to the NGSS. Additionally, the rubric and review process generate suggestions for improvement on how materials can be further improved and more closely aligned to the NGSS. As more NGSS lessons and units are developed, this rubric may change to meet the evolving needs of supporting both educators in evaluating materials and developers in the modification and creation of materials. Additionally, support materials will be developed to complement the use of this rubric, such as a professional development guide, a criterion discussion guide, and publishers' criteria that will be more focused on textbooks and comprehensive curriculums.

Directions

The first step in the review process is to become familiar with the rubric, the lesson or unit, and the practices, disciplinary core ideas, and crosscutting concepts targeted in the lesson or unit. The three categories in the rubric correspond to: alignment to the NGSS, instructional supports, and monitoring student progress. Specific criteria within each category should be considered separately as part of the complete review process and are used to provide sufficient information for determination of overall quality of the lesson or unit. For the purposes of using the rubric, a lesson is defined as: a coherent set of instructional activities and assessments aligned to the NGSS that may extend over a few to several class periods or days and a unit is defined as: coherent set of lessons aligned to the NGSS that extend over a longer period of time.

Also important to the review process is feedback and suggestions for improvement to the developer of the resource. For this purpose a set of response forms is included so that the reviewer can effectively provide criterion-based feedback and suggestions for improvement for each category. The response forms correspond to the criteria of the rubric. Evidence for each criterion must be identified and documented and criterion-based feedback and suggestions for improvement should be given to help improve the lesson or unit.

While it is possible for the rubric to be applied by an individual, the quality review process works best with a team of reviewers, as a collaborative process, with the individuals recording their thoughts and then discussing with other team members before finalizing their feedback and suggestions for improvement. Discussions should focus on understanding all reviewers' interpretations of the criteria and the evidence they have found. The goal of the process is to eventually calibrate responses across reviewers and to move toward agreement about quality with respect to the NGSS. Commentary needs to be constructive, with all lessons or units considered "works in progress." Reviewers must be respectful of team members and the resource contributor. Contributors should see the review process as an opportunity to gather feedback and suggestions for improvement rather than to advocate for their work. All feedback and suggestions for improvement should be criterion-based and have supporting evidence from the lesson or unit cited.

Note: This rubric will eventually have scoring guidelines for each category, as well as for an overall rating. However, given the current lack of NGSS-aligned materials, rather than focusing on ratings at this point in time, the focus should be on becoming familiar with the rubric and using it to provide criterion-based feedback and suggestions for improvement to developers and make revisions to existing materials.

Step 1 – Review Materials

The first step in the review process is to become familiar with the rubric, the lesson or unit, and the practices, disciplinary core ideas, and crosscutting concepts targeted in the lesson or unit.

- Review the rubric and record the grade and title of the lesson or unit on the response form.
- Scan to see what the lesson or unit contains, what practices, disciplinary core ideas, and crosscutting concepts are targeted, and how it is organized.
- Read key materials related to instruction, assessment, and teacher guidance.

Step 2 – Apply Criteria in Category I: Alignment to the NGSS

The second step is to evaluate the lesson or unit using the criteria in the first category, first individually and then as a team.

- Closely examine the lesson or unit through the "lens" of each criterion in the first category of the response form.
- Individually check each criterion on the response form for which clear and substantial evidence is found and record the evidence and reasoning.
- As a team, discuss criteria for which clear and substantial evidence is found, as well as criterion-based suggestions for specific improvements that might be needed to meet criteria.

If the lesson or unit is not closely aligned to the Next Generation Science Standards, it may not be appropriate to move on to the second and third categories. Professional judgment should be used when weighing the individual criterion. For example, a lesson without crosscutting concepts explicitly called out may be easier to revise than one without appropriate disciplinary core ideas; such a difference may determine whether reviewers believe the lesson merits continued evaluation or not.

Step 3 – Apply Criteria in Categories II and III: Instructional Supports and Monitoring Student Progress

The third step is to evaluate the lesson or unit using the criteria in the second and third categories, first individually and then as a group.

- Closely examine the lesson or unit through the "lens" of each criterion in the second and third categories of the response form.

- Individually check each criterion on the response form for which clear and substantial evidence is found and record the evidence and reasoning.
- As a team, discuss criteria for which clear and substantial evidence is found, as well as criterion-based suggestions for specific improvements that might be needed to meet criteria.

When working in a group, teams may choose to compare ratings after each category or delay conversation until each person has rated and recorded input for the two remaining categories. Complete consensus among team members is not required but discussion is a key component of the review process.

EQuIP Rubric for Lessons & Units: Science

I. Alignment to the NGSS	II. Instructional Supports	III. Monitoring Student Progress
The lesson or unit aligns with the conceptual shifts of the NGSS: A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems. i. Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems. ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems. iii. Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems. iv. The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems. A unit or longer lesson will also: B. Lessons fit together coherently targeting a set of performance expectations. i. Each lesson links to previous lessons and provides a need to engage in the current lesson. ii. The lessons help students develop proficiency on a targeted set of performance expectations. C. Where appropriate, disciplinary core ideas from different disciplines are used together to explain phenomena. D. Where appropriate, crosscutting concepts are used in the explanation of phenomena from a variety of disciplines. E. Provides grade-appropriate connection(s) to the Common Core State Standards in Mathematics and/or English Language Arts & Literacy in History/Social Studies, Science and Technical Subjects.	The lesson or unit supports instruction and learning for all students: A. Engages students in authentic and meaningful scenarios that reflect the practice of science and engineering as experienced in the real world and that provide students with a purpose (e.g., making sense of phenomena and/or designing solutions to problems). i. The context, including phenomena, questions, or problems, motivates students to engage in three-dimensional learning. ii. Provides students with relevant phenomena (either firsthand experiences or through representations) to make sense of and/or relevant problems to solve. iii. Engages students in multiple practices that work together with disciplinary core ideas and crosscutting concepts to support students in making sense of phenomena and/or designing solutions to problems. iv. Provides opportunities for students to connect their explanation of a phenomenon and/or their design solution to a problem to their own experience. v. When engineering performance expectations are included, they are used along with disciplinary core ideas from physical, life, or earth and space sciences. B. Develops deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts by identifying and building on students' prior knowledge. C. Uses scientifically accurate and grade-appropriate scientific information, phenomena, and representations to support students' three-dimensional learning. D. Provides opportunities for students to express, clarify, justify, interpret, and represent their ideas and respond to peer and teacher feedback orally and/or in written form as appropriate to support student's three-dimensional learning. E. Provides guidance for teachers to support differentiated instruction in the classroom so that every student's needs are addressed by including: i. Suggestions for how to connect instruction to the students' home, neighborhood, community and/or culture as appropriate. ii. Appropriate reading, writing, listening, and/or speaking alternatives (e.g., translations, picture support, graphic organizers) for students who are English language learners, have special needs, or read well below the grade level. iii. Suggested extra support (e.g., phenomena, representations, tasks) for students who are struggling to meet the performance expectations. iv. Extensions for students with high interest or who have already met the performance expectations to develop deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts. A unit or longer lesson will also: F. Provides guidance for teachers throughout the unit for how lessons build on each other to support students developing deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts over the course of the unit. G. Provides supports to help students engage in the practices as needed and gradually adjusts supports over time so that students are increasingly responsible for making sense of phenomena and/or designing solutions to problems.	The lesson or unit supports monitoring student progress: A. Elicits direct, observable evidence of three-dimensional learning by students using practices with core ideas and crosscutting concepts to make sense of phenomena and/or to design solutions. B. Formative assessments of three-dimensional learning are embedded throughout the instruction. C. Includes aligned rubrics and scoring guidelines that provide guidance for interpreting student performance along the three dimensions to support teachers in (a) planning instruction and (b) providing ongoing feedback to students. D. Assessing student proficiency using methods, vocabulary, representations, and examples that are accessible and unbiased for all students. A unit or longer lesson will also: E. Includes pre-, formative, summative, and self-assessment measures that assess three-dimensional learning. F. Provides multiple opportunities for students to demonstrate performance of practices connected with their understanding of disciplinary core ideas and crosscutting concepts and receive feedback.

Reviewer Name or ID: The Center for Learning with Nature **Grade:** HS **Lesson/Unit Title:** LP4 Tutelage of Trees

Main performance expectations addressed:

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

Material safety is a major global challenge across all manufacturing, with implications for human health. Hence, material safety is a factor in societal needs and wants. In this lab, students qualitatively and quantitatively analyze material design for safety by using models to empirically test and evaluate three different design solutions to the concentration of mechanical stress in material.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Ensuring the things we make do not fail is a complex, real-world problem. The things we make can be understood at various spatial scales and conceptual organization, e.g. (from smallest to biggest), chemical composition, material structure, component design, device architecture, and system interaction. The things we make can fail at any of these scales. A smaller, more manageable problem that is part of the bigger problem of failure focuses on the strength of the materials used in the things we make, and ensuring these do not fail. We can pursue a solution to the issue of material strength through engineering. In this lesson based on processes used by professional engineers, students consider the concentration of mechanical stress through different material structures (e.g., a notch with no fillet, a notch with a quarter-circle fillet, and a notch with a tree-based fillet).

I. Alignment to the NGSS

The lesson or unit aligns with the conceptual shifts of the NGSS:

Criteria	Specific evidence from materials and reviewers' reasoning
A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems. i. Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems. ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems. iii. Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems. iv. The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems.	Ai. Science and Engineering Practices In this lesson plan, students are involved in **Asking Questions and Defining Problems.** They formulate questions such as, What is the most important attribute of the things people engineer? What do we mean when we say something breaks for fails? Why do things fail? What makes a material strong? They also use models to empirically test and evaluate three different design solutions to the concentration of mechanical stress in material notches. (**HS-ETS1-1**) Students are also involved in **Constructing Explanations and Designing Solutions.** Students design a solution to a complex, real-world problem through scientific knowledge (i.e., an understanding of the mechanical forces acting on trees in wind) and student-generated sources of evidence (i.e., morphological patterns in trees, specifically the curvature at their bases, which have evolved an optimized design for managing mechanical stress concentration). (**HS-ETS1-2**) Aii. Disciplinary Core Ideas Students are involved in **Defining and Delimiting Engineering Problems.** Safety is a major criteria and constraint placed on engineering design by society, and students explore this issue in depth here (including in the homework assignment). (**HS-ETS1-1**) Students **optimize their design solution** through the photoelastic stress-test activities comparing stress concentration through different material structures. (**HS-ETS1-2**) Aiii. Crosscutting Concepts The interacting **influences of science, engineering, and technology on society and the natural world** and vice versa are quite explicit here, particularly in how understanding of how trees manage mechanical stress can inform our own engineering and design approaches to material structure. (**HS-ETS1-1**) Aiv. Dimensions Work Together The lesson plan touches on all of the dimensions and elements above in a single, cohesive discussion and set of activities exploring material structure.

A unit or longer lesson will also:

Criteria	Specific evidence from materials and reviewers’ reasoning
B. Lessons fit together coherently targeting a set of performance expectations. i. Each lesson links to previous lessons and provides a need to engage in the current lesson. ii. The lessons help students develop proficiency on a targeted set of performance expectations.	Bi. LP4 on material structure in trees builds specifically from LP3 on the topic of fracture mechanics, and develops these ideas further with an examination of the mechanical attributes of trees. Bii. These lessons helps students develop proficiency specifically on performance expectations **HS-ETS1-1**, and **HS-ETS1-2**.
C. Where appropriate, disciplinary core ideas from different disciplines are used together to explain phenomena.	C. Discussion around the evolution of material structures effective at minimizing stress concentrations connects with the life sciences core idea of adaption (**LS4.C**). The use of physical models to examine stress concentrations connects with **ETS1.B** (Developing Possible Solutions). The use of photoelasticity connects with the physical sciences (**HS-PS4-5**), specifically regarding wave properties (**PS4.A**) and Information Technologies and Instrumentation (**PS4.C**).
D. Where appropriate, crosscutting concepts are used in the explanation of phenomena from a variety of disciplines.	D. This lesson plan activity provides an opportunity for detailed examination of different material structures for how they function under tensile stress, addressing a crosscutting concept about structure and function (**HS-LS1-1**). The lesson plan also connect with engineering, technology and applications of science, a crosscutting concept in Engineering Design (**HS-ETS**), in which engineers continuously modify technologies through application of engineering design processes to increase benefits and decrease costs and risk.
E. Provides grade-appropriate connection(s) to the Common Core State Standards in Mathematics and/or English Language Arts & Literacy in History/Social Studies, Science and Technical Subjects.	TBD

II. Instructional Supports

The lesson or unit supports instruction and learning for all students:

Criteria	Specific evidence from materials and reviewers' reasoning
A. Engages students in authentic and meaningful scenarios that reflect the practice of science and engineering as experienced in the real world and that provide students with a purpose (e.g., making sense of phenomena and/or designing solutions to problems). i. The context, including phenomena, questions, or problems, motivates students to engage in three-dimensional learning. ii. Provides students with relevant phenomena (either firsthand experiences or through representations) to make sense of and/or relevant problems to solve. iii. Engages students in multiple practices that work together with disciplinary core ideas and crosscutting concepts to support students in making sense of phenomena and/or designing solutions to problems. iv. Provides opportunities for students to connect their explanation of a phenomenon and/or their design solution to a problem to their own experience. v. When engineering performance expectations are included, they are used along with disciplinary core ideas from physical, life, or earth and space sciences.	A. Material scientists and engineers have to address questions of material physical performance in everything designed and manufactured. Testing of material stress and designing items to adequately handle mechanical forces is a real world activity. Moreover, the importance of ensuring materials do not fail is emphasized with real life and dramatic examples, helping provide students with a sense of the importance of this topic. The methods of testing material strength (i.e., photoelasticity and stress tests) are used by modern material scientists. In addition, the method of Tensile Triangles, based on curvatures found in trees, in order to optimize material notches was developed by mechanical engineers and is used throughout the world in one form or another. In addition, because the design solutions are derived from common objects (trees) in the students' environment, these solutions are related to their own experience.
B. Develops deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts by identifying and building on students' prior knowledge.	TBD
C. Uses scientifically accurate and grade-appropriate scientific information, phenomena, and representations to support students' three-dimensional learning.	These methods are scientifically based and grade-appropriate.
D. Provides opportunities for students to express, clarify, justify, interpret, and represent their ideas and respond to peer and teacher feedback orally and/or in written form as appropriate to support student's three-dimensional learning.	Students are encouraged to participate in discussions structured throughout the lesson plan.
E. Provides guidance for teachers to support differentiated instruction in the classroom so that every student's needs are addressed by including: i. Suggestions for how to connect instruction to the students' home, neighborhood, community and/or culture as appropriate.	Ei. Homework and examples reinforce connections outside the classroom. Eii. The activity involves graphic forms. Eiii. Various descriptions are provided to help struggling students. Eiv. TBD

ii. Appropriate reading, writing, listening, and/or speaking alternatives (e.g., translations, picture support, graphic organizers) for students who are English language learners, have special needs, or read well below the grade level. iii. Suggested extra support (e.g., phenomena, representations, tasks) for students who are struggling to meet the performance expectations. iv. Extensions for students with high interest or who have already met the performance expectations to develop deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts.	

A unit or longer lesson will also:

Criteria	Specific evidence from materials and reviewers' reasoning
F. Provides guidance for teachers throughout the unit for how lessons build on each other to support students developing deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts over the course of the unit.	This lesson on addressing mechanical stress builds clearly from the previous one introducing fracture mechanics.
G. Provides supports to help students engage in the practices as needed and gradually adjusts supports over time so that students are increasingly responsible for making sense of phenomena and/or designing solutions to problems.	The activities provide students the opportunity to understand phenomena and design solutions.

III. Monitoring Student Progress

The lesson or unit supports monitoring student progress:

Criteria	Specific evidence from materials and reviewers' reasoning
A. Elicits direct, observable evidence of three-dimensional learning by students using practices with core ideas and crosscutting concepts to make sense of phenomena and/or to design solutions.	The activities of testing physical plastics of various structures provides this direct, observable evidence.
B. Formative assessments of three-dimensional learning are embedded throughout the instruction.	Informal formative assessments through discussions and activities are made available to the teacher for making formative assessments. The homework assignment also provides a formative assessment opportunity.
C. Includes aligned rubrics and scoring guidelines that provide guidance for interpreting student performance along the three dimensions to support teachers in (a) planning instruction and (b) providing ongoing feedback to students.	NA
D. Assessing student proficiency using methods, vocabulary, representations, and examples that are accessible and unbiased for all students.	Homework assignment provides good assessment opportunities.

A unit or longer lesson will also:

Criteria	Specific evidence from materials and reviewers' reasoning
E. Includes pre-, formative, summative, and self-assessment measures that assess three-dimensional learning.	Opportunities for assessment at all stages are included through discussions and activities in-class and after school.
F. Provides multiple opportunities for students to demonstrate performance of practices connected with their understanding of disciplinary core ideas and crosscutting concepts and receive feedback.	Yes.

Main performance expectations addressed:

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

Material efficiency is a major global challenge across all manufacturing, with implications for natural resources, energy, and environmental impacts. Hence, material efficiency is a factor in societal needs and wants. In this lab, students qualitatively and quantitatively analyze material design for efficiency and create design alternatives that take into account societal needs and wants.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

The use of raw material to make things is a complex real-world problem at the base of all physical engineering. Within this larger challenge, material efficiency is a smaller, more manageable problem that can be addressed through engineering. In this lesson based on processes used by professional engineers, students redesign common objects to be more materially efficient based on lessons learned from the growth processes of bones.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

Students evaluate two different design solutions addressing the complex real-world problem of material efficiency. Criteria and trade-offs considered include cost, safety, reliability, aesthetics, and possible social, cultural, and environmental impacts.

I. Alignment to the NGSS

The lesson or unit aligns with the conceptual shifts of the NGSS:

Criteria	Specific evidence from materials and reviewers' reasoning
A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems. i. Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems. ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems. iii. Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems. iv. The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems.	Ai. Science and Engineering Practices. Through **constructing explanations and designing solutions,** students design a solution to the complex real-world problem of material efficiency, based the photoelastic evidence they produce, criteria emphasizing dematerialization, and tradeoffs involving aesthetic consideration and material design (**HS-ETS1-2**). Aii. Disciplinary Core Ideas. **ETS1.A** In **defining and delimiting engineering problems**, students learn that humanity faces global challenges including the use of raw materials to make things, which can be addressed through engineering (**HS-ETS1-1**). **ETS1.B** Through **developing possible solutions**, students evaluate their design solutions considering a range of constraints and considerations (**HS-ETS1-3**). **ETS1.C** By **optimizing the design solution** in the lesson plan activities students come to see how the larger problem of material use can be addressed to a degree through design for dematerialization (**HS-ETS1-2**). Aiii. Cross-cutting Concepts. Students understand the **Influence of Science, Engineering, and Technology on Society and the Natural World** through the change in material use redesigning material objects can have on the use of raw materials, processing, and disposal (**HS-ETS1-1**)(**HS-ETS1-3**). Aiv. Dimensions Work Together The lesson plan touches on all of the dimensions and elements above in a single, cohesive discussion and set of activities exploring material efficiency.

A unit or longer lesson will also:

Criteria	Specific evidence from materials and reviewers' reasoning
B. Lessons fit together coherently targeting a set of performance expectations. i. Each lesson links to previous lessons and provides a need to engage in the current lesson. ii. The lessons help students develop proficiency on a targeted set	Bi. This lesson plan on material efficiency links clearly to the previous lessons on material safety and strength. Bii. The lesson plan helps students develop proficiency with performance expectations **HS-ETS1-1/2/3**.

of performance expectations.	
C. Where appropriate, disciplinary core ideas from different disciplines are used together to explain phenomena.	Core ideas are integrated from Life Sciences: **LS2.C** (**HS-LS2-7**) and Earth Sciences: **ESS3.A**, **ETS1.B** (**HS-ESS3-2), ESS3.C, ETS1.B (HS-ESS3-4**).
D. Where appropriate, crosscutting concepts are used in the explanation of phenomena from a variety of disciplines.	Yes, with regards to the **Influence of Engineering, Technology, and Science on Society and the Natural World**
E. Provides grade-appropriate connection(s) to the Common Core State Standards in Mathematics and/or English Language Arts & Literacy in History/Social Studies, Science and Technical Subjects.	TBD

II. Instructional Supports

The lesson or unit supports instruction and learning for all students:

Criteria	Specific evidence from materials and reviewers' reasoning
A. Engages students in authentic and meaningful scenarios that reflect the practice of science and engineering as experienced in the real world and that provide students with a purpose (e.g., making sense of phenomena and/or designing solutions to problems). i. The context, including phenomena, questions, or problems, motivates students to engage in three-dimensional learning. ii. Provides students with relevant phenomena (either firsthand experiences or through representations) to make sense of and/or relevant problems to solve. iii. Engages students in multiple practices that work together with disciplinary core ideas and crosscutting concepts to support students in making sense of phenomena and/or designing solutions to problems. iv. Provides opportunities for students to connect their explanation of a phenomenon and/or their design solution to a problem to their own experience. v. When engineering performance expectations are included, they are used along with disciplinary core ideas from physical, life, or earth and space sciences.	A. The lesson involves learning about the relevance of material design in terms of the use of natural resources, performance, and aesthetics, while engaging students in the practice of dematerialization or material optimization, practices that professional designers and engineers engage in on a regular basis. Moreover, the lesson does this through the engaging biological example of (human) bone growth and shaping processes, and provides students with a hands-on (firsthand) experience of applying these ideas to actual materials.
B. Develops deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts by identifying and building on students' prior knowledge.	This lesson builds directly from the previous lesson (Tutelage of Trees).
C. Uses scientifically accurate and grade-appropriate scientific information, phenomena, and representations to support students' three-dimensional learning.	The methods described and practiced are the result of peer-reviewed published research (by Dr. Claus Mattheck). The material is deemed grade-appropriate due to positive pilot evaluation results.
D. Provides opportunities for students to express, clarify, justify, interpret, and represent their ideas and respond to peer and teacher feedback orally and/or in written form as appropriate to support student's three-dimensional learning.	The lesson involves discussion and classroom sharing of student results.
E. Provides guidance for teachers to support differentiated instruction in the classroom so that every student's needs are addressed by including: i. Suggestions for how to connect instruction to the students' home, neighborhood, community and/or culture as appropriate.	The lesson relates concepts using material objects found in the students' environment. Presentation is through mixed modalities including spoken and written word, and graphics. Extensions are provided through homework suggestions.

ii. Appropriate reading, writing, listening, and/or speaking alternatives (e.g., translations, picture support, graphic organizers) for students who are English language learners, have special needs, or read well below the grade level. iii. Suggested extra support (e.g., phenomena, representations, tasks) for students who are struggling to meet the performance expectations. iv. Extensions for students with high interest or who have already met the performance expectations to develop deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts.	

A unit or longer lesson will also:

Criteria	Specific evidence from materials and reviewers' reasoning
F. Provides guidance for teachers throughout the unit for how lessons build on each other to support students developing deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts over the course of the unit.	Provided through background information give in this and previous lesson plans.
G. Provides supports to help students engage in the practices as needed and gradually adjusts supports over time so that students are increasingly responsible for making sense of phenomena and/or designing solutions to problems.	This possibility exists through how the teacher conducts the hands-on and discussion portions of the lesson.

III. Monitoring Student Progress

The lesson or unit supports monitoring student progress:

Criteria	Specific evidence from materials and reviewers' reasoning
A. Elicits direct, observable evidence of three-dimensional learning by students using practices with core ideas and crosscutting concepts to make sense of phenomena and/or to design solutions.	Yes, through the physical alteration of material by students using the principles described in the lesson.
B. Formative assessments of three-dimensional learning are embedded throughout the instruction.	Informal formative assessments through discussions and activities are made available to the teacher for making formative assessments.
C. Includes aligned rubrics and scoring guidelines that provide guidance for interpreting student performance along the three dimensions to support teachers in (a) planning instruction and (b) providing ongoing feedback to students.	NA
D. Assessing student proficiency using methods, vocabulary, representations, and examples that are accessible and unbiased for all students.	See above.

A unit or longer lesson will also:

Criteria	Specific evidence from materials and reviewers' reasoning
E. Includes pre-, formative, summative, and self-assessment measures that assess three-dimensional learning.	Opportunities for assessment at all stages are included through discussions and activities in-class.
F. Provides multiple opportunities for students to demonstrate performance of practices connected with their understanding of disciplinary core ideas and crosscutting concepts and receive feedback.	Yes, through the in-class hands-on and discussion activities.

Reviewer Name or ID: The Center for Learning with Nature **Grade:** HS **Lesson/Unit Title:** LP9 The Acumen of Ants

Main performance expectations addressed:

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

This lesson plan evaluates computer science solutions to the fundamental real-world challenge of search (i.e., search algorithms). The evaluation is based on the prioritized criteria and constraints related to efficiency (speed) and accuracy of results.

HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

This lesson plan uses a computer simulation to model computer science solutions to the complex real-world problem of search, and explores the criteria and constraints related to efficiency (speed) and accuracy of results within and between systems relevant to this challenge.

I. Alignment to the NGSS

The lesson or unit aligns with the conceptual shifts of the NGSS:

Criteria	Specific evidence from materials and reviewers' reasoning
A. Grade-appropriate elements of the science and engineering practice(s), disciplinary core idea(s), and crosscutting concept(s), work together to support students in three-dimensional learning to make sense of phenomena and/or to design solutions to problems. i. Provides opportunities to develop and use specific elements of the practice(s) to make sense of phenomena and/or to design solutions to problems. ii. Provides opportunities to develop and use specific elements of the disciplinary core idea(s) to make sense of phenomena and/or to design solutions to problems. iii. Provides opportunities to develop and use specific elements of the crosscutting concept(s) to make sense of phenomena and/or to design solutions to problems. iv. The three dimensions work together to support students to make sense of phenomena and/or to design solutions to problems.	Ai. The lesson plan is all about **computational thinking**, and compares two search algorithms used by computers, exhaustive search (i.e., brute force search) and ant colony optimization (inspired by the foraging methodologies used by ants). Students explore and contrast these two algorithms through the use of computer-based and other kinds of simulation, providing them the opportunity of using computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (**HS-ETS1-4**). Students in the process have the opportunity to evaluate a solution to a complex real-world problem (optimized search algorithms), based on student-generated sources of evidence, prioritized criteria, and tradeoff considerations (e.g., time and accuracy). (**HS-ETS1-3**). Aii. The lesson provides opportunities for students to explore disciplinary core ideas, specifically through its contrasting of two possible computer science solutions (**ETS1.B: Developing Possible Solutions**), evaluating each in terms of various criteria and constraints (**HS-ETS1-3**) and using physical and computer-based models as aids in this evaluation process (**HS-ETS1-4**). Aiii. The lesson addresses cross-cutting concepts through its use of physical and computers models (**HS-ETS1-4**) and provides **Connections to Engineering, Technology, and Applications of Science** in exploring these algorithms within the context of their impact on computer technology and human well-being, as a matter of cost and benefit. Aiv. The lesson uses ideas and approaches from all 3 dimensions of the NGSS to support student learning.

A unit or longer lesson will also:

Criteria	Specific evidence from materials and reviewers' reasoning
B. Lessons fit together coherently targeting a set of performance expectations. i. Each lesson links to previous lessons and provides a need to engage in the current lesson. ii. The lessons help students develop proficiency on a targeted set of performance expectations.	Bi. The lesson links to other lesson plans primarily through the theme of innovation inspired by Nature running throughout the entire curriculum. Bii. The lesson helps students develop proficiency on the specific performance expectations of HS-ETS1-3 and HS-ETS1-4.
C. Where appropriate, disciplinary core ideas from different disciplines are used together to explain phenomena.	C. The lesson is fairly self-contained in specifically addressing the performance expectations mentioned, and there does not appear to be appropriate opportunities for involving disciplinary core ideas from different disciplines. However, the lesson itself is

	fairly interdisciplinary, involving ideas from mathematics, computer science, and biology.
D. Where appropriate, crosscutting concepts are used in the explanation of phenomena from a variety of disciplines.	D. The lesson is fairly self-contained in specifically addressing the performance expectations mentioned, and there does not appear to be appropriate opportunities for involving disciplinary core ideas from different disciplines. However, the lesson itself is fairly interdisciplinary, involving ideas from mathematics, computer science, and biology.
E. Provides grade-appropriate connection(s) to the Common Core State Standards in Mathematics and/or English Language Arts & Literacy in History/Social Studies, Science and Technical Subjects.	E. The lesson explores combinatorial mathematics, an aspect connected to the high school mathematics standards of the Common Core (e.g., http://www.corestandards.org/Math/Content/HSA/APR/)

II. Instructional Supports

The lesson or unit supports instruction and learning for all students:

Criteria	Specific evidence from materials and reviewers' reasoning
A. Engages students in authentic and meaningful scenarios that reflect the practice of science and engineering as experienced in the real world and that provide students with a purpose (e.g., making sense of phenomena and/or designing solutions to problems). i. The context, including phenomena, questions, or problems, motivates students to engage in three-dimensional learning. ii. Provides students with relevant phenomena (either firsthand experiences or through representations) to make sense of and/or relevant problems to solve. iii. Engages students in multiple practices that work together with disciplinary core ideas and crosscutting concepts to support students in making sense of phenomena and/or designing solutions to problems. iv. Provides opportunities for students to connect their explanation of a phenomenon and/or their design solution to a problem to their own experience. v. When engineering performance expectations are included, they are used along with disciplinary core ideas from physical, life, or earth and space sciences.	Ai. This lesson combines two relevant and engaging contexts, computer science (an increasingly pertinent part of the modern world) and Nature, and does so by posing questions that are readily grasped by students (i.e., search optimization). Aii. See above. Aiii. This lesson makes particularly good use of physical, mathematical, and computer-based modeling to explore the lesson topic. Aiv. The lesson uses phenomena students are very familiar with (e.g., internet searches) to explore larger computer science questions, as well as physical modeling to make these phenomena more intuitive. Av. The lesson is fairly self-contained in specifically addressing the performance expectations mentioned, and there does not appear to be appropriate opportunities for involving disciplinary core ideas from different disciplines. However, the lesson itself is fairly interdisciplinary, involving ideas from mathematics, computer science, and biology.
B. Develops deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts by identifying and building on students' prior knowledge.	B. Students have vague ideas about search algorithms from frequent use of internet search and this lesson clarifies and builds upon these experiences.

C. Uses scientifically accurate and grade-appropriate scientific information, phenomena, and representations to support students' three-dimensional learning.	C. The information in the lesson is well-referenced and accurately depicted. The concepts are readily understandable to high school and middle school students, and uses various models to help students deepen their understanding of the concepts addressed.
D. Provides opportunities for students to express, clarify, justify, interpret, and represent their ideas and respond to peer and teacher feedback orally and/or in written form as appropriate to support student's three-dimensional learning.	D. The lesson includes these opportunities primarily through classroom discussion.
E. Provides guidance for teachers to support differentiated instruction in the classroom so that every student's needs are addressed by including: i. Suggestions for how to connect instruction to the students' home, neighborhood, community and/or culture as appropriate. ii. Appropriate reading, writing, listening, and/or speaking alternatives (e.g., translations, picture support, graphic organizers) for students who are English language learners, have special needs, or read well below the grade level. iii. Suggested extra support (e.g., phenomena, representations, tasks) for students who are struggling to meet the performance expectations. iv. Extensions for students with high interest or who have already met the performance expectations to develop deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts.	Ei. The context of this lesson relates well to the students' personal experiences. Eii. The lesson uses methods like mathematical symbols and physical modeling to convey ideas in a way that a wide variety of students can understand. Eiii. The lesson is crafted in such a way that extra support should not be needed, but additional resources are provided in the "More Resources" section. Eiv. This is provided through the homework.

A unit or longer lesson will also:

Criteria	Specific evidence from materials and reviewers' reasoning
F. Provides guidance for teachers throughout the unit for how lessons build on each other to support students developing deeper understanding of the practices, disciplinary core ideas, and crosscutting concepts over the course of the unit.	Provided through background information give in the lesson plan.
G. Provides supports to help students engage in the practices as needed and gradually adjusts supports over time so that students are increasingly responsible for making sense of phenomena and/or designing solutions to problems.	This is provided through the design of the lesson, which draws on students to think through questions in classroom discussion.

III. Monitoring Student Progress

The lesson or unit supports monitoring student progress:

Criteria	Specific evidence from materials and reviewers' reasoning
A. Elicits direct, observable evidence of three-dimensional learning by students using practices with core ideas and crosscutting concepts to make sense of phenomena and/or to design solutions.	Provided through classroom discussion and individual homework assignments.
B. Formative assessments of three-dimensional learning are embedded throughout the instruction.	Yes, primarily through classroom discussion, since the lesson plan spans only one classroom period.
C. Includes aligned rubrics and scoring guidelines that provide guidance for interpreting student performance along the three dimensions to support teachers in (a) planning instruction and (b) providing ongoing feedback to students.	Not so much; could be improved.
D. Assessing student proficiency using methods, vocabulary, representations, and examples that are accessible and unbiased for all students.	Not provided since individual student assessments are not provided, but could readily be incorporated e.g., through the individualized homework assignment.

A unit or longer lesson will also:

Criteria	Specific evidence from materials and reviewers' reasoning
E. Includes pre-, formative, summative, and self-assessment measures that assess three-dimensional learning.	Yes, through in-class discussion and individual homework assignments.
F. Provides multiple opportunities for students to demonstrate performance of practices connected with their understanding of disciplinary core ideas and crosscutting concepts and receive feedback.	Yes, through in-class discussion and individual homework assignments.

Some other high school performance expectations from the NGSS related directly to engineering:

HS-PS1-6

HS-PS2-3 p.78

Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.*

HS-PS3-3 p.80

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*

HS-PS4-5 p.82

HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.*

HS-LS2-7 p.87

Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.*

HS-LS4-6 p.87

Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.*

HS-ESS3-2 p.100

Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*

HS-ESS3-4 p.100

Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*

HS-ETS1-1

HS-ETS1-2

HS-ETS1-3

HS-ETS1-4