School District of the City of St. Charles

Industrial Technology Addendum - PLTW Engineering Design and Development

Approved by the Board of Education
July 15, 2021

Addendum to the 7-12 Industrial Technology Curriculum

Curriculum Committee Chairperson

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7-12 Industrial Technology Addendum

Table of Contents

District Mission

The City of St. Charles School District will REACH, TEACH, and EMPOWER all students by providing a challenging, diverse, and innovative education.

District Vision

The City of St. Charles School District will be an educational leader recognized for high performance and academic excellence that prepares students to succeed in an ever-changing global society.

District Values

We, the City of St. Charles School District community of students, parents, staff, and patrons, value:

- High quality education for all students which includes:
    - Lifelong learning from early childhood through adult education
    - Rigorous learning experiences that challenge all students
    - Instruction that meets the needs of a diverse community
    - Respect for all
    - Real world, critical thinking and problem-solving skills to prepare students for the 21st Century
    - Developing caring, productive, and responsible citizens
    - Strong engagement of family and community
    - A safe, secure, and nurturing school environment
- Achievement through:
    - Celebration of individual success
    - Collaboration with parents and community stakeholders
    - Exploration, Innovation, and creativity
- High quality staff by:
    - Hiring and retaining highly qualified and invested employees
    - Providing professional development and collaboration focused on increasing student achievement
    - Empowering staff to use innovative resources and practices
- Informed decisions that are:
    - Student-centered
    - Focused on student achievement
    - Data Driven
    - Considerate of all points of view
    - Fiscally responsible

District Goals

For planning purposes, five overarching goals have been developed. These goals are statements of the key functions of the school district.

1. Student Performance
   - Develop and enhance the quality educational/instructional programs to improve student performance and enable students to meet their personal, academic, and career goals.
2. Highly qualified staff
   - Recruit, attract, develop, and retain highly qualified staff to carry out the District's mission, vision, goals, and objectives.
3. Facilities, Support, and Instructional Resource
   - Provide and maintain appropriate instructional resources, support services, and functional and safe facilities.
4. Parent and Community Involvement
   - Promote, facilitate and enhance parent, student, and community involvement in district educational programs.
5. Governance
   - Govern the district in an efficient and effective manner providing leadership and representation to benefit the students, staff, and patrons of the district.

School District Philosophical Foundations

Teachers in the School District of the City of St. Charles share in and ascribe to a philosophy that places children at the heart of the educational process. We feel that it is our professional responsibility to strive to be our best at all times and to maximize our efforts by ensuring that the following factors are present in our classrooms and our schools.

1. Learning is developed within the personal, physical, social, and intellectual contexts of the learner.
2. A strong educational program should provide developmental continuity.
3. The successful learner is motivated, strategic, knowledgeable, and interactive.
4. Children learn best when they have real purposes and can make connections to real life.
5. Effective learning is a combination of student exploration and teacher and mentor modeling.
6. Assessment is an ongoing and multidimensional process that is an integral part of instruction.
7. Making reading and writing connections across multiple sources and curricula facilitates meaning.
8. Literacy for the future means literacy in multiple technologies.
9. Education must respond to society's diverse population and serve all children.
10. Interactions among students, teachers, parents, and community form the network that supports learning.

7-12 Industrial Technology Philosophy

The Industrial Technology Program of the School District of the City of St. Charles offers a diverse program of developmental, sequential and creative learning experiences common to the industrial world of work. This program enhances each student's self-esteem, eagerness to learn, and intellectual curiosity. The natural approach to industrial technology instruction considers the continual evolution reflected by constant and rapid changes inherent in modern industry. The Industrial Technology Program illustrates the practical applications of our district's core subjects. There is a firm professional commitment by the teaching staff to stay abreast of these changes and to implement current teaching approaches and technologies within the industrial technology field.

PLTW Engineering Design and Development Course Description

PLTW Engineering Design and Development (grades 11-12) - In this course, students identify a real-world challenge and then research, design, and test a solution, ultimately presenting their unique solutions to a panel of engineers. Students apply the professional skills they have developed to document a design process to standards, completing Engineering Design and Development ready to take on any post-secondary program or career.

PLTW Engineering Design and Development Curriculum

PLTW Engineering Design and Development *Course Overview*	
Grade level(s): 11-12	**Credits earned:** 1
Course Rationale	**Course Description**
Students will complete from start to finish a real life experience of what it is really like to be an engineer. They will find a solution to a real world problem to solve. They will research, design, test, and build a prototype then present their findings to a panel.	In this course, students identify a real-world challenge and then research, design, and test a solution, ultimately presenting their unique solutions to a panel of engineers. Students apply the professional skills they have developed to document a design process to standards, completing Engineering Design and Development ready to take on any post-secondary program or career.
Transfer Goals/Big Ideas	
In PLTW Engineering Design and Development (EDD) students develop skills in problem solving, research, and design while learning strategies for design process documentation, collaboration, and presentation of a real world problem that they will choose and they will figure out how to solve that problem.	
Priority Missouri Learning Standards/National Standards	
Project Lead the Way (PLTW) aligns to the Next Generation Science Standards which is a reference used by the state of Missouri to determine the Missouri Learning Standards for Science. **Next Generation Science Standards (NGSS):** **HS.ETS1.2 -** Engineering Design: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering. **HS.ETS1.3 -** Engineering Design: 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. **Science and Engineering Practice -** Using Mathematics and Computational Thinking Apply techniques of algebra and functions to represent and solve scientific and engineering problems	

Science and Engineering Practice - Using Mathematics and Computational Thinking Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m3, acre-feet, etc.).

Science and Engineering Practice - Using Mathematics and Computational Thinking
Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

Science and Engineering Practice - Obtaining, Evaluating, and Communicating Information Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible. Communicate scientific and/or technical information or ideas (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically).

Science and Engineering Practice - Using Mathematics and Computational Thinking Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system.
6a Foster a culture where students take ownership of their learning goals and outcomes in both independent and group settings.
7a Provide alternative ways for students to demonstrate competency and reflect on their learning using technology.
4b Students select and use digital tools to plan and manage a design process that considers design constraints and calculated risks.
4c Students develop, test, and refine prototypes as part of a cyclical design process.

2.9-12.FF Students will develop an understanding of the core concepts of technology.
FF. Complex systems have many layers of controls and feedback loops to provide information.

12.9-12.L Students will develop the abilities to use and maintain technological products and systems.
L. Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.

12.9-12.P Students will develop the abilities to use and maintain technological products and systems.
P. Use computers and calculators to access, retrieve, organize, process, maintain, interpret, and evaluate data and information in order to communicate.

17.9-12.P Students will develop an understanding of and be able to select and use information and communication technologies.
P. There are many ways to communicate information, such as graphic and electronic means.

Component 0: Project Management

<table>
<tr><th>Standards</th><th colspan="2">Transfer Goal(s) /Big Ideas</th></tr>
<tr><td rowspan="3">NGSS:
HS.ETS1.2 - Engineering Design: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS.ETS1.3 - Engineering Design: 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..</td><td colspan="2">Strategic and systematic design and inquiry processes guide the development of an effective solution to the problem.</td></tr>
<tr><th>Enduring Understandings</th><th>Essential Questions</th></tr>
<tr><td>Students will understand an engineering design process is an iterative, systematic approach to problem solving.</td><td>How would you describe major steps of a design process ?
What are the typical tasks involved in each step?
How do you demonstrate the design process in an engineering notebook according to best practices?
Why is it crucial to use a design process when trying to solve complex problems?</td></tr>
<tr><th colspan="3">Learning Targets</th></tr>
<tr><td colspan="3">Students will:
Describe major steps of a design process and identify typical tasks involved in each step.
Document a design process in an engineering notebook according to best practices.
Represent concepts using a variety of visual tools, such as sketches, graphs, and charts, to communicate details of an idea.</td></tr>
<tr><th colspan="3">Unit Duration:</th></tr>
<tr><td colspan="3">Ongoing throughout the year</td></tr>
</table>

Component 1:
Research

<table>
<tr><th>Standards</th><th colspan="2">Transfer Goal(s) /Big Ideas</th></tr>
<tr><td rowspan="3">NGSS:
HS.ETS1.2 - Engineering Design: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS.ETS1.3 - Engineering Design: 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..</td><td colspan="2">Strategic and systematic design and inquiry processes guide the development of an effective solution to the problem.
Research is essential when developing a problem statement and solving a potential real world problem.</td></tr>
<tr><th>Enduring Understandings</th><th>Essential Questions</th></tr>
<tr><td>Students will understand an engineering design process is an iterative, systematic approach to problem solving.
Students will use</td><td>What are the major steps of a design process?
What are the typical tasks involved in each step?
How do you demonstrate the design process in an engineering notebook according to best practices?
Why is it crucial to use a design process when trying to solve complex problems?</td></tr>
<tr><th colspan="3">Learning Targets</th></tr>
<tr><td colspan="3">Students will:
Use resources to research and develop a problem statement to solve.
Document a design process in an engineering notebook according to best practices.
Validate the problem through experts, scholarly articles, and data.</td></tr>
<tr><th colspan="3">Unit Duration:</th></tr>
<tr><td colspan="3">Ongoing throughout the year</td></tr>
</table>

Component 2: Design

Standards	Transfer Goal(s) /Big Ideas	
NGSS: 4b Students select and use digital tools to plan and manage a design process that considers design constraints and calculated risks. 4c Students develop, test, and refine prototypes as part of a cyclical design process.	Strategic and systematic design and inquiry processes guide the development of an effective solution to the problem. Design is essential when developing a problem statement and solving a potential real world problem.	
	Enduring Understandings	**Essential Questions**
	Students will understand an engineering design process is an iterative, systematic approach to problem solving. Students will use various forms of technology to create a design for their potential solution to their problem statement.	How do you show evidence that the proposed design has merit beyond the classroom or lab as a real solution? How do you show evidence that the design could realistically get into the hands of the people the design is trying to help in a sustainable way?

Learning Targets
Students will: Use resources to create and design their product. Document their entire design process.
Unit Duration:
Ongoing throughout the year

Component 3:
Prototype and Test

<table>
<tr><th>Standards</th><th colspan="2">Transfer Goal(s) /Big Ideas</th></tr>
<tr><td rowspan="3">NGSS:
Science and Engineering Practice - Using Mathematics and Computational Thinking Apply techniques of algebra and functions to represent and solve scientific and engineering problems

Science and Engineering Practice - Using Mathematics and Computational Thinking Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m3, acre-feet, etc.).

Science and Engineering Practice - Using Mathematics and Computational Thinking
Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

4b Students select and use digital tools to plan and manage a design process that considers design constraints and calculated risks.</td><td colspan="2">Strategic and systematic design and inquiry processes guide the development of an effective solution to the problem.
Prototype and Testing is essential when developing a product to solve a potential real world problem.</td></tr>
<tr><th>Enduring Understandings</th><th>Essential Questions</th></tr>
<tr><td>Students will use the engineering design process as a way to iterative, systematic approach to design solutions.
Students will use different forms of technology to create and build a prototype.</td><td>What is the plan to test the prototype design?
How can I show others that the testing plan for each design requirement is a well thought out test and would yield believable data?
Why are test criteria important in test design?
How does having a highly functional prototype relate to testing?</td></tr>
</table>

Learning Targets
Students will: Use Technology resources to create, design and develop a prototype to solve their Problem Statement. Document a design process in an engineering notebook according to best practices.
Unit Duration:
Ongoing throughout the year

Component 4:
Evaluation of Project and Process

<table>
<tr><th>Standards</th><th colspan="2">Transfer Goal(s) /Big Ideas</th></tr>
<tr><td rowspan="3">NGSS:
6a Foster a culture where students take ownership of their learning goals and outcomes in both independent and group settings.

7a Provide alternative ways for students to demonstrate competency and reflect on their learning using technology.</td><td colspan="2">Strategic and systematic design and inquiry processes guide the development of an effective solution to the problem.
Once students have completed the cycle of going through the Design Process it is important for them to identify areas of their project that have met their stated objective at the beginning of the project or if they didn’t meet the objective why didn’t they meet it.</td></tr>
<tr><th>Enduring Understandings</th><th>Essential Questions</th></tr>
<tr><td>Students will understand an engineering design process is an iterative, systematic approach to problem solving.

Students will use this as an opportunity to take away from their project what worked well, what didn’t work well, and what would they have done differently if they could start over.</td><td>What do end users and experts directly related to this project and problem statement think of the testing results and my/our conclusions about the effectiveness of this idea?

If I/we were going to do this project over, what should be done differently during the design process to improve the project? How would those recommendations make the project better overall?

Did I/we document each step of the design process in this portfolio well enough that anyone else interested in the problem could pick up this work and replicate what I/we have done, as well as continue working from where I/we ended up?</td></tr>
</table>

Learning Targets
Students will: Document and reflect on their time solving their problem statement. Document a design process in an engineering notebook according to best practices.
Unit Duration:
Ongoing throughout the year

Component 5:
Reflection and Presenting the Design Process

<table>
<tr><th rowspan="1">Standards</th><th colspan="2">Transfer Goal(s) /Big Ideas</th></tr>
<tr><td rowspan="3">NGSS:
7a Provide alternative ways for students to demonstrate competency and reflect on their learning using technology.

12.9-12.L Students will develop the abilities to use and maintain technological products and systems. L. Document processes and procedures and communicate them to different audiences using appropriate oral and written techniques.

12.9-12.P Students will develop the abilities to use and maintain technological products and systems. P. Use computers and calculators to access, retrieve, organize, process, maintain, interpret, and evaluate data and information in order to communicate.

17.9-12.P Students will develop an understanding of and be able to select and use information and communication technologies. P. There are many ways to communicate information, such as graphic and electronic means.</td><td colspan="2">Strategic and systematic design and inquiry processes guide the development of an effective solution to the problem.
Reflecting and Presenting is essential when solving a problem statement to a potential real world problem.</td></tr>
<tr><th>Enduring Understandings</th><th>Essential Questions</th></tr>
<tr><td>Students will understand an engineering design process is an iterative, systematic approach to problem solving.
Students will use their engineering notebooks to create a presentation that outlines their journey through the design process, while solving their Problem Statements.</td><td>How did I/we document each step of the design process in this portfolio so that anyone else interested in the problem could pick up this work and replicate what I/we have done as well as continue working from where I/we ended up?

Throughout the entire portfolio, why is it critical that the explanations, descriptions and information in each section be developed and presented with a wide variety of readers in mind?</td></tr>
</table>

Learning Targets
Students will: Use resources to research and develop a presentation about their Problem Statement. Present a presentation to a panel of judges.
Unit Duration:
Ongoing throughout the year

Assessment Evidence

Rubric/Scoring	Assessment
Rubric: The teacher will look at the problem statement and the research to make sure it meets all specifications. (Project Management, Research, Design, Prototype & Test, Evaluation, and Presentation) Quizzes, Tests and Exams	Students will complete Elements A - N. In Elements A-C students will use the Research Process of validating their problem statement through ample evidence of data (experts, scholarly articles, data charts. etc..) that backs up the fact that their problem is worth solving. Elements D-F students will Design their product as a solution to their original statement and test this product for its effectiveness. Elements G-I students will build and test their product to see if it meets the requirements they first set out to accomplish. Elements J-L students will reflect on their findings. Elements M & N the students will present their entire findings of their coursework to a panel of judges. Students will be assessed over topics including: Research Designing Constructing Presentation Reflection

Learning Plan

Week(s)	Topic	Resources/Texts	Learning Targets	Assessment
Design- Ongoing through out the year	Engineering Design Process	PLTW Student Resources	Students will be able to describe the major steps of a design process, identify typical tasks involved in each step and document a design process in an engineering notebook according to best practices.	Teacher will evaluate the documentation of the design process in the engineering notebook.
Weeks 1-3	Mini Project	PLTW Student Resources	Students will gain an understanding of the Design process they will use throughout the rest of the course.	Completed projects and presentations.
Weeks 4-14	Component 0 & 1	PLTW Student Resources	Students will learn about the tools they will need to come up with a problem statement and begin solving their problem statement.	Completed projects and presentations.
Weeks 15-27	Component 2	PLTW Student Resources	Students will begin the process of designing their solution.	Completed projects and presentations.
Weeks 28-38	Component 3	PLTW Student Resources	Students will construct, test and present their findings to their Problem Statements.	Completed projects and presentations.
Week 39-40	Components 4 & 5	PLTW Student Resources	Students will evaluate and reflect on solutions to their Problem Statements.	Completed projects and presentations.

PLTW Engineering Design and Development Proficiency Scales

Strand: Project Management - Component 0			
Topic/Objective: Engineering Design Process			
Level: PLTW - Engineering Design and Development			**Sample Tasks**
Score 4.0		**In addition to Score 3.0, in-depth inferences and applications that go beyond what was taught.**	
	3.5	In addition to score 3.0 performance, in-depth inferences and applications with partial success.	
Score 3.0		**The student will be able to:** ● Document a design process in an engineering notebook according to best practices.	● Engineering Design Project ● Quizzes/Tests
	2.5	No major errors or omissions regarding 2.0 content and partial knowledge of the 3.0 content	
Score 2.0		**There are no major errors or omissions regarding the simpler details and processes as the student:** ● recognizes or recalls specific terminology such as: ○ Decision Matrix, Constraints ● performs basic processes, such as: ○ Describe major steps of a design process and identify typical tasks involved in each step. ○ Represent concepts using a variety of visual tools, such as sketches, graphs, and charts, to communicate details of an idea. **However, the student exhibits major errors or omissions regarding the more complex ideas and processes.**	● Engineering Design Project ● Quizzes/Tests
	1.5	Partial knowledge of the 2.0 content but major errors or omissions regarding the 3.0 content	
Score 1.0		**With help, a partial understanding of some of the simpler details and processes and some of the more complex ideas and processes.**	
Score 0.0		**Even with help, no understanding or skill demonstrated.**	

Strand: Researching A Problem - Component 1			
Topic/Objective: Element A			
Level: PLTW - Engineering Design and Development			**Sample Tasks**
Score 4.0		**In addition to Score 3.0, in-depth inferences and applications that go beyond what was taught.**	
	3.5	In addition to score 3.0 performance, in-depth inferences and applications with partial success.	
Score 3.0		**The student will be able to:** ● Justify the problem statement using market research, expert knowledge, and beginning a business plan.	● Brainstorming activity ● Writing a problem statement activity ● Conducting market research
	2.5	No major errors or omissions regarding 2.0 content and partial knowledge of the 3.0 content	
Score 2.0		**There are no major errors or omissions regarding the simpler details and processes as the student:** ● recognizes or recalls specific terminology such as: ○ Market research, Business plan ● performs basic processes, such as: ○ Develop a problem statement. ○ Identify a problem to solve. **However, the student exhibits major errors or omissions regarding the more complex ideas and processes.**	● Brainstorming activity ● Writing a problem statement activity ● Conducting market research
	1.5	Partial knowledge of the 2.0 content but major errors or omissions regarding the 3.0 content	
Score 1.0		**With help, a partial understanding of some of the simpler details and processes and some of the more complex ideas and processes.**	
Score 0.0		**Even with help, no understanding or skill demonstrated.**	

Strand: Researching A Problem - Component 1			
Topic/Objective: Element B			
Level: PLTW - Engineering Design and Development			**Sample Tasks**
Score 4.0		**In addition to Score 3.0, in-depth inferences and applications that go beyond what was taught.**	
	3.5	In addition to score 3.0 performance, in-depth inferences and applications with partial success.	
Score 3.0		**The student will be able to:** ● Document patent findings and cite where they found the patent. ● Create a decision matrix to come up with a solution.	● Patent searchers ● Patent Summary Sheet ● Create a solution matrix
	2.5	No major errors or omissions regarding 2.0 content and partial knowledge of the 3.0 content	
Score 2.0		**There are no major errors or omissions regarding the simpler details and processes as the student:** ● recognizes or recalls specific terminology such as: ○ Patents, Solution Matrix ● performs basic processes, such as: ○ Researching patents, developing a decision matrix **However, the student exhibits major errors or omissions regarding the more complex ideas and processes.**	● Patent searchers ● Patent Summary Sheet ● Create a solution matrix
	1.5	Partial knowledge of the 2.0 content but major errors or omissions regarding the 3.0 content	
Score 1.0		**With help, a partial understanding of some of the simpler details and processes and some of the more complex ideas and processes.**	
Score 0.0		**Even with help, no understanding or skill demonstrated.**	

Strand: Researching A Problem - Component 1			
Topic/Objective: Element C			
Level: PLTW - Engineering Design and Development			**Sample Tasks**
Score 4.0		**In addition to Score 3.0, in-depth inferences and applications that go beyond what was taught.**	●
	3.5	In addition to score 3.0 performance, in-depth inferences and applications with partial success.	
Score 3.0		**The student will be able to:** ● Create a test survey ● Come up with a design proposal ● Present their first 3 elements to the class/.	● Presentation of first 3 elements ● Design specification activity
	2.5	No major errors or omissions regarding 2.0 content and partial knowledge of the 3.0 content	
Score 2.0		**There are no major errors or omissions regarding the simpler details and processes as the student:** ● recognizes or recalls specific terminology such as: ○ Design specifications & goals, concept test survey, project proposal ● performs basic processes, such as: ○ Creating a timeline. ○ Creating design specifications. **However, the student exhibits major errors or omissions regarding the more complex ideas and processes.**	● Presentation of first 3 elements ● Design specification activity
	1.5	Partial knowledge of the 2.0 content but major errors or omissions regarding the 3.0 content	
Score 1.0		**With help, a partial understanding of some of the simpler details and processes and some of the more complex ideas and processes.**	
Score 0.0		**Even with help, no understanding or skill demonstrated.**	

Strand: Design - Component 2			
Topic/Objective: Element D			
Level: PLTW - Engineering Design and Development			**Sample Tasks**
Score 4.0		**In addition to Score 3.0, in-depth inferences and applications that go beyond what was taught.**	
	3.5	In addition to score 3.0 performance, in-depth inferences and applications with partial success.	
Score 3.0		**The student will be able to:** ● Design Concepts using analysis to generate and select best product solutions. ● Develop a plan of action that has considerable merit and would easily support repetition and testing for effectiveness by others.	● Concept Development Activity ● Selecting the Best Solution Activity ● Concept Analysis Activity
	2.5	No major errors or omissions regarding 2.0 content and partial knowledge of the 3.0 content	
Score 2.0		**There are no major errors or omissions regarding the simpler details and processes as the student:** ● recognizes or recalls specific terminology such as: ○ Concept development, Isometric, Orthographic, Solution path, Product concept, concept analysis ● performs basic processes, such as: ○ Selecting the best solution using the SCAMMPEER process **However, the student exhibits major errors or omissions regarding the more complex ideas and processes.**	● Concept Development Activity ● Selecting the Best Solution Activity ● Concept Analysis Activity
	1.5	Partial knowledge of the 2.0 content but major errors or omissions regarding the 3.0 content	
Score 1.0		**With help, a partial understanding of some of the simpler details and processes and some of the more complex ideas and processes.**	
Score 0.0		**Even with help, no understanding or skill demonstrated.**	

Strand: Design - Component 2			
Topic/Objective: Element E			
Level: PLTW - Engineering Design and Development			**Sample Tasks**
Score 4.0		**In addition to Score 3.0, in-depth inferences and applications that go beyond what was taught.**	
	3.5	In addition to score 3.0 performance, in-depth inferences and applications with partial success.	
Score 3.0		**The student will be able to:** ● Propose a solution that is well substantiated with STEM principles and practices applicable to all or nearly all design requirements and functional claims. ● Substantiate evidence that the application of STEM principles and practices by the student have been reviewed by two or more experts (qualified consultants and/or project mentors). ● Document the reviews of experts that provide confirmation (verification) or detail necessary to inform a corrective response.	● Complete Engineering Formula Sheet ● Document Engineering Symbols
	2.5	No major errors or omissions regarding 2.0 content and partial knowledge of the 3.0 content	
Score 2.0		**There are no major errors or omissions regarding the simpler details and processes as the student:** ● recognizes or recalls specific terminology such as: ○ Engineering symbols, STEM principles and practices ● performs basic processes, such as: ○ Documenting the Engineering Design Process ○ Using the Engineering Formula Sheet **However, the student exhibits major errors or omissions regarding the more complex ideas and processes.**	● Complete Engineering Formula Sheet ● Document Engineering Symbols
	1.5	Partial knowledge of the 2.0 content but major errors or omissions regarding the 3.0 content	
Score 1.0		**With help, a partial understanding of some of the simpler details and processes and some of the more complex ideas and processes.**	
Score 0.0		**Even with help, no understanding or skill demonstrated.**	

Strand: Design - Component 2			
Topic/Objective: Element F			
Level: PLTW - Engineering Design and Development			**Sample Tasks**
Score 4.0		**In addition to Score 3.0, in-depth inferences and applications that go beyond what was taught.**	
	3.5	In addition to score 3.0 performance, in-depth inferences and applications with partial success.	
Score 3.0		**The student will be able to:** ● Propose that the design was carefully reviewed based on several relevant extra-functional considerations. ● Pass judgement on design viability based on those considerations—the capacity of the proposed solution to address the problem—is clearly realistic and well supported with credible evidence.	● Viability of the Proposed Solution Activity ● Project Presentation for each element to this point
	2.5	No major errors or omissions regarding 2.0 content and partial knowledge of the 3.0 content	
Score 2.0		**There are no major errors or omissions regarding the simpler details and processes as the student:** ● recognizes or recalls specific terminology such as: ○ Viability, Preliminary Design. ● performs basic processes, such as: ○ Completing the viability of the proposed solution. ○ Completing the Preliminary Design Review. **However, the student exhibits major errors or omissions regarding the more complex ideas and processes.**	● Viability of the Proposed Solution Activity ● Project Presentation for each element to this point
	1.5	Partial knowledge of the 2.0 content but major errors or omissions regarding the 3.0 content	
Score 1.0		**With help, a partial understanding of some of the simpler details and processes and some of the more complex ideas and processes.**	
Score 0.0		**Even with help, no understanding or skill demonstrated.**	

Strand: Prototype and Test - Component 3			
Topic/Objective: Statistics			
Level: PLTW - Element G			**Sample Tasks**
Score 4.0		**In addition to Score 3.0, in-depth inferences and applications that go beyond what was taught.**	
	3.5	In addition to score 3.0 performance, in-depth inferences and applications with partial success.	
Score 3.0		**The student will be able to:** ● Clearly and fully explain the final prototype iteration and is constructed with enough detail to assure that objective data on all or nearly all design requirements could be determined. ● Make sure that all attributes (subsystems) of the unique solution that can be tested or modeled mathematically are addressed. ● Support the justification that is provided for those attributes that cannot be tested or modeled mathematically and thus require expert review.	● Virtual Solutions Activity ● Mock Up Activity ● Choosing Materials Activity ● Resources Planning Activity ● Identifying Incremental Testing Opportunities Activity
	2.5	No major errors or omissions regarding 2.0 content and partial knowledge of the 3.0 content	
Score 2.0		**There are no major errors or omissions regarding the simpler details and processes as the student:** ● recognizes or recalls specific terminology such as: ○ Prototypes, Virtual Solutions, Mock ups, Resource Planning, Build Procedure. ● performs basic processes, such as: ○ Choosing Materials. ○ Creating a Building Procedure. ○ Creating a mockup and virtual solution. **However, the student exhibits major errors or omissions regarding the more complex ideas and processes.**	● Virtual Solutions Activity ● Mock Up Activity ● Choosing Materials Activity ● Resources Planning Activity ● Identifying Incremental Testing Opportunity Activity
	1.5	Partial knowledge of the 2.0 content but major errors or omissions regarding the 3.0 content	
Score 1.0		**With help, a partial understanding of some of the simpler details and processes and some of the more complex ideas and processes.**	
Score 0.0		**Even with help, no understanding or skill demonstrated.**	

Strand: Prototype and Test - Component 3			
Topic/Objective: Element H			
Level: PLTW - Engineering Design and Development			**Sample Tasks**
Score 4.0		**In addition to Score 3.0, in-depth inferences and applications that go beyond what was taught.**	
	3.5	In addition to score 3.0 performance, in-depth inferences and applications with partial success.	
Score 3.0		**The student will be able to:** ● Through the conduct of several tests for high-priority requirements that are reasonably based on instructional contexts, or through physical or mathematical modeling, the student demonstrates considerable understanding of testing procedure, including the gathering and analysis of resultant data. ● Analyze the effectiveness with which the design met stated goals and include a consistently detailed explanation and summary of the data from each portion of the testing procedure and from expert reviews, generously supported by pictures, graphs, charts, and other visuals. ● Analyze the overall summary of the implications of all data and proceeding with designing and solving the problem.	● Test Procedure Activity ● Test Criteria Document
	2.5	No major errors or omissions regarding 2.0 content and partial knowledge of the 3.0 content	
Score 2.0		**There are no major errors or omissions regarding the simpler details and processes as the student:** ● recognizes or recalls specific terminology such as: ○ Testing procedures, Test Criteria, Test Plan ● performs basic processes, such as: ○ Creating a testing Criteria. ○ Creating a Testing Procedure. **However, the student exhibits major errors or omissions regarding the more complex ideas and processes.**	● Test Procedure Activity ● Test Criteria Document
	1.5	Partial knowledge of the 2.0 content but major errors or omissions regarding the 3.0 content	
Score 1.0		**With help, a partial understanding of some of the simpler details and processes and some of the more complex ideas and processes.**	●
Score 0.0		**Even with help, no understanding or skill demonstrated.**	

Strand: Prototype and Test - Component 3			
Topic/Objective: Element I			
Level: PLTW - Engineering Design and Development			**Sample Tasks**
Score 4.0		**In addition to Score 3.0, in-depth inferences and applications that go beyond what was taught.**	
	3.5	In addition to score 3.0 performance, in-depth inferences and applications with partial success.	
Score 3.0		**The student will be able to:** ● Document the project evaluation by multiple, demonstrably qualified stakeholders and field experts is presented and is synthesized in a consistently specific, detailed, and thorough way. ● Document sufficiently in two or more categories to yield meaningful analysis of that evaluation data. ● Synthesizing the evaluations consistently addresses evaluators' specific questions, concerns, and opinions related to design requirements.	● Test and Evaluate the Prototype. ● Redesign and Refine the Prototype.
	2.5	No major errors or omissions regarding 2.0 content and partial knowledge of the 3.0 content	
Score 2.0		**There are no major errors or omissions regarding the simpler details and processes as the student:** ● recognizes or recalls specific terminology such as: ○ Critical Design Review, Redesign and Refine ● performs basic processes, such as: ○ Test and Evaluate the Prototype. ○ Redesign and Refine the Prototype. **However, the student exhibits major errors or omissions regarding the more complex ideas and processes.**	● Test and Evaluate the Prototype. ● Redesign and Refine the Prototype.
	1.5	Partial knowledge of the 2.0 content but major errors or omissions regarding the 3.0 content	
Score 1.0		**With help, a partial understanding of some of the simpler details and processes and some of the more complex ideas and processes.**	
Score 0.0		**Even with help, no understanding or skill demonstrated.**	

Strand: Evaluation of Project and Process - Component 4			
Topic/Objective: Elements J, K, L			
Level: PLTW - Engineering Design and Development			**Sample Tasks**
Score 4.0		**In addition to Score 3.0, in-depth inferences and applications that go beyond what was taught.**	
	3.5	In addition to score 3.0 performance, in-depth inferences and applications with partial success.	
Score 3.0		**The student will be able to:** ● Document the project evaluation using multiple, demonstrably qualified stakeholders and field experts to present and is synthesized in a consistently specific, detailed, and thorough way. ● Document sufficiently in two or more categories to yield meaningful analysis of that evaluation data; the synthesis of evaluations consistently addresses evaluators' specific questions, concerns, and opinions related to design requirements. ● Provide a consistently clear, insightful, and comprehensive reflection on, and value judgment of, each major step in the project. ● Reflect on their product and include a substantive summary of lessons learned that would be clearly useful to others who attempt the same or similar project. ● Include consistently detailed and salient recommendations regarding the conduct of the same or similar project in the future. ● Make recommendations to include caveats as warranted and specific ways the project could be improved with consistently detailed plans for the implementation of those improvements.	● Presentation - Prep
	2.5	No major errors or omissions regarding 2.0 content and partial knowledge of the 3.0 content	
Score 2.0		**There are no major errors or omissions regarding the simpler details and processes as the student:** ● recognizes or recalls specific terminology such as: ○ External evaluation, Personal Reflection, Designer Recommendations ● performs basic processes, such as: ○ Preparing a presentation that documents the process. **However, the student exhibits major errors or omissions regarding the more complex ideas and processes.**	● Presentation - Prep
	1.5	Partial knowledge of the 2.0 content but major errors or omissions regarding the 3.0 content	
Score 1.0		**With help, a partial understanding of some of the simpler details and processes and some of the more complex ideas and processes.**	
Score 0.0		**Even with help, no understanding or skill demonstrated.**	

Strand: Reflection and Presenting the Design Process - Component 5			
Topic/Objective: Elements M and N			
Level: PLTW - Engineering Design and Development			**Sample Tasks**
Score 4.0		**In addition to Score 3.0, in-depth inferences and applications that go beyond what was taught.**	
	3.5	In addition to score 3.0 performance, in-depth inferences and applications with partial success.	
Score 3.0		**The student will be able to:** ● Show that their portfolio provides consistently clear, detailed, and extensive documentation of the design process and project that would with certainty facilitate subsequent replication and refinement by the designers and/or others. ● Explain their design to an audience and the purpose was abundantly evident in the choice of modes of presentation, professionalism of style and tone, and the variety, quality, and suitability of supporting materials. ● Make abundantly clear the evidence of the ability to write consistently clear and well-organized texts that are developed to the fullest degree suitable for the audience and purposes intended (to explain, question, persuade). ● Make texts consistently demonstrate the ability to adjust language, style, and tone to address the needs and interests of a variety of audiences (expert, informed, or general/lay audience) and to use a wide variety of forms which are commonplace among STEM disciplines (notes, descriptive/narrative accounts, research reports). ● Appropriately documented in standardized form (APA) is consistently evident.	● Presentation
	2.5	No major errors or omissions regarding 2.0 content and partial knowledge of the 3.0 content	
Score 2.0		**There are no major errors or omissions regarding the simpler details and processes as the student:** ● recognizes or recalls specific terminology such as: ○ Rules of Quarters, Three Panel Display, Technical writing. ● performs basic processes, such as: ○ Presenting their findings from their project. **However, the student exhibits major errors or omissions regarding the more complex ideas and processes.**	● Presentation
	1.5	Partial knowledge of the 2.0 content but major errors or omissions regarding the 3.0 content	
Score 1.0		**With help, a partial understanding of some of the simpler details and processes and some of the more complex ideas and processes.**	
Score 0.0		**Even with help, no understanding or skill demonstrated.**	

Appendix A - Next Generation Science Standards (High School Engineering Design)

High School Engineering Design

At the high school level students are expected to engage with major global issues at the interface of science, technology, society and the environment, and to bring to bear the kinds of analytical and strategic thinking that prior training and increased maturity make possible. As in prior levels, these capabilities can be thought of in three stages—defining the problem, developing possible solutions, and improving designs.

Defining the problem at the high school level requires both qualitative and quantitative analysis. For example, the need to provide food and fresh water for future generations comes into sharp focus when considering the speed at which world population is growing, and conditions in countries that have experienced famine. While high school students are not expected to solve these challenges, they are expected to begin thinking about them as problems that can be addressed, at least in part, through engineering.

Developing possible solutions for major global problems begins by breaking them down into smaller problems that can be tackled with engineering methods. To evaluate potential solutions students are expected to not only consider a wide range of criteria, but to also recognize that criteria need to be prioritized. For example, public safety or environmental protection may be more important than cost or even functionality. Decisions on priorities can then guide tradeoff choices.

Improving designs at the high school level may involve sophisticated methods, such as using computer simulations to model proposed solutions. Students are expected to use such methods to take into account a range of criteria and constraints, to try and anticipate possible societal and environmental impacts, and to test the validity of their simulations by comparison to the real world.

Connections with other science disciplines help high school students develop these capabilities in various contexts. For example, in the life sciences students are expected to design, evaluate, and refine a solution for reducing human impact on the environment (HS-LS2-7) and to create or revise a simulation to test solutions for mitigating adverse impacts of human activity on biodiversity (HS-LS4-6). In the physical sciences students solve problems by applying their engineering capabilities along with their knowledge of conditions for chemical reactions (HS-PS1-6), forces during collisions (HS-PS2-3), and conversion of energy from one form to another (HS-PS3-3). In the Earth and space sciences students apply their engineering capabilities to reduce human impacts on Earth systems, and improve social and environmental cost-benefit ratios (HS-ESS3-2, HS-ESS3-4).

By the end of 12th grade students are expected to achieve all four HS-ETS1 performance expectations (HS-ETS1-1, HS-ETS1-2, HS-ETS1-3, and HS-ETS1-4) related to a single problem in order to understand the interrelated processes of engineering design. These include analyzing major global challenges, quantifying criteria and constraints for solutions; breaking down a complex problem into smaller, more manageable problems, evaluating alternative solutions based on prioritized criteria and trade-offs, and using a computer simulation to model the impact of proposed solutions. While the performance expectations shown in High School Engineering Design couple particular practices with specific disciplinary core ideas, instructional decisions should include use of many practices that lead to the performance expectations.

HS.Engineering Design

HS.Engineering Design

Students who demonstrate understanding can:

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.**

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.**

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.**

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.**

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Asking Questions and Defining Problems
Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.

- Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1)

Using Mathematics and Computational Thinking
Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4)

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories.

- Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2)
- Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting Engineering Problems

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1)
- Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)

ETS1.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. (HS-ETS1-3)
- Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)

ETS1.C: Optimizing the Design Solution

- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)

Crosscutting Concepts

Systems and System Models

- Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions— including energy, matter, and information flows— within and between systems at different scales. (HS-ETS1-4)

Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-1) (HS-ETS1-3)

Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include:
Physical Science: HS-PS2-3, HS-PS3-3
Connections to HS-ETS1.B: Designing Solutions to Engineering Problems include:
Earth and Space Science: HS-ESS3-2, HS-ESS3-4, **Life Science:** HS-LS2-7, HS-LS4-6
Connections to HS-ETS1.C: Optimizing the Design Solution include:
Physical Science: HS-PS1-6, HS-PS2-3

Articulation of DCIs across grade-bands: **MS.ETS1.A** (HS-ETS1-1),(HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4); **MS.ETS1.B** (HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4); **MS.ETS1.C** (HS-ETS1-2),(HS-ETS1-4)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-ETS1-1),*(HS-ETS1-3)*
RST.11-12.8	Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. *(HS-ETS1-1)*,(HS-ETS1-3)
RST.11-12.9	Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-ETS1-1),*(HS-ETS1-3)*

Mathematics –

MP.2	Reason abstractly and quantitatively. (HS-ETS1-1),*(HS-ETS1-3)*,*(HS-ETS1-4)*
MP.4	Model with mathematics. (HS-ETS1-1),(HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4)

The section entitled "Disciplinary Core Ideas" is reproduced verbatim from A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas. Integrated and reprinted with permission from the National Academy of Sciences.

Appendix B - Next Generation Science Standards (Science and Engineering Practices)

Science and Engineering Practices in the NGSS

A Science Framework for K-12 Science Education provides the blueprint for developing the *Next Generation Science Standards* (NGSS). The *Framework* expresses a vision in science education that requires students to operate at the nexus of three dimensions of learning: Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas. The *Framework* identified a small number of disciplinary core ideas that all students should learn with increasing depth and sophistication, from Kindergarten through grade twelve. Key to the vision expressed in the *Framework* is for students to learn these disciplinary core ideas in the context of science and engineering practices. The importance of combining science and engineering practices and disciplinary core ideas is stated in the *Framework* as follows:

> *Standards and performance expectations that are aligned to the framework must take into account that students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined. At the same time, they cannot learn or show competence in practices except in the context of specific content.* (NRC *Framework*, 2012, p. 218)

The *Framework* specifies that each performance expectation must combine a relevant practice of science or engineering, with a core disciplinary idea and crosscutting concept, appropriate for students of the designated grade level. That guideline is perhaps the most significant way in which the NGSS differs from prior standards documents. In the future, science assessments will not assess students' understanding of core ideas separately from their abilities to use the practices of science and engineering. They will be assessed together, showing students not only "know" science concepts; but also, students can use their understanding to investigate the natural world through the practices of science inquiry, or solve meaningful problems through the practices of engineering design. The *Framework* uses the term "practices," rather than "science processes" or "inquiry" skills for a specific reason:

> *We use the term "practices" instead of a term such as "skills" to emphasize that engaging in scientific investigation requires not only skill but also knowledge that is specific to each practice.* (NRC *Framework*, 2012, p. 30)

The eight practices of science and engineering that the *Framework* identifies as essential for all students to learn and describes in detail are listed below:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Rationale
Chapter 3 of the *Framework* describes each of the eight practices of science and engineering and presents the following rationale for why they are essential.

> *Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model, and explain the world. Engaging in the practices of engineering likewise helps students understand the work of engineers, as well as the links between engineering and science. Participation in these practices also*

helps students form an understanding of the crosscutting concepts and disciplinary ideas of science and engineering; moreover, it makes students' knowledge more meaningful and embeds it more deeply into their worldview.

The actual doing of science or engineering can also pique students' curiosity, capture their interest, and motivate their continued study; the insights thus gained help them recognize that the work of scientists and engineers is a creative endeavor—one that has deeply affected the world they live in. Students may then recognize that science and engineering can contribute to meeting many of the major challenges that confront society today, such as generating sufficient energy, preventing and treating disease, maintaining supplies of fresh water and food, and addressing climate change.

Any education that focuses predominantly on the detailed products of scientific labor—the facts of science—without developing an understanding of how those facts were established or that ignores the many important applications of science in the world misrepresents science and marginalizes the importance of engineering. (NRC *Framework* 2012, pp. 42-43)

As suggested in the rationale, above, Chapter 3 derives the eight practices based on an analysis of what professional scientists and engineers do. It is recommended that users of the NGSS read that chapter carefully, as it provides valuable insights into the nature of science and engineering, as well as the connections between these two closely allied fields. The intent of this section of the NGSS appendices is more limited—to describe what each of these eight practices implies about what students can do. Its purpose is to enable readers to better understand the performance expectations. The "Practices Matrix" is included, which lists the specific capabilities included in each practice for each grade band (K-2, 3-5, 6-8, 9-12).

Guiding Principles

The development process of the standards provided insights into science and engineering practices. These insights are shared in the following guiding principles:

Students in grades K-12 should engage in all eight practices over each grade band. All eight practices are accessible at some level to young children; students' abilities to use the practices grow over time. However, the NGSS only identifies the capabilities students are expected to acquire by the end of each grade band (K-2, 3-5, 6-8, and 9-12). Curriculum developers and teachers determine strategies that advance students' abilities to use the practices.

Practices grow in complexity and sophistication across the grades. The *Framework* suggests how students' capabilities to use each of the practices should progress as they mature and engage in science learning. For example, the practice of "planning and carrying out investigations" begins at the kindergarten level with guided situations in which students have assistance in identifying phenomena to be investigated, and how to observe, measure, and record outcomes. By upper elementary school, students should be able to plan their own investigations. The nature of investigations that students should be able to plan and carry out is also expected to increase as students mature, including the complexity of questions to be studied, the ability to determine what kind of investigation is needed to answer different kinds of questions, whether or not variables need to be controlled and if so, which are most important, and at the high school level, how to take measurement error into account. As listed in the tables in this chapter, each of the eight practices has its own progression, from kindergarten to grade 12. While these progressions are derived from Chapter 3 of the *Framework*, they are refined based on experiences in crafting the NGSS and feedback received from reviewers.

Each practice may reflect science or engineering. Each of the eight practices can be used in the service of scientific inquiry or engineering design. The best way to ensure a practice is being used for science or engineering is to ask about the goal of the activity. Is the goal to answer a question? If so, students are doing science. Is the purpose to define and solve a problem? If so, students are doing engineering. Box 3-2 on pages 50-53 of the *Framework* provides a side-by-side comparison of how scientists and engineers use these practices. This chapter briefly summarizes what it "looks like" for a student to use each practice for science or engineering.

Practices represent what students are expected to do, and are not teaching methods or curriculum. The *Framework* occasionally offers suggestions for instruction, such as how a science unit might begin with a scientific investigation, which then leads to the solution of an engineering problem. The NGSS avoids such suggestions since the goal is to describe what students should be able to do, rather than how they should be taught. For example, it was suggested for the NGSS to recommend certain teaching strategies such as using biomimicry—the application of biological features to solve engineering design problems. Although instructional units that make use of biomimicry seem well-aligned with the spirit of the *Framework* to encourage integration of core ideas and practices, biomimicry and similar teaching approaches are more closely related to curriculum and instruction than to assessment. Hence, the decision was made not to include biomimicry in the NGSS.

The eight practices are not separate; they intentionally overlap and interconnect. As explained by Bell, et al. (2012), the eight practices do not operate in isolation. Rather, they tend to unfold sequentially, and even overlap. For example, the practice of "asking questions" may lead to the practice of "modeling" or "planning and carrying out an investigation," which in turn may lead to "analyzing and interpreting data." The practice of "mathematical and computational thinking" may include some aspects of "analyzing and interpreting data." Just as it is important for students to carry out each of the individual practices, it is important for them to see the connections among the eight practices.

Performance expectations focus on some but not all capabilities associated with a practice. The *Framework* identifies a number of features or components of each practice. The practices matrix, described in this section, lists the components of each practice as a bulleted list within each grade band. As the performance expectations were developed, it became clear that it's too much to expect each performance to reflect all components of a given practice. The most appropriate aspect of the practice is identified for each performance expectation.

Engagement in practices is language intensive and requires students to participate in classroom science discourse. The practices offer rich opportunities and demands for language learning while advancing science learning for all students (Lee, Quinn, & Valdés, in press). English language learners, students with disabilities that involve language processing, students with limited literacy development, and students who are speakers of social or regional varieties of English that are generally referred to as "non-Standard English" stand to gain from science learning that involves language-intensive scientific and engineering practices. When supported appropriately, these students are capable of learning science through their emerging language and comprehending and carrying out sophisticated language functions (e.g., arguing from evidence, providing explanations, developing models) using less-than-perfect English. By engaging in such practices, moreover, they simultaneously build on their understanding of science and their language proficiency (i.e., capacity to do more with language).

On the following pages, each of the eight practices is briefly described. Each description ends with a table illustrating the components of the practice that students are expected to master at the end of each grade band. All eight tables comprise the *practices matrix*. During development of the NGSS, the practices matrix was revised several times to reflect improved understanding of how the practices connect with the disciplinary core ideas.

Practice 1 Asking Questions and Defining Problems

> *Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution.* (NRC Framework 2012, p. 56)

Scientific questions arise in a variety of ways. They can be driven by curiosity about the world, inspired by the predictions of a model, theory, or findings from previous investigations, or they can be stimulated by the need to solve a problem. Scientific questions are distinguished from other types of questions in that the answers lie in explanations supported by empirical evidence, including evidence gathered by others or through investigation.

While science begins with questions, engineering begins with defining a problem to solve. However, engineering may also involve asking questions to define a problem, such as: What is the need or desire that underlies the problem? What are the criteria for a successful solution? Other questions arise when generating ideas, or testing possible solutions, such as: What are the possible trade-offs? What evidence is necessary to determine which solution is best?

Asking questions and defining problems also involves asking questions about data, claims that are made, and proposed designs. It is important to realize that asking a question also leads to involvement in another practice. A student can ask a question about data that will lead to further analysis and interpretation. Or a student might ask a question that leads to planning and design, an investigation, or the refinement of a design.

Whether engaged in science or engineering, the ability to ask good questions and clearly define problems is essential for everyone. The following progression of Practice 1 summarizes what students should be able to do by the end of each grade band. Each of the examples of asking questions below leads to students engaging in other scientific practices.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Asking questions and defining problems in K–2 builds on prior experiences and progresses to simple descriptive questions that can be tested. • Ask questions based on observations to find more information about the natural and/or designed world(s). • Ask and/or identify questions that can be answered by an investigation. • Define a simple problem that can be solved through the development of a new or improved object or tool.	Asking questions and defining problems in 3–5 builds on K–2 experiences and progresses to specifying qualitative relationships. • Ask questions about what would happen if a variable is changed. • Identify scientific (testable) and non-scientific (non-testable) questions. • Ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships. • Use prior knowledge to describe problems that can be solved. • Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost.	Asking questions and defining problems in 6–8 builds on K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models. • Ask questions ○ that arise from careful observation of phenomena, models, or unexpected results, to clarify and/or seek additional information. ○ to identify and/or clarify evidence and/or the premise(s) of an argument. ○ to determine relationships between independent and dependent variables and relationships in models. ○ to clarify and/or refine a model, an explanation, or an engineering problem. ○ that require sufficient and appropriate empirical evidence to answer. ○ that can be investigated within the scope of the classroom, outdoor environment, and museums and other public facilities with available resources and, when	Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. • Ask questions ○ that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. ○ that arise from examining models or a theory, to clarify and/or seek additional information and relationships. ○ to determine relationships, including quantitative relationships, between independent and dependent variables. ○ to clarify and refine a model, an explanation, or an engineering problem. • Evaluate a question to determine if it is testable and

		appropriate, frame a hypothesis based on observations and scientific principles. ◦ that challenge the premise(s) of an argument or the interpretation of a data set. • Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.	relevant. • Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory. • Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design. • Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations.

Practice 2 Developing and Using Models

Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system. (NRC Framework, 2012, p. 58)

Models include diagrams, physical replicas, mathematical representations, analogies, and computer simulations. Although models do not correspond exactly to the real world, they bring certain features into focus while obscuring others. All models contain approximations and assumptions that limit the range of validity and predictive power, so it is important for students to recognize their limitations.

In science, models are used to represent a system (or parts of a system) under study, to aid in the development of questions and explanations, to generate data that can be used to make predictions, and to communicate ideas to others. Students can be expected to evaluate and refine models through an iterative cycle of comparing their predictions with the real world and then adjusting them to gain insights into the phenomenon being modeled. As such, models are based upon evidence. When new evidence is uncovered that the models can't explain, models are modified.

In engineering, models may be used to analyze a system to see where or under what conditions flaws might develop, or to test possible solutions to a problem. Models can also be used to visualize and refine a design, to communicate a design's features to others, and as prototypes for testing design performance.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Modeling in K–2 builds on prior experiences and progresses to include using and developing models (i.e., diagram, drawing, physical replica, diorama, dramatization, or storyboard) that represent concrete events or design solutions. • Distinguish between a model and the actual object, process, and/or events the model represents. • Compare models to identify common features and differences. • Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s). • Develop a simple model based on evidence to represent a proposed object or tool.	Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions. • Identify limitations of models. • Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events. • Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. • Develop and/or use models to describe and/or predict phenomena. • Develop a diagram or simple physical prototype to convey a proposed object, tool, or process. • Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.	Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Evaluate limitations of a model for a proposed object or tool. • Develop or modify a model— based on evidence – to match what happens if a variable or component of a system is changed. • Use and/or develop a model of simple systems with uncertain and less predictable factors. • Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena. • Develop and/or use a model to predict and/or describe phenomena. • Develop a model to describe unobservable mechanisms. • Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.	Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria. • Design a test of a model to ascertain its reliability. • Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. • Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. • Develop a complex model that allows for manipulation and testing of a proposed process or system. • Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

Practice 3 Planning and Carrying Out Investigations

> *Students should have opportunities to plan and carry out several different kinds of investigations during their K-12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)—to those that emerge from students' own questions.* (NRC Framework, 2012, p. 61)

Scientific investigations may be undertaken to describe a phenomenon, or to test a theory or model for how the world works. The purpose of engineering investigations might be to find out how to fix or improve the functioning of a technological system or to compare different solutions to see which best solves a problem. Whether students are doing science or engineering, it is always important for them to state the goal of an investigation, predict outcomes, and plan a course of action that will provide the best evidence to support their conclusions. Students should design investigations that generate data to provide evidence to support claims they make about phenomena. Data aren't evidence until used in the process of supporting a claim. Students should use reasoning and scientific ideas, principles, and theories to show why data can be considered evidence.

Over time, students are expected to become more systematic and careful in their methods. In laboratory experiments, students are expected to decide which variables should be treated as results or outputs, which should be treated as inputs and intentionally varied from trial to trial, and which should be controlled, or kept the same across trials. In the case of field observations, planning involves deciding how to collect different samples of data under different conditions, even though not all conditions are under the direct control of the investigator. Planning and carrying out investigations may include elements of all of the other practices.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Planning and carrying out investigations to answer questions or test solutions to problems in K–2 builds on prior experiences and progresses to simple investigations, based on fair tests, which provide data to support explanations or design solutions. • With guidance, plan and conduct an investigation in collaboration with peers (for K). • Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence to answer a question. • Evaluate different ways of observing and/or measuring a phenomenon to determine which way can answer a question. • Make observations (firsthand or from media) and/or measurements to collect data that can be used to make comparisons. • Make observations (firsthand or from media) and/or measurements of a proposed object or tool or solution to determine if it	Planning and carrying out investigations to answer questions or test solutions to problems in 3–5 builds on K–2 experiences and progresses to include investigations that <u>control variables</u> and provide evidence to support explanations or design solutions. • Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered. • Evaluate appropriate methods and/or tools for collecting data. • Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution. • Make predictions about what would happen if a variable changes. • Test two different models of the same proposed object, tool, or process to	Planning and carrying out investigations in 6-8 builds on K-5 experiences and progresses to include investigations that use <u>multiple variables</u> and provide evidence to support explanations or solutions. • Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. • Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation. • Evaluate the accuracy of various methods for collecting data. • Collect data to produce data to serve as the basis for evidence to answer scientific questions or test	Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models. • Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. • Plan and conduct an investigation or test a design solution in a safe and ethical manner including considerations of environmental, social, and personal impacts. • Select appropriate tools to collect, record, analyze, and evaluate data.

solves a problem or meets a goal. • Make predictions based on prior experiences.	determine which better meets criteria for success.	design solutions under a range of conditions. • Collect data about the performance of a proposed object, tool, process or system under a range of conditions.	• Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated. • Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables.

Practice 4 Analyzing and Interpreting Data

> *Once collected, data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others. Because raw data as such have little meaning, a major practice of scientists is to organize and interpret data through tabulating, graphing, or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence.*
>
> *Engineers, too, make decisions based on evidence that a given design will work; they rarely rely on trial and error. Engineers often analyze a design by creating a model or prototype and collecting extensive data on how it performs, including under extreme conditions. Analysis of this kind of data not only informs design decisions and enables the prediction or assessment of performance but also helps define or clarify problems, determine economic feasibility, evaluate alternatives, and investigate failures.* (NRC Framework, 2012, p. 61-62)

As students mature, they are expected to expand their capabilities to use a range of tools for tabulation, graphical representation, visualization, and statistical analysis. Students are also expected to improve their abilities to interpret data by identifying significant features and patterns, use mathematics to represent relationships between variables, and take into account sources of error. When possible and feasible, students should use digital tools to analyze and interpret data. Whether analyzing data for the purpose of science or engineering, it is important students present data as evidence to support their conclusions.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Analyzing data in K–2 builds on prior experiences and progresses to collecting, recording, and sharing observations. • Record information (observations, thoughts, and ideas). • Use and share pictures, drawings, and/or writings of observations. • Use observations (firsthand or from media) to describe patterns and/or relationships in the natural and designed world(s) in order to answer scientific questions and solve problems. • Compare predictions (based on prior experiences) to what occurred (observable events). • Analyze data from tests of an object or tool to determine if it works as intended.	Analyzing data in 3–5 builds on K–2 experiences and progresses to introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations. When possible and feasible, digital tools should be used. • Represent data in tables and/or various graphical displays (bar graphs, pictographs and/or pie charts) to reveal patterns that indicate relationships. • Analyze and interpret data to make sense of phenomena, using logical reasoning, mathematics, and/or computation. • Compare and contrast data collected by different groups in order to discuss similarities and differences in their findings. • Analyze data to refine a problem statement or the design of a proposed object, tool, or process. • Use data to evaluate and refine design solutions.	Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. • Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships. • Use graphical displays (e.g., maps, charts, graphs, and/or tables) of large data sets to identify temporal and spatial relationships. • Distinguish between causal and correlational relationships in data. • Analyze and interpret data to provide evidence for phenomena. • Apply concepts of statistics and probability (including mean, median, mode, and variability) to analyze and characterize data, using digital tools when feasible. • Consider limitations of data analysis (e.g., measurement error), and/or seek to improve precision and accuracy of data with better technological tools and methods (e.g., multiple trials). • Analyze and interpret data to determine similarities and differences in findings. • Analyze data to define an optimal operational range for a proposed object, tool, process or system that best meets criteria for success.	Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data. • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. • Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. • Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data. • Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. • Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. • Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.

Practice 5 Using Mathematics and Computational Thinking

> *Although there are differences in how mathematics and computational thinking are applied in science and in engineering, mathematics often brings these two fields together by enabling engineers to apply the mathematical form of scientific theories and by enabling scientists to use powerful information technologies designed by engineers. Both kinds of professionals can thereby accomplish investigations and analyses and build complex models, which might otherwise be out of the question.* (NRC Framework, 2012, p. 65)

Students are expected to use mathematics to represent physical variables and their relationships, and to make quantitative predictions. Other applications of mathematics in science and engineering include logic, geometry, and at the highest levels, calculus. Computers and digital tools can enhance the power of mathematics by automating calculations, approximating solutions to problems that cannot be calculated precisely, and analyzing large data sets available to identify meaningful patterns. Students are expected to use laboratory tools connected to computers for observing, measuring, recording, and processing data. Students are also expected to engage in computational thinking, which involves strategies for organizing and searching data, creating sequences of steps called algorithms, and using and developing new simulations of natural and designed systems. Mathematics is a tool that is key to understanding science. As such, classroom instruction must include critical skills of mathematics. The NGSS displays many of those skills through the performance expectations, but classroom instruction should enhance all of science through the use of quality mathematical and computational thinking.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Mathematical and computational thinking in K–2 builds on prior experience and progresses to recognizing that mathematics can be used to describe the natural and designed world(s). • Decide when to use qualitative vs. quantitative data. • Use counting and numbers to identify and describe patterns in the natural and designed world(s). • Describe, measure, and/or compare quantitative attributes of different objects and display the data using simple graphs. • Use quantitative data to compare two alternative solutions to a problem.	Mathematical and computational thinking in 3–5 builds on K–2 experiences and progresses to extending quantitative measurements to a variety of physical properties and using computation and mathematics to analyze data and compare alternative design solutions. • Decide if qualitative or quantitative data are best to determine whether a proposed object or tool meets criteria for success. • Organize simple data sets to reveal patterns that suggest relationships. • Describe, measure, estimate, and/or graph quantities (e.g., area, volume, weight, time) to address scientific and engineering questions and problems. • Create and/or use graphs and/or charts generated from simple algorithms to compare alternative solutions to an engineering problem.	Mathematical and computational thinking in 6–8 builds on K–5 experiences and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments. • Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends. • Use mathematical representations to describe and/or support scientific conclusions and design solutions. • Create algorithms (a series of ordered steps) to solve a problem. • Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems. • Use digital tools and/or mathematical concepts and arguments to test and compare proposed solutions to an engineering design problem.	Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system. • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. • Apply techniques of algebra and functions to represent and solve scientific and engineering problems. • Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world. • Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m^3, acre-feet, etc.).

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Practice 6 Constructing Explanations and Designing Solutions

The goal of science is to construct explanations for the causes of phenomena. Students are expected to construct their own explanations, as well as apply standard explanations they learn about from their teachers or reading. The *Framework* states the following about explanation:

> "*The goal of science is the construction of theories that provide explanatory accounts of the world. A theory becomes accepted when it has multiple lines of empirical evidence and greater explanatory power of phenomena than previous theories.*"(NRC Framework, 2012, p. 52)

An explanation includes a claim that relates how a variable or variables relate to another variable or a set of variables. A claim is often made in response to a question and in the process of answering the question, scientists often design investigations to generate data.

The goal of engineering is to solve problems. Designing solutions to problems is a systematic process that involves defining the problem, then generating, testing, and improving solutions. This practice is described in the *Framework* as follows.

> *Asking students to demonstrate their own understanding of the implications of a scientific idea by developing their own explanations of phenomena, whether based on observations they have made or models they have developed, engages them in an essential part of the process by which conceptual change can occur.*
>
> *In engineering, the goal is a design rather than an explanation. The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers' activities, however, have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing and testing models or prototypes, selecting among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation.* (NRC Framework, 2012, p. 68-69)

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Constructing explanations and designing solutions in K–2 builds on prior experiences and progresses to the use of evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions. • Make observations (firsthand or from media) to construct an evidence-based account for natural phenomena. • Use tools and/or materials to design and/or build a device that solves a specific problem or a solution to a specific problem. • Generate and/or compare multiple solutions to a problem.	Constructing explanations and designing solutions in 3–5 builds on K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems. • Construct an explanation of observed relationships (e.g., the distribution of plants in the back yard). • Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem. • Identify the evidence that supports particular points in an explanation. • Apply scientific ideas to solve design problems. • Generate and compare multiple solutions to a problem based on how	Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories. • Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena. • Construct an explanation using models or representations. • Construct a scientific explanation based on valid and reliable evidence obtained from sources (including the students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific ideas, principles, and/or evidence to construct, revise and/or use an explanation for real-world phenomena, examples, or events. • Apply scientific reasoning to show why the data or evidence is adequate for the explanation or conclusion.	Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Make a quantitative and/or qualitative claim regarding the relationship between dependent and independent variables. • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. • Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.

	well they meet the criteria and constraints of the design solution.	• Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system. • Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. • Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing.	• Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Practice 7 Engaging in Argument from Evidence

> *The study of science and engineering should produce a sense of the process of argument necessary for advancing and defending a new idea or an explanation of a phenomenon and the norms for conducting such arguments. In that spirit, students should argue for the explanations they construct, defend their interpretations of the associated data, and advocate for the designs they propose.* (NRC Framework, 2012, p. 73)

Argumentation is a process for reaching agreements about explanations and design solutions. In science, reasoning and argument based on evidence are essential in identifying the best explanation for a natural phenomenon. In engineering, reasoning and argument are needed to identify the best solution to a design problem. Student engagement in scientific argumentation is critical if students are to understand the culture in which scientists live, and how to apply science and engineering for the benefit of society. As such, argument is a process based on evidence and reasoning that leads to explanations acceptable by the scientific community and design solutions acceptable by the engineering community.

Argument in science goes beyond reaching agreements in explanations and design solutions. Whether investigating a phenomenon, testing a design, or constructing a model to provide a mechanism for an explanation, students are expected to use argumentation to listen to, compare, and evaluate competing ideas and methods based on their merits. Scientists and engineers engage in argumentation when investigating a phenomenon, testing a design solution, resolving questions about measurements, building data models, and using evidence to evaluate claims.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Engaging in argument from evidence in K–2 builds on prior experiences and progresses to comparing ideas and representations about the natural and designed world(s). • Identify arguments that are supported by evidence. • Distinguish between explanations that account for all gathered evidence and those that do not. • Analyze why some evidence is relevant to a scientific question and some is not. • Distinguish between opinions and evidence in one's own explanations. • Listen actively to arguments to indicate agreement or disagreement based on evidence, and/or to retell the main points of the argument. • Construct an argument with evidence to support a claim. • Make a claim about the effectiveness of an object, tool, or solution that is supported by relevant evidence.	Engaging in argument from evidence in 3–5 builds on K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world(s). • Compare and refine arguments based on an evaluation of the evidence presented. • Distinguish among facts, reasoned judgment based on research findings, and speculation in an explanation. • Respectfully provide and receive critiques from peers about a proposed procedure, explanation, or model by citing relevant evidence and posing specific questions. • Construct and/or support an argument with evidence, data, and/or a model. • Use data to evaluate claims about cause and effect. • Make a claim about the merit of a solution to a problem by citing relevant evidence about how it meets the criteria and constraints of the problem.	Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world(s). • Compare and critique two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretations of facts. • Respectfully provide and receive critiques about one's explanations, procedures, models, and questions by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail. • Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. • Make an oral or written argument that supports or refutes the advertised performance of a device, process, or system based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints.	Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science. • Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues. • Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments. • Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence, challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining additional information required to resolve contradictions. • Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence. • Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence. • Evaluate competing design solutions to a real-world problem based on scientific ideas and principles,

		• Evaluate competing design solutions based on jointly developed and agreed-upon design criteria.	empirical evidence, and/or logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations).

Practice 8 Obtaining, Evaluating, and Communicating Information

> *Any education in science and engineering needs to develop students' ability to read and produce domain-specific text. As such, every science or engineering lesson is in part a language lesson, particularly reading and producing the genres of texts that are intrinsic to science and engineering.* (NRC Framework, 2012, p. 76)

Being able to read, interpret, and produce scientific and technical text are fundamental practices of science and engineering, as is the ability to communicate clearly and persuasively. Being a critical consumer of information about science and engineering requires the ability to read or view reports of scientific or technological advances or applications (whether found in the press, the Internet, or in a town meeting) and to recognize the salient ideas, identify sources of error and methodological flaws, distinguish observations from inferences, arguments from explanations, and claims from evidence. Scientists and engineers employ multiple sources to obtain information used to evaluate the merit and validity of claims, methods, and designs. Communicating information, evidence, and ideas can be done in multiple ways: using tables, diagrams, graphs, models, interactive displays, and equations as well as orally, in writing, and through extended discussions.

Grades K-2	Grades 3-5	Grades 6-8	Grades 9-12
Obtaining, evaluating, and communicating information in K–2 builds on prior experiences and uses observations and texts to communicate new information. • Read grade-appropriate texts and/or use media to obtain scientific and/or technical information to determine patterns in and/or evidence about the natural and designed world(s). • Describe how specific images (e.g., a diagram showing how a machine works) support a scientific or engineering idea. • Obtain information using various texts, text features (e.g., headings, tables of contents, glossaries, electronic menus, icons), and other media that will be useful in answering a scientific question and/or supporting a scientific claim. • Communicate information or design ideas and/or solutions with others in oral and/or written forms using models, drawings, writing, or numbers that provide detail about scientific ideas, practices, and/or design ideas.	Obtaining, evaluating, and communicating information in 3–5 builds on K–2 experiences and progresses to evaluating the merit and accuracy of ideas and methods. • Read and comprehend grade-appropriate complex texts and/or other reliable media to summarize and obtain scientific and technical ideas and describe how they are supported by evidence. • Compare and/or combine across complex texts and/or other reliable media to support the engagement in other scientific and/or engineering practices. • Combine information in written text with that contained in corresponding tables, diagrams, and/or charts to support the engagement in other scientific and/or engineering practices. • Obtain and combine information from books and/or other reliable media to explain phenomena or solutions to a design problem. • Communicate scientific and/or technical information orally and/or in written formats, including various forms of media as well as tables, diagrams, and charts.	Obtaining, evaluating, and communicating information in 6–8 builds on K–5 experiences and progresses to evaluating the merit and validity of ideas and methods. • Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s). • Integrate qualitative and/or quantitative scientific and/or technical information in written text with that contained in media and visual displays to clarify claims and findings. • Gather, read, and synthesize information from multiple appropriate sources and assess the credibility, accuracy, and possible bias of each publication and methods used, and describe how they are supported or not supported by evidence. • Evaluate data, hypotheses, and/or conclusions in scientific and technical texts in light of competing information or accounts. • Communicate scientific and/or technical information (e.g. about a proposed object, tool, process, system) in writing and/or through oral presentations.	Obtaining, evaluating, and communicating information in 9–12 builds on K–8 experiences and progresses to evaluating the validity and reliability of the claims, methods, and designs. • Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. • Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem. • Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source. • Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible. • Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically).

Reflecting on the Practices of Science and Engineering

Engaging students in the practices of science and engineering outlined in this section is not sufficient for science literacy. It is also important for students to stand back and reflect on how these practices have contributed to their own development, and to the accumulation of scientific knowledge and engineering accomplishments over the ages. Accomplishing this is a matter for curriculum and instruction, rather than standards, so specific guidelines are not provided in this document. Nonetheless, this section would not be complete without an acknowledgment that reflection is essential if students are to become aware of themselves as competent and confident learners and doers in the realms of science and engineering.

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