2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering
Education for 130 Years
ASEE
Paper ID #38341

P-12 Engineering Performance Matrices: Where Did They Come From and How Can They Be Used? (Research to Practice)

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P-12 Engineering Performance Matrices
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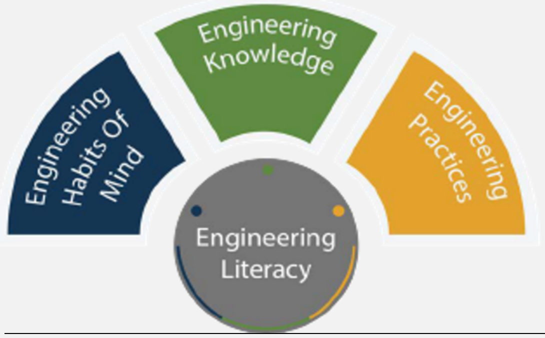
Introduction

To help remove barriers to engineering career pathways, foster a sense of belonging in the field, develop important skills for student success in any career they may choose, and ultimately create a transformed engineering workforce that can better serve the whole of society, it can be critical to act early in the educational experiences provided for our nation's youth. While initiatives to engage children in engineering learning experiences over the last couple decades have been encouraging and millions of students participate in formalized P-12 engineering-related courses, there has been uncertainty as to how engineering should be intentionally taught across schools in a coherent manner. To help fill this void, the *Framework for P-12 Engineering Learning* was published in 2020 by the *American Society for Engineering Education*. This framework is positioned to offer a unifying vision and guidance for informing state and local decisions to enhance the purposefulness, coherency, and equity of engineering teaching and learning. While the framework supplies the potential "endpoints" for each component of engineering literacy (i.e., habits of mind, practices, and knowledge) and details what students could learn by the end of secondary school, it does not specify a potential blueprint of how the engineering concepts and sub-concepts may be related and build upon each other to arrive at these endpoints. Accordingly, following the review of literature and the collection of insights from a variety of engineering education stakeholders, including teachers, professors, and industry representatives, an *Engineering Performance Matrix* (EPM) conceptual model was created to provide an instructional/assessment blueprint for engineering programs/initiatives. In addition, an EPM for each engineering concept found within the framework was drafted to help teachers scaffold learning to their students' needs and progress teaching toward a targeted performance goal. This paper will highlight the research and development work that was enacted to draft the EPMs and discuss how they can be used for developing engineering lessons and activities as well as aligning/scoping P-12 engineering programs.

Where Did They Come From? The Research & Development Process

The *Framework for P-12 Engineering Learning* states that engineering literacy is three dimensional and involves engineering habits of mind, practices, and knowledge (See Figure 1). The framework also describes that engineering literacy should be developed for students across the span of their P-12 education experience, scaffolding from more explicitly developing *Engineering Habits of Mind* in the early grades and moving toward more explicitly developing *Engineering Knowledge* at the higher grades—all while developing competence in *Engineering Practice* (see Figure 2).



1. **Engineering Habits of Mind** that students should develop over time through repetition and conditioning,
2. **Engineering Practices** in which students should become competent, and
3. **Engineering Knowledge** that students should be able to recognize and access to inform their engineering practice.

Literacy Dimensions	Main Components	
Engineering Habits of Mind	Optimism Persistence Conscientiousness	Systems Thinking Creativity Collaboration
Engineering Practices	Engineering Design Material Processing	Quantitative Analysis Professionalism
Engineering Knowledge Domains	Engineering Sciences Engineering Mathematics	Engineering Technical Applications

Figure 1. Dimensions of Engineering Literacy.

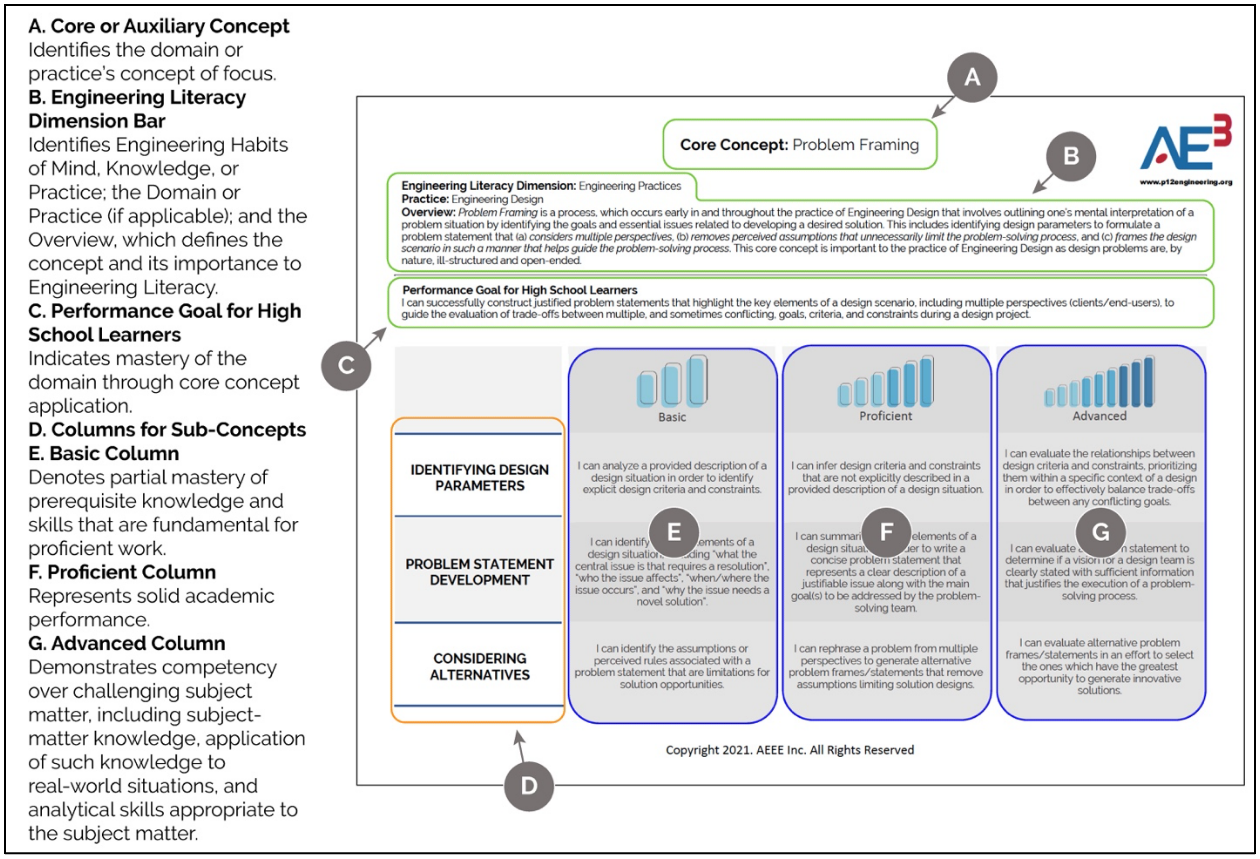
	Engineering Habits of Mind	*Engineering Practices*	*Engineering Knowledge*
Primary School (Grades preK-2)	■	▒	□
Elementary School Grades 3-5	■	■	▒
Middle School Grades 6-8	▒	■	■
High School Grades 9-12	□	▒	■

Figure 2. Scaffolding toward Engineering Literacy across the three dimensions of engineering learning (The darker shading indicating a more explicit emphasis of instruction with the lighter shading indicating more implicit instruction).

In addition, the framework provides a taxonomy of engineering concepts and sub-concepts related to the three dimensions of engineering literacy (see Appendix A) as well as a list of performance expectations for students to strive for by the end of secondary school. The taxonomy of engineering concepts and sub-concepts found within the framework were established through a modified Delphi study approach. The Delphi study method is a mixed methods approach to build a consensus of opinions related to a specific topic across a group of specialists through multiple rounds of questioning (Helmer & Rescher, 1959). This can typically involve one qualitative round of questioning followed by two or more rounds of more quantitative questions to assess agreement among the specialists with the responses to the previous questions. In this case, the modified Delphi approach included three rounds of questions in survey format and one final round in a face-to-face focus group setting. Through this questioning, the specialists, which included representatives from the engineering, engineering education, technology and engineering education, and teacher education communities, were asked to identify, rate, and then verify core concepts and the corresponding sub-concepts deemed important for inclusion in a framework for engineering learning at the pre-college level. More specifically, the four rounds consisted of concept discovery, concept prioritization, concept rating, and then concept verification/refinement. Lastly, a synthesis of relevant literature at the time (i.e., Carr, Bennett, & Strobel, 2012; Custer & Erekson, 2008; Merrill, et al., 2009; National Academy of Engineering, 2009; 2010; Sneider & Rosen, 2009) as well as the *National Academies' Taxonomy of Engineering*, the *Fundamentals of Engineering Exams* (National Council of Examiners for Engineering & Surveying, 2017), a first-year engineering program review (Strimel et al., 2018), the *Accreditation Board for Engineering and Technology* (ABET) standards, and the International Technology and Engineering Educators Association's *Engineering Endorsement Responsibility Matrix* were used to inform the prioritization and refinement of the concept taxonomy.

While this research resulted in a "menu" of concepts to be included in a framework in which to build instruction around, it did not specify how the concepts and sub-concepts build upon each other to support engineering learning across educational experiences. That said, during the framework development process, EPMs were also developed, tested, and refined through a design-based research approach. This approach, which included three multi-day symposia, brought together engineering learning specialists and stakeholders to articulate how the engineering concepts and sub-concepts are related and how they can be connected to support a student's progression toward engineering literacy performance expectations.

An EPM is a conceptual model (adapted from Strimel et al., 2020) that demonstrates ways in which the concepts identified in the *Framework for P-12 Engineering Learning* can be used to guide engineering instruction and serve as an assessment blueprint for the development of engineering literacy. EPMs are then intended to provide teachers with a sharper understanding of how concepts and sub-concepts may be related in order to influence more equitable, timely, and specific feedback through purposeful instructional practices. The hope is that the EPMs help teachers think through the engineering concepts to inform their instruction from day-to-day or week-to-week. Accordingly, the EPM template in Figure 3 was developed based on relevant literature (Corcoran, Mosher, & Rogat, 2009; Duncan & Hmelo Silver, 2009; Lehrer & Schauble, 2015; Magana, 2017) and then, following the consultation with over 200 P-12 engineering education stakeholders from 32 states at the multi-day symposia, an EPM for each of the concepts in the engineering taxonomy (see Appendix A) were created. More specifically, the development of these EPMs involved iterative cycles of research, design, and experimentation over the process of three years. These cycles included a) establishing an instructional blueprint for sequencing the learning of these engineering concepts, b) coordinating focus groups for validation of these blueprints, c) designing sample socially-relevant/culturally-situated learning activities, and c) establishing pilot sites for testing and refining this work within K-12 classrooms. As a result of this work, 60 EPMs that cover the concepts related to engineering habits of mind, engineering practices, and engineering knowledge have been created. Figure 3 provides an example of one of these EPMs for the concept of *Problem Framing* which is core to the practice of engineering design. Figure 3 also provides an explanation of each component of the sample EPM. All 60 of the EPMs can be accessed for free at https://www.p12engineering.org/epm. While these EPMs can indicate how to scaffold learning across different depths of student understanding from basic to advanced, it is important to note that learning experiences should be shaped according to the individualities of students and their communities. That said, the remaining sections of this paper will further describe how the EPMs can be used to plan instructional materials and develop/align P-12 engineering programs/courses.



A. Core or Auxiliary Concept
Identifies the domain or practice's concept of focus.
B. Engineering Literacy Dimension Bar
Identifies Engineering Habits of Mind, Knowledge, or Practice; the Domain or Practice (if applicable); and the Overview, which defines the concept and its importance to Engineering Literacy.
C. Performance Goal for High School Learners
Indicates mastery of the domain through core concept application.
D. Columns for Sub-Concepts
E. Basic Column
Denotes partial mastery of prerequisite knowledge and skills that are fundamental for proficient work.
F. Proficient Column
Represents solid academic performance.
G. Advanced Column
Demonstrates competency over challenging subject matter, including subject-matter knowledge, application of such knowledge to real-world situations, and analytical skills appropriate to the subject matter.

Core Concept: Problem Framing

Engineering Literacy Dimension: Engineering Practices
Practice: Engineering Design
Overview: *Problem Framing* is a process, which occurs early in and throughout the practice of Engineering Design that involves outlining one's mental interpretation of a problem situation by identifying the goals and essential issues related to developing a desired solution. This includes identifying design parameters to formulate a problem statement that (a) *considers multiple perspectives*, (b) *removes perceived assumptions that unnecessarily limit the problem-solving process*, and (c) *frames the design scenario in such a manner that helps guide the problem-solving process*. This core concept is important to the practice of Engineering Design as design problems are, by nature, ill-structured and open-ended.

Performance Goal for High School Learners
I can successfully construct justified problem statements that highlight the key elements of a design scenario, including multiple perspectives (clients/end-users), to guide the evaluation of trade-offs between multiple, and sometimes conflicting, goals, criteria, and constraints during a design project.

	Basic	Proficient	Advanced
IDENTIFYING DESIGN PARAMETERS	I can analyze a provided description of a design situation in order to identify explicit design criteria and constraints.	I can infer design criteria and constraints that are not explicitly described in a provided description of a design situation.	I can evaluate the relationships between design criteria and constraints, prioritizing them within a specific context of a design in order to effectively balance trade-offs between any conflicting goals.
PROBLEM STATEMENT DEVELOPMENT	I can identify [illegible] ements of a design situation, [illegible] ding "what the central issue is that requires a resolution", "who the issue affects", "when/where the issue occurs", and "why the issue needs a novel solution".	I can summari[illegible] elements of a design situa[illegible] der to write a concise problem statement that represents a clear description of a justifiable issue along with the main goal(s) to be addressed by the problem-solving team.	I can evaluate [illegible] n statement to determine if a vision for a design team is clearly stated with sufficient information that justifies the execution of a problem-solving process.
CONSIDERING ALTERNATIVES	I can identify the assumptions or perceived rules associated with a problem statement that are limitations for solution opportunities.	I can rephrase a problem from multiple perspectives to generate alternative problem frames/statements that remove assumptions limiting solution designs.	I can evaluate alternative problem frames/statements in an effort to select the ones which have the greatest opportunity to generate innovative solutions.

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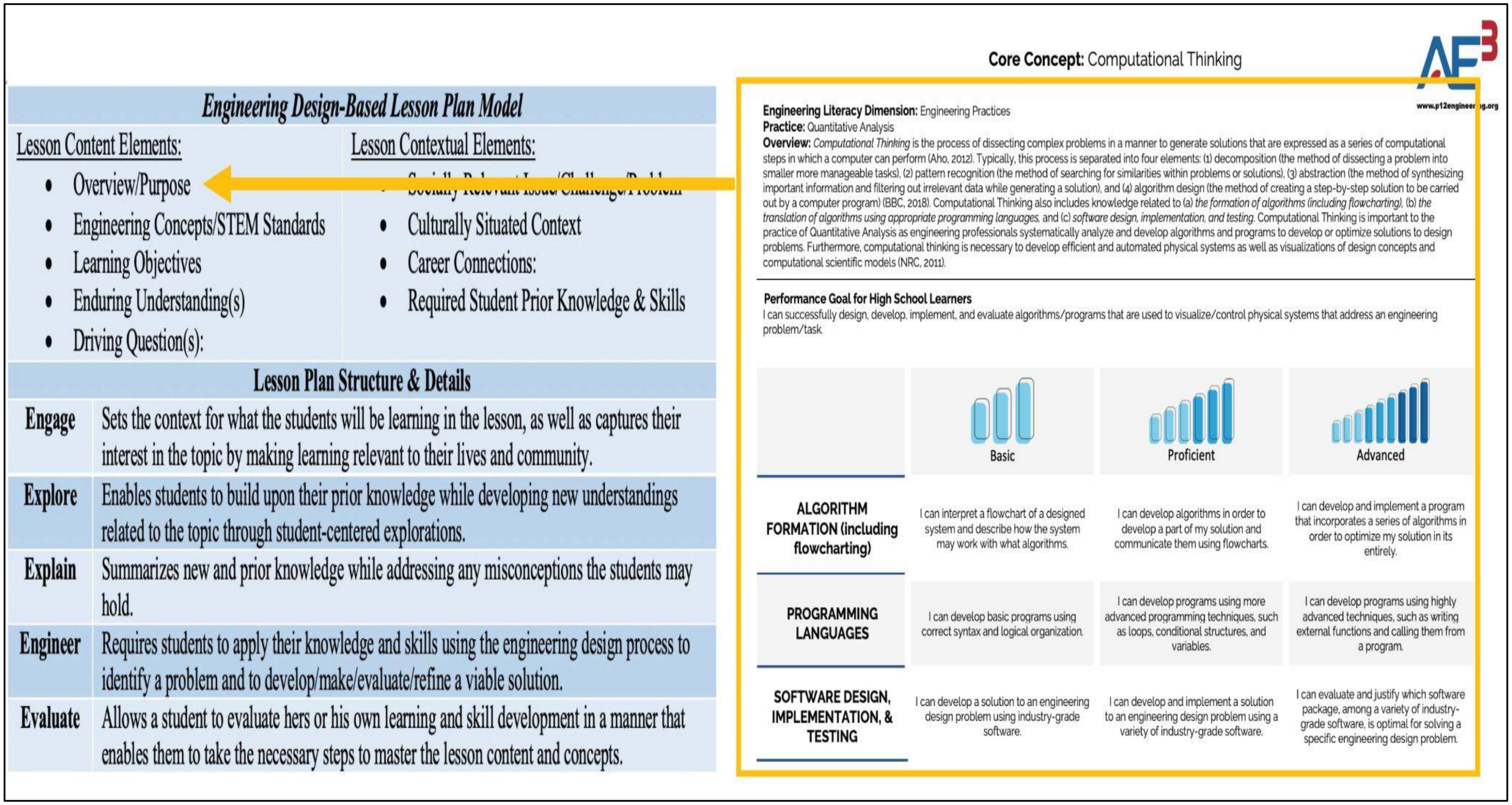
Figure 3. Engineering Performance Matrix Example and Explanation.

Developing Engineering Lessons/Activities using the EPMs

The *Framework for P-12 Engineering Learning* (2020) included a lesson planning model to assist in the preparation of engineering instruction. The lesson planning model was based upon the 5-E lesson model created by Bybee (2002) and later adapted for engineering learning by Grubbs and Strimel (2016). The lesson planning model has three main components which are the lesson content elements, the lesson contextual elements, and then the step-by-step 5-E lesson plan. First, the lesson content elements include 1) the lesson overview and purpose, 2) the targeted engineering concepts and the related STEM standards for the lesson, 3) the learning objectives, 4) the enduring understandings for the lesson which are the key knowledge points that can transcend the lesson itself, and 5) the driving questions that can help direct students in their information gathering efforts in an attempt develop solutions to the overarching issue or challenge at the center of the lesson. The lesson contextual elements include 1) the socially and/or locally relevant issue/challenge/problem at the center of the lesson, 2) the cultural connection between the lesson and the students as well as the local community, 3) the connections between the lesson content and the related careers, and 4) pre-requisite knowledge and skills that will enable students to be successful within the learning experience. Then, the 5-E plan includes the following sections for guiding the structure of the specific lesson activities:

- **Engage:** This section of the lesson should set the context for what the students will be learning in the lesson as well as captures their interests in the topic by making learning relevant to their lives and community
- **Explore:** This section of the lesson should allow students to build upon their prior knowledge while developing new understandings related to the topic through student-centered explorations.
- **Explain:** This section of the lesson should summarize new and prior knowledge while addressing any misconceptions the students may hold.
- **Engineer:** This section of the lesson should require students to apply their knowledge and practices to identify a problem and then design/make/evaluate/refine a viable solution.
- **Evaluate:** This section of the lesson should allow a student to evaluate their own learning and skill development in a manner that supports them in taking the necessary steps to master the lesson content and concepts.

The EPMs are then positioned as a tool to aid in the process of developing engineering curriculum and instruction using this lesson planning model. Figures 4 through 9 will illustrate how the EPMs can help establish the lesson content elements. The example EPM for the core concept of *computational thinking* for the *engineering practice* of *quantitative analysis* is presented on the rights side of each figure with the lesson planning model on the left of each figure.



Engineering Design-Based Lesson Plan Model

Lesson Content Elements:

- Overview/Purpose
- Engineering Concepts/STEM Standards
- Learning Objectives
- Enduring Understanding(s)
- Driving Question(s):

Lesson Contextual Elements:

- Socially Relevant Issue/Challenge/Problem
- Culturally Situated Context
- Career Connections:
- Required Student Prior Knowledge & Skills

Lesson Plan Structure & Details

Engage	Sets the context for what the students will be learning in the lesson, as well as captures their interest in the topic by making learning relevant to their lives and community.
Explore	Enables students to build upon their prior knowledge while developing new understandings related to the topic through student-centered explorations.
Explain	Summarizes new and prior knowledge while addressing any misconceptions the students may hold.
Engineer	Requires students to apply their knowledge and skills using the engineering design process to identify a problem and to develop/make/evaluate/refine a viable solution.
Evaluate	Allows a student to evaluate hers or his own learning and skill development in a manner that enables them to take the necessary steps to master the lesson content and concepts.

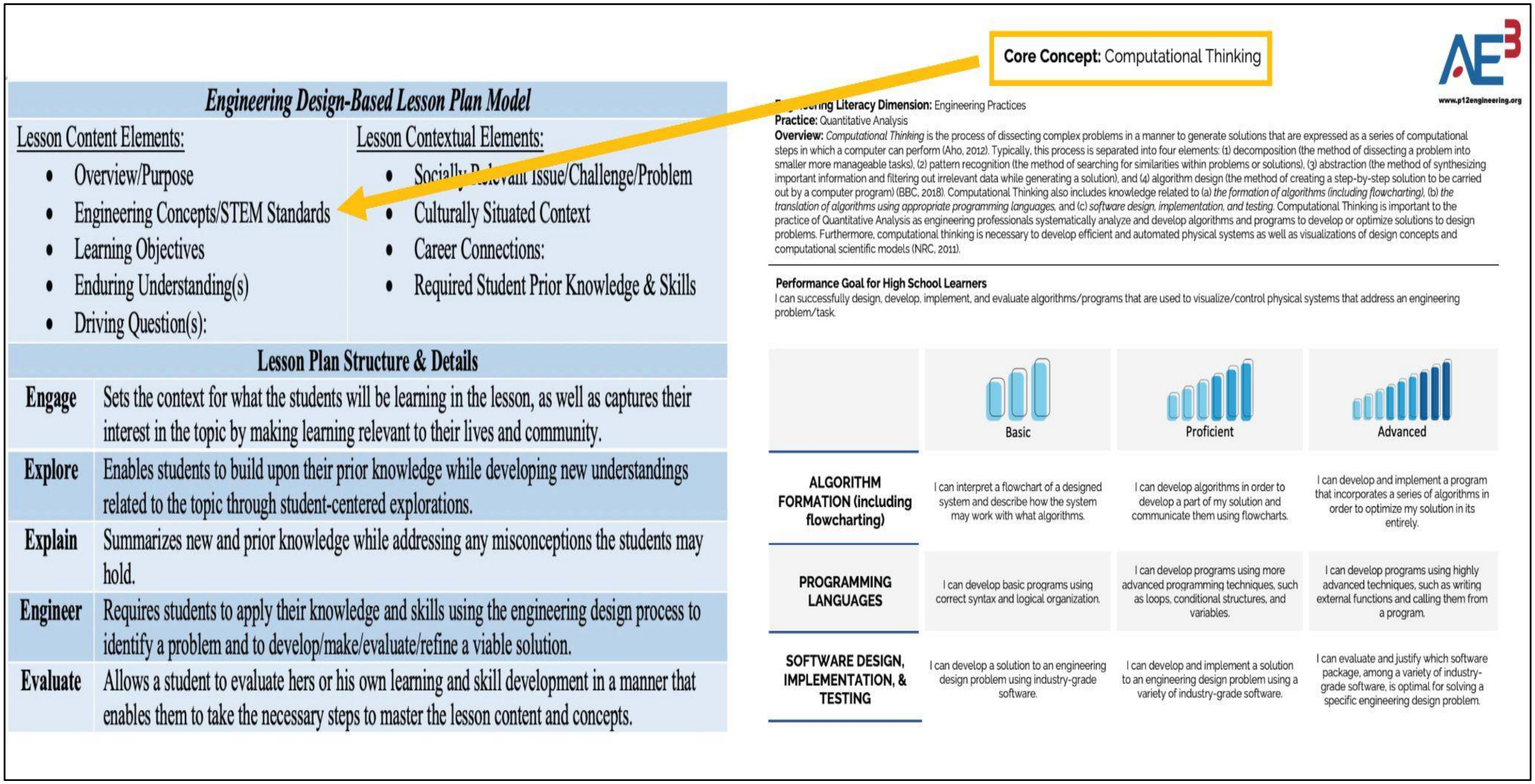
Core Concept: Computational Thinking

Engineering Literacy Dimension: Engineering Practices
Practice: Quantitative Analysis
Overview: *Computational Thinking* is the process of dissecting complex problems in a manner to generate solutions that are expressed as a series of computational steps in which a computer can perform (Aho, 2012). Typically, this process is separated into four elements: (1) decomposition (the method of dissecting a problem into smaller more manageable tasks), (2) pattern recognition (the method of searching for similarities within problems or solutions), (3) abstraction (the method of synthesizing important information and filtering out irrelevant data while generating a solution), and (4) algorithm design (the method of creating a step-by-step solution to be carried out by a computer program) (BBC, 2018). Computational Thinking also includes knowledge related to (a) *the formation of algorithms (including flowcharting)*, (b) *the translation of algorithms using appropriate programming languages*, and (c) *software design, implementation, and testing*. Computational Thinking is important to the practice of Quantitative Analysis as engineering professionals systematically analyze and develop algorithms and programs to develop or optimize solutions to design problems. Furthermore, computational thinking is necessary to develop efficient and automated physical systems as well as visualizations of design concepts and computational scientific models (NRC, 2011).

Performance Goal for High School Learners
I can successfully design, develop, implement, and evaluate algorithms/programs that are used to visualize/control physical systems that address an engineering problem/task.

	Basic	Proficient	Advanced
ALGORITHM FORMATION (including flowcharting)	I can interpret a flowchart of a designed system and describe how the system may work with what algorithms.	I can develop algorithms in order to develop a part of my solution and communicate them using flowcharts.	I can develop and implement a program that incorporates a series of algorithms in order to optimize my solution in its entirely.
PROGRAMMING LANGUAGES	I can develop basic programs using correct syntax and logical organization.	I can develop programs using more advanced programming techniques, such as loops, conditional structures, and variables.	I can develop programs using highly advanced techniques, such as writing external functions and calling them from a program.
SOFTWARE DESIGN, IMPLEMENTATION, & TESTING	I can develop a solution to an engineering design problem using industry-grade software.	I can develop and implement a solution to an engineering design problem using a variety of industry-grade software.	I can evaluate and justify which software package, among a variety of industry-grade software, is optimal for solving a specific engineering design problem.

Figure 4. The EPM can be used to establish the lesson purpose and overview.



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Lesson Contextual Elements:

- Socially R[illegible]vant Issue/Challenge/Problem
- Culturally Situated Context
- Career Connections:
- Required Student Prior Knowledge & Skills

Lesson Plan Structure & Details

Engage	Sets the context for what the students will be learning in the lesson, as well as captures their interest in the topic by making learning relevant to their lives and community.
Explore	Enables students to build upon their prior knowledge while developing new understandings related to the topic through student-centered explorations.
Explain	Summarizes new and prior knowledge while addressing any misconceptions the students may hold.
Engineer	Requires students to apply their knowledge and skills using the engineering design process to identify a problem and to develop/make/evaluate/refine a viable solution.
Evaluate	Allows a student to evaluate hers or his own learning and skill development in a manner that enables them to take the necessary steps to master the lesson content and concepts.

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PROGRAMMING LANGUAGES	I can develop basic programs using correct syntax and logical organization.	I can develop programs using more advanced programming techniques, such as loops, conditional structures, and variables.	I can develop programs using highly advanced techniques, such as writing external functions and calling them from a program.
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Figure 5. The Core Concept from the EPM can be used as the Engineering Content for the lesson.

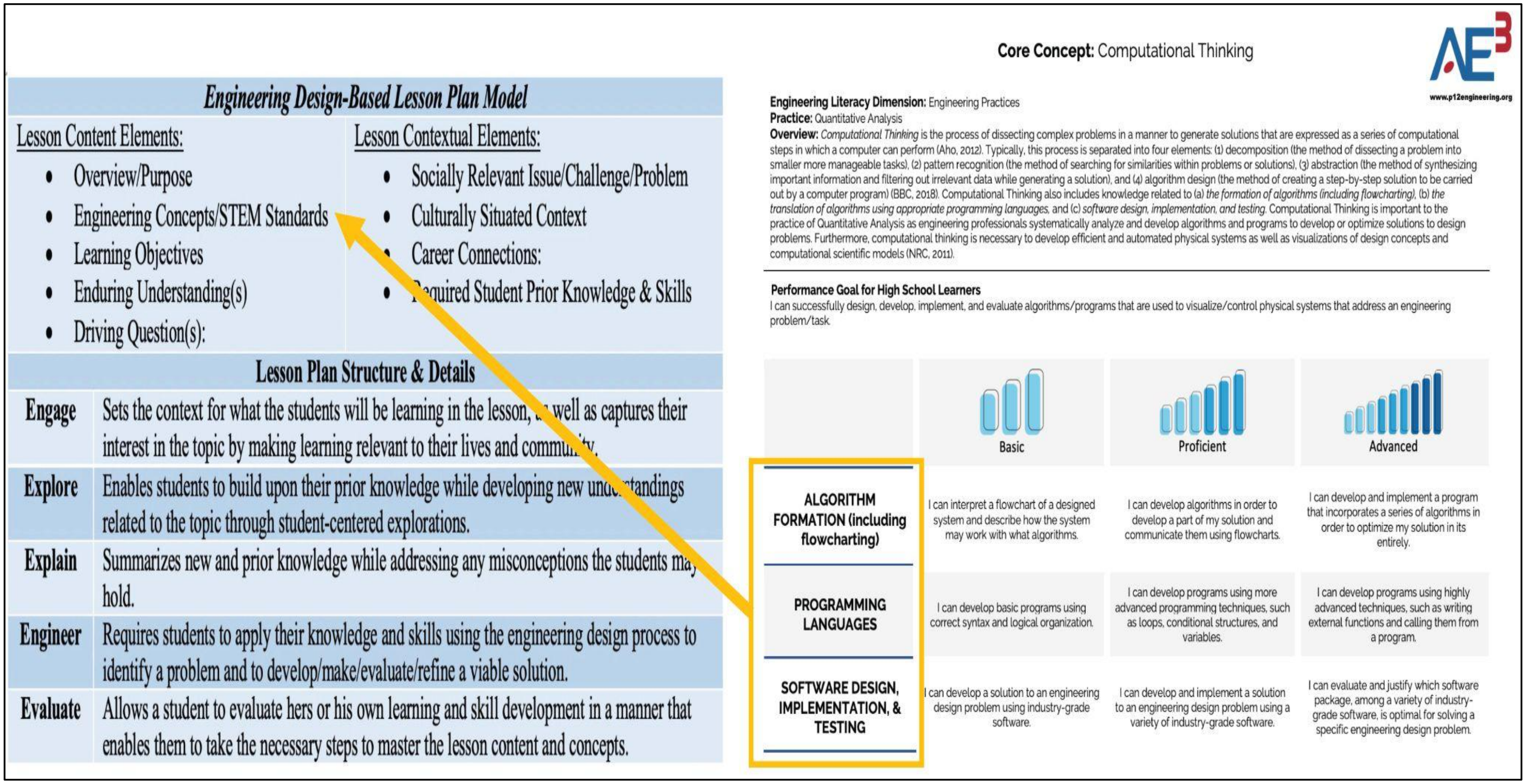

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Figure 6. The Sub-Concepts of the EPM can also be used as the Engineering Concepts for the lesson and also help to determine any other relevant STEM standards to address in the lesson.

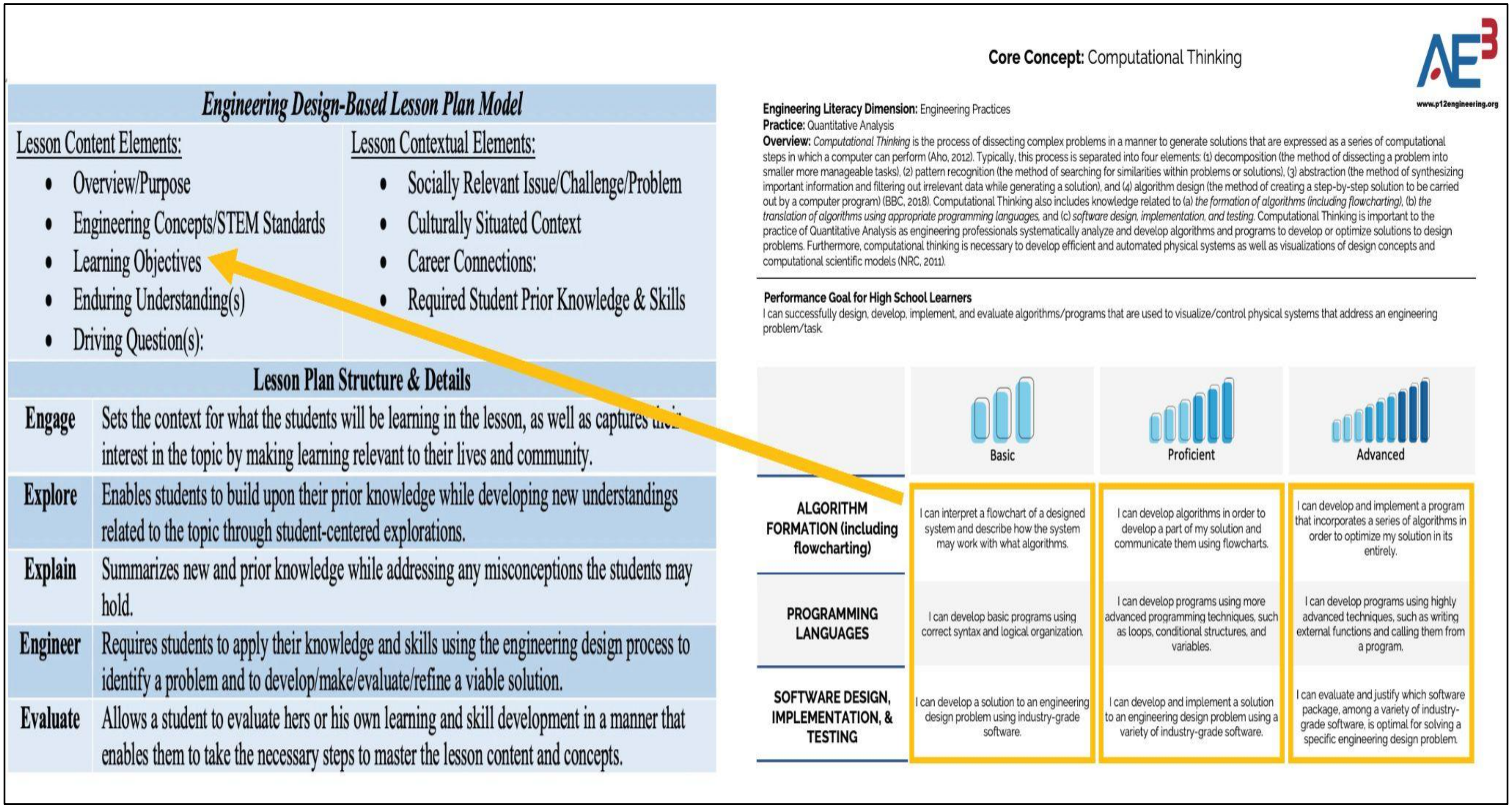

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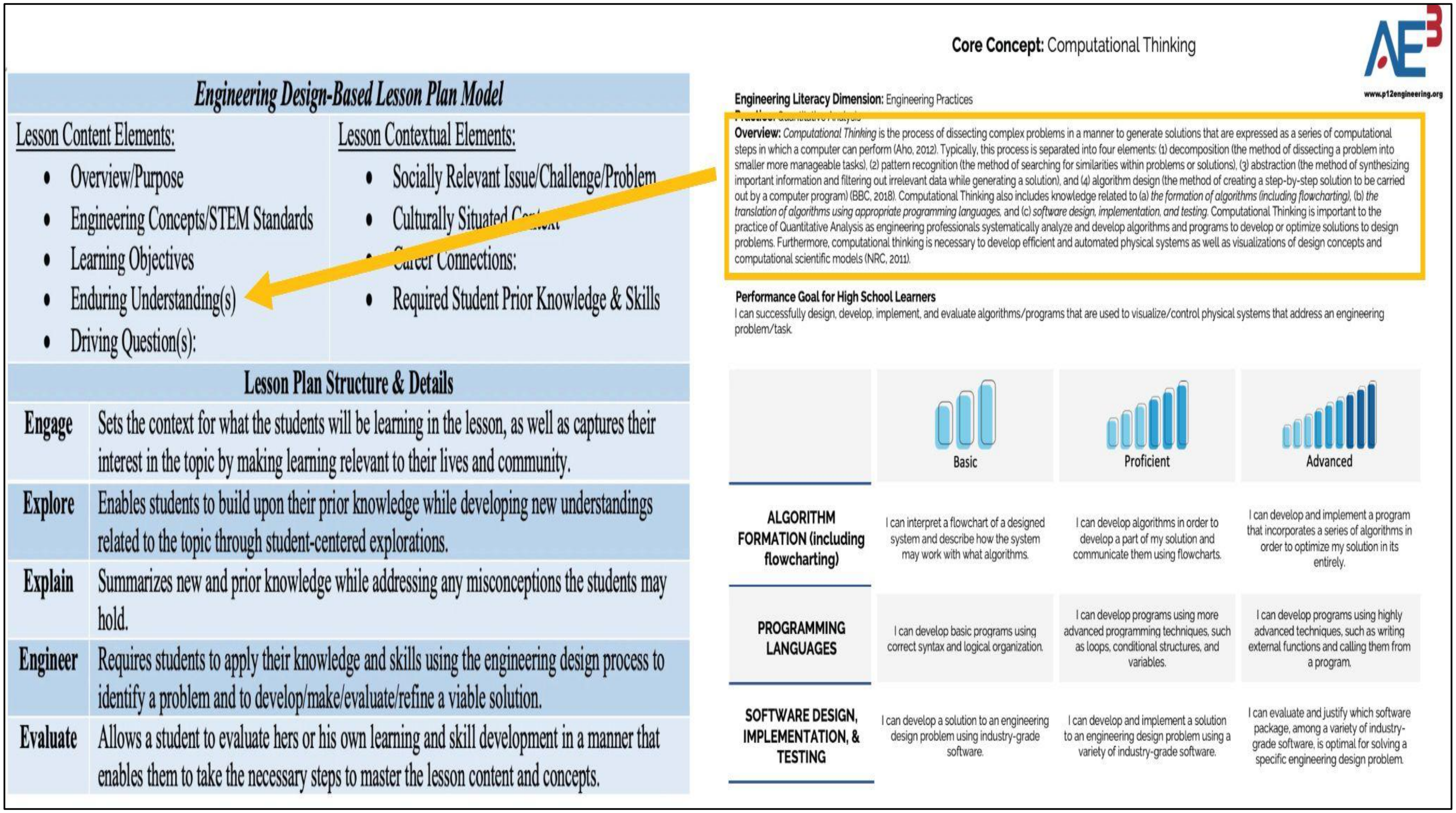
Figure 7. The "I Can" statements for each sub-concept of the EPM can be used to determine the appropriate learning objectives based on the class's prior knowledge.



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Core Concept: Computational Thinking

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Engineering Literacy Dimension: Engineering Practices

Practice: Quantitative Analysis

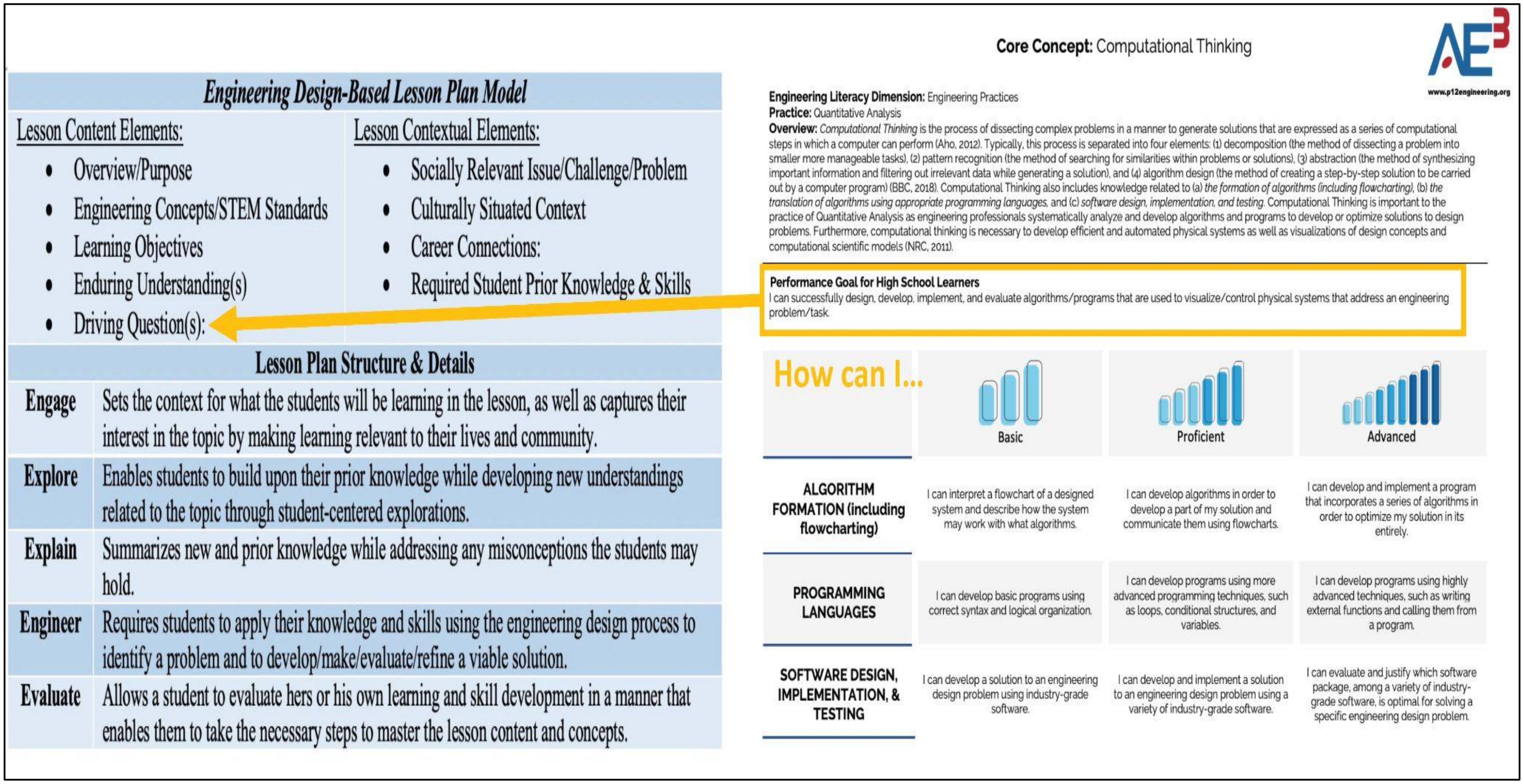
Overview: *Computational Thinking* is the process of dissecting complex problems in a manner to generate solutions that are expressed as a series of computational steps in which a computer can perform (Aho, 2012). Typically, this process is separated into four elements: (1) decomposition (the method of dissecting a problem into smaller more manageable tasks), (2) pattern recognition (the method of searching for similarities within problems or solutions), (3) abstraction (the method of synthesizing important information and filtering out irrelevant data while generating a solution), and (4) algorithm design (the method of creating a step-by-step solution to be carried out by a computer program) (BBC, 2018). Computational Thinking also includes knowledge related to (a) *the formation of algorithms (including flowcharting)*, (b) *the translation of algorithms using appropriate programming languages*, and (c) *software design, implementation, and testing*. Computational Thinking is important to the practice of Quantitative Analysis as engineering professionals systematically analyze and develop algorithms and programs to develop or optimize solutions to design problems. Furthermore, computational thinking is necessary to develop efficient and automated physical systems as well as visualizations of design concepts and computational scientific models (NRC, 2011).

Performance Goal for High School Learners

I can successfully design, develop, implement, and evaluate algorithms/programs that are used to visualize/control physical systems that address an engineering problem/task.

	Basic	Proficient	Advanced
ALGORITHM FORMATION (including flowcharting)	I can interpret a flowchart of a designed system and describe how the system may work with what algorithms.	I can develop algorithms in order to develop a part of my solution and communicate them using flowcharts.	I can develop and implement a program that incorporates a series of algorithms in order to optimize my solution in its entirely.
PROGRAMMING LANGUAGES	I can develop basic programs using correct syntax and logical organization.	I can develop programs using more advanced programming techniques, such as loops, conditional structures, and variables.	I can develop programs using highly advanced techniques, such as writing external functions and calling them from a program.
SOFTWARE DESIGN, IMPLEMENTATION, & TESTING	I can develop a solution to an engineering design problem using industry-grade software.	I can develop and implement a solution to an engineering design problem using a variety of industry-grade software.	I can evaluate and justify which software package, among a variety of industry-grade software, is optimal for solving a specific engineering design problem.

Figure 8. The overview of the EPM can be used as the enduring understanding for the lesson as it describes the concept and its relationship to engineering literacy as well as engineering-related careers.



Engineering Design-Based Lesson Plan Model

Lesson Content Elements:

- Overview/Purpose
- Engineering Concepts/STEM Standards
- Learning Objectives
- Enduring Understanding(s)
- Driving Question(s):

Lesson Contextual Elements:

- Socially Relevant Issue/Challenge/Problem
- Culturally Situated Context
- Career Connections:
- Required Student Prior Knowledge & Skills

Lesson Plan Structure & Details

Engage	Sets the context for what the students will be learning in the lesson, as well as captures their interest in the topic by making learning relevant to their lives and community.
Explore	Enables students to build upon their prior knowledge while developing new understandings related to the topic through student-centered explorations.
Explain	Summarizes new and prior knowledge while addressing any misconceptions the students may hold.
Engineer	Requires students to apply their knowledge and skills using the engineering design process to identify a problem and to develop/make/evaluate/refine a viable solution.
Evaluate	Allows a student to evaluate hers or his own learning and skill development in a manner that enables them to take the necessary steps to master the lesson content and concepts.

Core Concept: Computational Thinking

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Engineering Literacy Dimension: Engineering Practices
Practice: Quantitative Analysis
Overview: *Computational Thinking* is the process of dissecting complex problems in a manner to generate solutions that are expressed as a series of computational steps in which a computer can perform (Aho, 2012). Typically, this process is separated into four elements: (1) decomposition (the method of dissecting a problem into smaller more manageable tasks), (2) pattern recognition (the method of searching for similarities within problems or solutions), (3) abstraction (the method of synthesizing important information and filtering out irrelevant data while generating a solution), and (4) algorithm design (the method of creating a step-by-step solution to be carried out by a computer program) (BBC, 2018). Computational Thinking also includes knowledge related to (a) *the formation of algorithms (including flowcharting)*, (b) *the translation of algorithms using appropriate programming languages*, and (c) *software design, implementation, and testing*. Computational Thinking is important to the practice of Quantitative Analysis as engineering professionals systematically analyze and develop algorithms and programs to develop or optimize solutions to design problems. Furthermore, computational thinking is necessary to develop efficient and automated physical systems as well as visualizations of design concepts and computational scientific models (NRC, 2011).

Performance Goal for High School Learners
I can successfully design, develop, implement, and evaluate algorithms/programs that are used to visualize/control physical systems that address an engineering problem/task.

How can I...	Basic	Proficient	Advanced
ALGORITHM FORMATION (including flowcharting)	I can interpret a flowchart of a designed system and describe how the system may work with what algorithms.	I can develop algorithms in order to develop a part of my solution and communicate them using flowcharts.	I can develop and implement a program that incorporates a series of algorithms in order to optimize my solution in its entirely.
PROGRAMMING LANGUAGES	I can develop basic programs using correct syntax and logical organization.	I can develop programs using more advanced programming techniques, such as loops, conditional structures, and variables.	I can develop programs using highly advanced techniques, such as writing external functions and calling them from a program.
SOFTWARE DESIGN, IMPLEMENTATION, & TESTING	I can develop a solution to an engineering design problem using industry-grade software.	I can develop and implement a solution to an engineering design problem using a variety of industry-grade software.	I can evaluate and justify which software package, among a variety of industry-grade software, is optimal for solving a specific engineering design problem.

Figure 9. The Performance Goal can be posed as a "how can I" question to help direct a student's own learning throughout the engineering lesson.

Scoping and Aligning P-12 Engineering Programs Using the EPMs

The increasing interest for engineering programming in schools around the country provides a unique opportunity for using the habits of mind, practices, and knowledge identified in the *Framework for P-12 Engineering Learning* along with the EPMs to review existing curriculum and determine areas of strengths and areas of opportunity for striving toward engineering literacy for all students. This was the focus taken by one city public school system in the mid-Atlantic region. This section will highlight this example to show how the research related to the framework and the EPMs can be put into practice. The approach provided can be one way that teachers and district leaders scope and strengthen existing, or new, engineering or STEM curriculum

First, the school team conducted an initial review of the engineering literacy/content organization and the guiding principles for engineering programs found in the *Framework for P-12 Engineering Learning* as well as the 60 EPMs. The team, consisting of a group of teachers (engineering, biology, chemistry, and computer science) and the STEM instructional specialist, then decided to pursue five main objectives as they used the framework and EPMs over the course of the school year to scope and align their STEM programming. These objectives included:

1. Analyzing the current curriculum to identify where the concepts related to the engineering habits, practices, and knowledge are explicitly taught and assessed.
2. Determining additional areas of opportunity to address the missing engineering concepts.
3. Creating more intentional areas for integrating engineering concepts within biology and chemistry courses.
4. Creating vertical maps for engineering units and projects to ensure the engineering concepts are addressed over time.
5. Developing instructional materials during common teacher planning times using the EPMs to address all of the core concepts for engineering learning.

In order to analyze their current curriculum and to identify where concepts related to the three dimensions of the framework were currently being implemented with fidelity, the team focused first on the engineering practices. In analyzing each unit of instruction, the teachers used the EPMs and were able to identify the level at which each sub-concept was being addressed. At this step the group also horizontally aligned the career and technical education standards for the state to each of the engineering practices to ensure that state standards were aligned and met. It was clear in doing this step that the framework provided a clearer picture of what the enduring understandings and key knowledge points were as it relates to engineering practices. The next step within the process focused on the engineering knowledge dimension. The EPMs in this dimension enabled the team to create a map of where their current curriculum embedded the science, mathematics, or technical concepts within the knowledge dimension. These first two steps of the process took multiple days. While the process of creating individual lessons continued throughout the school year, after the initial analysis was complete, obvious areas of strengths within the STEM programming were illuminated. Subsequently, the process also pointed to key knowledge areas and engineering concepts that were areas of opportunity for enhancing the current curriculum. Once the initial review was complete and the team had identified missing or underdeveloped engineering concepts areas, they were able to embed many of the sub-concepts naturally into the school system's curriculum. The team found that this process enabled many pre-requisite knowledge connections to be built into the curriculum and corresponding lessons. One of the highlights of the process happened within this phase of the project as natural conversations and discussions arose and many innovative ideas and additions were articulated related to the current units. An unintended consequence of using the framework and its taxonomy is that it provided an opportunity for the school team to discuss their understandings and provide support to one another in their background knowledge. The framework also helped to highlight where there were needs for professional learning and understanding of the teachers. The framework and the EPMs provided an innocuous way to then discuss what professional development was needed to enhance instruction.

The philosophy of this school system is one of STEM integration. Therefore, having biology, chemistry and computer science teachers a part of the unpacking and analysis of the framework was instrumental to fostering increased intentional integration across subjects. Most importantly, through the process described above, the science teachers were able to see their standards and subject matter within the engineering knowledge dimension. This was extremely helpful to making increased engineering connections in areas like chemistry where integration between the subjects had been a challenge. The knowledge dimension was helpful in providing the other STEM teachers an opportunity to see how their coursework connected to engineering. In addition, by having them hear and participate in the unpacking and auditing of the engineering practices within the engineering coursework they were able to find ways to embed these skills within their instruction and make the integration more of a two-way endeavor.

In the school system involved there has been a high investment in STEM education across K-12. So, in order to better prepare students for future success, the framework was used to create vertical maps at each grade-level for engineering units to ensure the engineering concepts are addressed over time. For example, Figure 10 provides a sample of the mapping of *engineering habits of mind* and the content related to the practices of *engineering design* and *quantitative analysis*. In this example, looking at elementary instructional units, each unit name is notated at the top, while in the far-left column each of the engineering habits are listed. Since each core concept also has sub-concepts, the numbers beside each core concept correspond to the specific sub-concept in the EPMs. The elementary school team noted where a unit supported a habit or practice with an x and, if the unit intentionally taught a sub-concept, then the number of that sub-concept was listed.

	Unit 1: Force to the Rescue	**Unit 2: Bubbles Bubbles**	**Unit 3: Teddy Bear Playground**	**Unit 4: Wiggling Worms**	**Unit 5: Build a Beak**	**Unit 6: Kinetic Cars**	**Unit 7: Keep it Cool**
Engineering Habits of Mind							
Optimism				x	x	x	
Persistence	x	**x**			x	x	
Collaboration	x	x	x		x	x	
Creativity		x	x		x	x	x
Conscientiousness					x		
Systems Thinking	x		x	x	x	x	x
Engineering Practices							
Engineering Design							
Problem Framing 1,2,3		1,2	1,2	1,2			1,2
Project Management 1,2,3,4		1					
Information Gathering 1,2,3	1,2	1,2	1	1,2,3	1, 2	1,2	1,2
Ideation 1,2,3	1,2	1	1,2		1	1,2	1,2
Prototyping 1,2,3,4	1,2	1,2	1,2,3	2,	1,2,3	1,2	1,2,3
Decision-Making 1,2,3,4,5	2,5	1,2,5	1,5	1,5		1,2	1,2
Design Methods 1,2,3,4,5	4	4					2,5
Engineering Graphics 1,2,3,4		3					
Design Communication 1,2,3,4		1,2,3	x				
Quantitative Analysis							
Computational Thinking 1,2,3							1
Computational Tools 1,2,3							1
Data Collection, Analysis, & Communication 1,2,3,4,5						2,4	1,2,3,4
System Analytics 1,2,3,4						4	

Figure 10. Engineering content alignment for STEM units provided across grades K-5.

As seen in Figure 10, in elementary the school team determined that the focus of engineering learning is centered on the engineering habits of mind as well as the core content related to the engineering practice of engineering design. However, at the elementary level, the team saw that the engineering knowledge dimension could be connected to each engineering challenge as it relates to the standards of learning for science, mathematics, or technology for the state.

At the middle school level, the engineering vertical alignment tool (see Figure 11) assisted in creating opportunities for discussion about the engineering practices that were not included in the current curriculum and how to embed these into instruction moving forward. In many cases, these were small changes to the curriculum while in others it stimulated the development of new lessons. At each instructional level, the engineering vertical alignment tool can provide a starting point for discussions of what each engineering practice means and hopefully helps to further the development of teacher capacity toward achieving engineering literacy for students. In some cases, as the school team used this tool with a STEM unit, they began to see that the unit may not be as strong as originally perceived and may need to be retired in order to better serve the students and promote deeper engagement with engineering learning. In the example section of the middle school vertical alignment tool provided in Figure 11, the cold frame engineering design project is highlighted. The middle school teachers took a similar approach to using the tool for the unit scoping and alignment as the elementary teachers did. However, since middle school is able to incorporate more of the EPMs, the teachers listed the sub-concept numbers at the top and delineated separately the sub-concepts for each core concept that were used. For example, the core concept of problem framing has three sub-concepts. In this unit the teachers specifically incorporated: identifying design parameters (1), problem statement development (2) and considering alternatives (3). Since this unit is based on life science standards of learning and the group of teachers were trying to track and be intentional about mathematics concepts, one can see how they have adjusted the tool to include mathematics practices as part of their knowledge dimension. As with the integration of the knowledge dimension at the elementary level, at the middle school level the science standards of learning as well as the career and technical education competencies become an additional part of the integration of science, mathematics and technical knowledge used in the engineering-focused instruction.

	UNIT: Cold frame						
	Sub-Concepts						
Dimension & Core Concepts	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Engineering Habits of Minds							
Optimism	x						
Persistence	x						
Collaboration	x						
Creativity	x						
Conscientiousness	x						
Systems Thinking	x						
Engineering Practices							
Engineering Design							
Problem Framing	1	2	3				
Information Gathering	1	2	3				
Ideation	1	2	3				
Prototyping		2		4			
Decision-Making		2	3	4	5		
Project Management	1	2					
Design Methods			3	4			
Design Communication							
Engineering Graphics			3				
Material Processing							
Measurement & Precision	1	2					
Manufacturing							
Fabrication	1	2	3	4	5		
Material Classification							
Joining	1						
Casting/Molding/Forming							
Separating/Machining	1	2					
Conditioning/Finishing							
Safety	1	2	3				
Quantitative Analysis							
Computational Thinking							
Computational Tools			3				
Data Collection, Analysis, & Communication	1	2	3	4			
System Analytics	1	2					
Modeling & Simulation							
Professionalism							
Professional Ethics							
Workplace Behavior/Operations							
Honoring Intellectual Property							
Technological Impacts	1						7
Role of Society in Technological Development		2					
Engineering-Related Careers							
Engineering Knowledge Domains							
Mathematical Knowledge							
Computation Basics	Y						
Supports Algebraic Thinking	Y						

Precision & Accuracy							
Mathematical Thinking	Y						
Number Sense							
Significant Digits							
Scientific Notation							
Ratios							
Data Analysis	Y						

Figure 11. Engineering Vertical Alignment Tool for a Middle School STEM Unit.

Lastly, at the high school level, the teachers were able to align across all three dimensions of engineering literacy described in the engineering framework. The rigor and concepts of the knowledge dimension that were developed for high school coursework found in the EPMs can be applied at the intended high school level. As appeared evident in both elementary and middle school, the use of the framework and EPMs seemed to foster valuable discussions between STEM educators that resulted in enhanced collaboration across subjects and adjustments to the engineering-related curriculum.

Conclusion

The *Framework for P-12 Engineering learning* and the connected EPMs can be more than a conceptual model. They appear to be a useful tool for supporting coherence and structure in regard to engineering learning. When put into practice, they seemed to provide a common language and understanding around the engineering habits of mind, practices, and knowledge that could help guide teachers, district leaders, and other stakeholders in making informed decisions when developing STEM educational programming. It is the hope that the framework and EPMs, along with the examples of their use presented in this paper, can help to guide instruction and prepare schools/teachers to move toward meaningful and relevant engineering learning. For example, a guide for using the EPMs is provided to help in the development of engineering lessons/activities that includes defining the desired engineering concepts, establishing learning objectives, crafting enduring understandings for the students, and posing driving questions for the instructional activities—all within meaningful contexts for learning. Also, an example is provided for aligning, scoping, and enhancing engineering or STEM programming/curriculum to help strive for achieving engineering literacy for all students throughout their K-12 experience.

References

Advancing Excellence in P-12 Engineering Education & American Society of Engineering Education (2020). *A Framework for P-12 Engineering Learning: A defined and cohesive educational foundation for P-12 engineering.* American Society of Engineering Education. https://doi.org/10.18260/1-100-1153-1.

Bybee, R. (2002). *Learning Science and the Science of Learning*. Arlington, VA: NSTA Press.

Carr, R. L., Bennett, L. D., IV, & Strobel, J. (2012). Engineering in the K-12 STEM standards of the 50 U.S. states: An analysis of presence and extent. *Journal of Engineering Education, 101*(3), 539–564. https://doi.org/10.1002/j.2168-9830.2012.tb00061.x

Corcoran, T., Mosher, F. A., & Rogat, A. (2009). *Learning progressions in science: An evidence-based approach to reform*. Philadelphia, PA: Center on Continuous Instructional Improvement.

Custer, R. L., & Erekson, T. L. (2008). *Engineering and technology education*. Woodland Hills, CA: Council on Technology Teacher Education.

Duncan, R. G., & Hmelo-Silver, C. E. (2009). Learning progressions: Aligning curriculum, instruction, and assessment. *Journal of Research in Science Teaching, 46*(6), 606–609.

Grubbs, M. E., & Strimel, G. (2015). Engineering design: The great integrator. *Journal of STEM Teacher Education, 50*(1), 77-90.

Helmer, O., & Rescher, N. (1959). On the epistemology of the inexact sciences. *Management Science, 6*(1), 25–52.

Lehrer, R., & Schauble, L. (2015). Learning progressions: The whole world is NOT a stage. *Science Education, 99*(3), 432–437.

Magana, A. (2017). Modeling and simulation in engineering education: A learning progression. *Journal of Professional Issues in Engineering Education and Practice,* 143, 1–19.

Merrill, C., Custer, R. L., Daugherty, J., Westrick, M., & Zeng, Y. (2009). Delivering core engineering concepts to secondary level students. *Journal of Technology Education, 20*(1), 48-64.

National Council of Examiners for Engineering and Surveying (NCEES). (2017). The fundamentals of engineering (FE) exam. https://ncees.org/engineering/fe/.

National Academy of Engineering. (2009). *Engineering in K-12 education*. Washington, DC: The National Academies Press.

National Academy of Engineering. (2010). *Standards for K-12 engineering education?* Washington, DC: The National Academies Press.

Sneider, C. & Rosen, L. (2009). Towards a vision for engineering education in science and mathematics standards. In *Standards for k–12 engineering education?* Washington, DC: National Academies Press.

Strimel, G. J., Huffman, T. J., Grubbs, M. E., Kim, E., & Gurganus, J. (2020). Establishing a taxonomy for the coherent study of engineering in secondary schools. *Journal of Pre-College Engineering Education Research, 10*(1), 23-59.

Strimel, G. J., Krause, L., Kim, E., Grubbs, M. E., & Hensel, R. (2018). An engineering journey: A high school guide toward the engineering profession. *Technology & Engineering Teacher, 77*(5), 1-11.

Appendix A

Taxonomy of Content for Engineering Practices

Practice	Core Concepts	Sub-Concepts			
Engineering Design	**Problem Framing**	Identifying Design Parameters	Considering Alternatives	Problem Statement Development	
	Information Gathering	Research & Investigation	Information Quality Assessment	Data Collection & Organization Methods	
	Ideation	Spatial Visualization	Convergent Thinking	Divergent Thinking	
	Prototyping	Testing & Modification Manufacturing Processes	Computer Aided Design &	Material Selection	Manufacturing
	Decision Making	Evidence/Data-Driven Decisions Application of STEM Principles	Using Decision Making Tools	Balancing Tradeoffs	Group Decision Making
	Project Management	Initiating & Planning	Risk, Quality, Teams, & Procurement	Product Life Cycle Management	Scope, Time, & Cost Management
	Design Methods	Iterative Cycles User Centered Design	Troubleshooting	Systems Design	Reverse Engineering
	Design Communication	Engineering Graphics Dimensioning & Tolerances	3D Parametric Modeling	2D Computer Aided Design	Technical Writing
Material Processing	**Measurement and Precision**	Measurement	Units & Significant Figures	Accurate Layout & Precision	Measurement Instrumentation
	Manufacturing	Design for Manufacture	Subtractive Manufacturing	Additive Manufacturing	
	Fabrication	Tool Selection Product Assembly	Equipment & Machines	Hand Tools	Quality & Reliability
	Material Classification	Metals & Alloys	Polymers	Ceramics	Composites
	Joining	Fastening Adhesion	Welding	Soldering	Brazing

	Casting/Molding/Forming	Forging	Rolling	Extruding	
	Separating/Machining	Drilling Cutting	Turning Grinding	Milling	Reaming
	Conditioning/Finishing	Grinding	Burnishing	Polishing	
	Safety	Laboratory Guidelines	Attire & Equipment	Machine Safety	
Quantitative Analysis	**Computational Thinking**	Algorithm Forming	Software Design, Implementation, & Testing	Programming Languages	
	Computational Tools	Spreadsheet Tools	Computational Environment	System Design Tools	
	Data Collection, Analysis, and Communication	Data Collection Techniques Estimation	Data-Driven Decision Making	Data Visualization	Reporting Data
	System Analytics	Inputs & Outputs	Optimization	Feedback Loops	System Optimization
	Modeling and Simulation	Scaled Physical Models Mathematical Models	Computational Simulations	Design Validation through Calculations	Failure Analysis & Destructive Testing
Professionalism	**Professional Ethics**	Morals, Values, & the Ethics Continuum	Legal and Ethical Considerations	Engineering Code of Ethics	
	Workplace Behavior/Operations	Public Health, Safety, & Welfare Workplace Culture	Agreements & Contracts Public Policy & Regulation	Ethical Business Operations Professional Liability	Responsible Conduct of Research
	Honoring Intellectual Property	Patents, Copyright, & Licensure	Intellectual Property Terminology & Laws	Referencing Sources & Plagiarism	
	Impacts of Technology	Environmental Impacts Global Impacts	Economic Impacts Individual Impacts	Cultural Impacts Political Impacts	Social Impacts
	Role of Society in Technological Development	Societal Needs & Desires Design for Sustainability	Appropriate Technology Applications Inclusion & Accessibility	Cultural Influences Scaling of Technology	Public Participation in Decision Making
	Engineering-Related Careers	Professional Licensing Engineering Entrepreneurship	Professional/Trade Organizations	Recognition of Engineering-Related Careers	Engineering-Related Career Pathways & Disciplines

Taxonomy of Content for Engineering Knowledge

Domain	Auxiliary Concept	Sub-Concepts			
Engineering Sciences	**Statics**	Resultants of force systems Equilibrium of rigid bodies	Frames & Trusses Area moments of inertia	Equivalent force systems	Centroid of area
	Dynamics	Kinematics (e.g., particles and rigid bodies) Mass moments of inertia	Impulse momentum (e.g., particles & rigid bodies)	Force acceleration (e.g., particles & rigid bodies)	Work, energy, & power (e.g., particles & rigid bodies)
	Mechanics of Materials	Stress Types & Transformations Material Characteristics, Properties, & Composition (e.g. Heat Treating)	Material Equations Phase Diagrams	Young's Modulus Stress-Strain Analysis	Material Deformations Mohr's circle
	Fluid Mechanics	Fluid Properties Pumps, Turbines, & Compressors	Fluid Statics & Motion (Bernoulli's equation)	Lift, Drag, & Fluid Resistance	Pneumatics & Hydraulics
	Circuit Theory	Series & Parallel Circuits Ohm's Laws	Wave forms Signals	Resistance, Capacitance, & Inductance Kirchhoff's Laws	Current, Voltage, Charge, Energy, Power, & Work
	Thermodynamics	Thermodynamic Properties, Laws, & Processes Power Cycles & Efficiency	Gas Properties	Heat Exchangers	Equilibrium
	Mass Transfer & Separation	Molecular Diffusions Separation Systems	Humidification & Drying Continuous Contact Methods	Convective Mass Transfer	Equilibrium State Methods
	Chemical Reactions & Catalysts	Reaction Rate, Rate Constant, & Order	Chemical Equilibrium	Fuels	Conversion, Yield, & Selectivity
Engineering Technical Applications	**Electrical Power**	Motors & Generators AC & DC	Voltage Regulation Transmission & Distribution	Electro-magnetics Electrical Materials	Magnetism
	Electronics	Instrumentation Components	Closed & Open loop & Feedback (systems – system response)	Integrated Circuits	Digital Electronics (e.g. gates & logic)
	Computer Architecture	Computer Hardware Computer Software	Interfacing	Processors & Microprocessors	Memory

	Communication Technologies	Digital Communications	Photonics	Networks	Telecommunications
	Chemical Applications	Applications of Inorganic Chemistry Applications of Organic Chemistry	Material Types & Compatibilities Membrane Science	Corrosion	Chemical, Electrical, Mechanical, & Physical Properties
	Mechanical Design	Machine Elements (e.g. springs, pressure vessels, beams, piping, cams & gears)	Manufacturing Processes	Machine Control	
	Process Design	Process Controls & Systems	Recycle & Bypass Processes	Process Flow, Piping, & Instrumentation Diagrams	Industrial Chemical Operations
	Structural Analysis	Physical Properties of Building Materials Deflection	Deformations	Implementation of Design Codes	Column & Beam Analysis
	Hydrologic Systems	Hydrology Water Distribution & Collection Systems	Open Channel Closed Conduits (Pressurized)	Pumping Stations Watershed Analysis	Laboratory & Field Tests
	Transportation Infrastructure	Street, Highway, & Intersection Design	Traffic Designs	Pavement Design	Transportation Planning & Control (safety, capacity, flow)
	Geotechnics	Laboratory & Field tests Erosion Control	Bearing Capacity Drainage Systems	Foundations & Retaining Walls Geological Properties & Classifications	Slope Stability Soil Characteristics
	Environmental Considerations	Ground & Surface Water Quality	Environmental Impact Regulations & Tests	Wastewater Management	
Engineering Mathematics	**Engineering Algebra**	Recognizing, Selecting, & Applying Appropriate Algebraic Concepts & Practices	Curve Fitting Linear Algebra	Manipulation of Algebraic Equations	2D & 3D Coordinate Systems
	Engineering Geometry	Recognizing, Selecting, & Applying Appropriate Geometric Concepts & Practices	Manipulation of Geometric Equations	Application of Trigonometry	Vector Analysis
	Engineering Statistics and Probability	Recognizing, Selecting, & Applying Appropriate Probability & Statistical Concepts & Practices	Probability Regression	Applications of Basic Statistics (normal distributions, percentiles)	Inferential Statistics & Tests of Significance (e.g., t-tests, statistical tolerance)
	Engineering Calculus	Derivatives	· Differential Equations	Integrals	Vectors