Engineering Literacy Expectations for High School Learners

White Paper from the Advancing Excellence in P12 Engineering Education Research Collaborative

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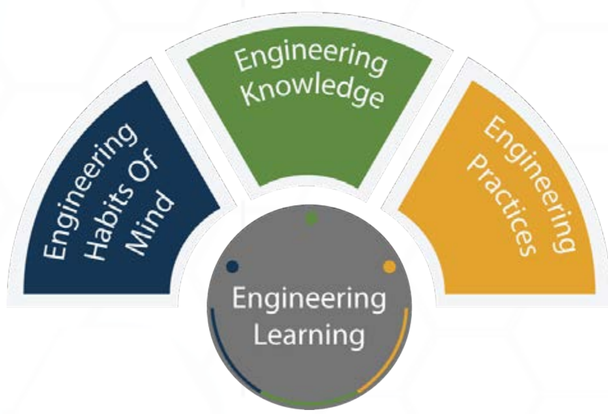
Engineering Literacy

Engineering Literacy is defined as the confluence of content knowledge, habits, and practices merged with the ability to communicate, think, and perform in a way that is meaningful within the context of engineering and the human-made world (Wisconsin Department of Public Instruction, 2011; Lent, 2015; Strimel et al. 2020). It is not only relevant to all individuals, but also to communities and society as a whole. It is an attribute concerned with the journey that inventors, innovators, makers, designers, and literate citizens take while improving and interacting with the systems, products, and services of our world. These interactions require that an engineering literate person become familiar with associated scientific, mathematical, and technical knowledge, as well as engineering practices and habits of mind.

Engineering Literacy is achieved through ***Engineering Learning*** which is three-dimensional (NAE & NRC, 2006; 2009; NAE, 2010; Sneider & Rosen, 2009) (see Figure 1-4) and focuses on:

(1) *Engineering Habits of Mind* (e.g. Optimism, Persistence, Creativity) that students should develop over time through repetition and conditioning,
(2) *Engineering Practices* (Engineering Design, Materials Processing, Quantitative Analysis, and Professionalism) in which students should become competent, and
(3) *Engineering Knowledge* (Engineering Sciences, Engineering Mathematics, and Technical Applications) that students should be able to recognize and access, when appropriate, to inform their *Engineering Practice*.

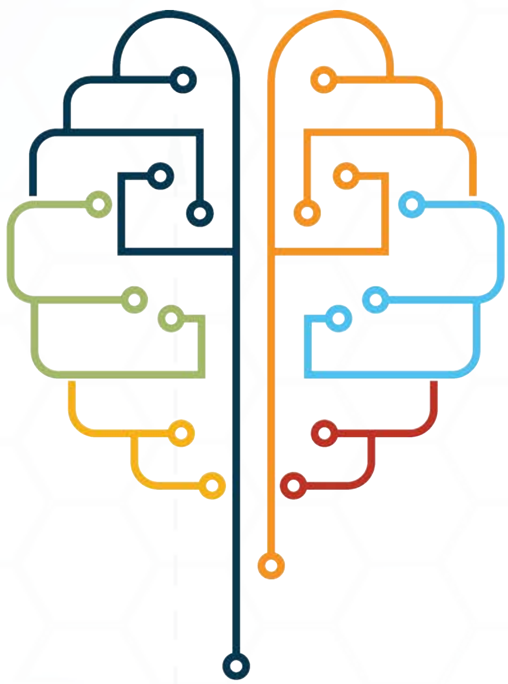
Engineering literacy develops beginning in the early years of a child's education and extends through the completion of their secondary education goals. Therefore, by the end of secondary



school all students must be provided the three-dimensional learning experiences that (1) cultivate habits of mind necessary to orient themselves to an engineering way of thinking, (2) engage them in authentic practices of engineering to resolve real challenges, and (3) require them to appreciate, acquire, and apply, when appropriate, scientific, mathematical, and technical concepts in relevant ways to better perform their engineering practice and confront and solve the problems in which they encounter.

Engineering Habits of Mind - HS

Engineering Habits of Mind are the traits or ways of thinking that influence how a person views the world and reacts to every day challenges. These habits should become engrained within a student's everyday cognizance and allow them to effortlessly, efficiently, and autonomously devise solutions to problems or develop improvements to current technologies, processes, and practices (RAE, 2017). As the Engineering Habits of Mind are developed, they should become a student's automatic response to an engineering related activity or problem-solving scenario that enables them to pursue a specific goal that is aimed toward a learning breakthrough or technological success (Lally & Gardner, 2013; Wood & Runger, 2016). <u>As a goal of P-12 Engineering Learning, by the end of secondary school, engineering literate students should orient themselves to an engineering way of thinking by developing the engineering habits of mind.</u> These Engineering Habits of Mind include:



Engineering Habit of Mind: *Optimism (EM-OP)*
Optimism is the ability to look at the more favorable side of an event or to expect the best outcomes in various situations. It allows a person to view challenging situations as opportunities to learn/improve or as chances to develop new ideas. An optimistic habit of mind enables a person to be persistent in looking for the optimal solutions to problems. This *Engineering Habit of Mind* is important to *Engineering Literacy* as engineering literate individuals will often experience repeated failures or unfavorable situations when solving a problem. An optimistic way of thinking provides ongoing motivation to focus on successfully resolving the problem at hand. Engineering literate individuals, as a general rule, believe that things can always be improved. Just because it hasn't been done yet, doesn't mean it can't be done. Good ideas can come from anywhere and engineering is based on the premise

that everyone is capable of designing something new or different (NAE, 2019). Therefore, by the end of secondary school, engineering literate students should be able to maintain an **optimistic** outlook throughout the course of an engineering project/activity in order to persevere in accomplishing designated tasks.

Engineering Habit of Mind: *Persistence (EM-PR)*
Persistence is the ability to follow through with a course of action despite of the challenges and oppositions one may encounter. This ability also allows a person to continuously look for improvements in their operations. A persistent habit of mind enables an engineering literate individual to develop optimal solutions to problems and see a project to its completion, as well as meet established goals and deadlines. This *Engineering Habit of Mind* is important to *Engineering Literacy* as failure is expected, even embraced, as engineering literate individuals work to optimize a solution to a particular challenge. Engineering, particularly engineering design, is an iterative process. It involves trying and learning and trying again (NAE, 2019). Therefore, by the end of secondary school, engineering literate students should be able to be **persistent** throughout the course of an engineering project/activity in order to meet the project's objectives, uphold established deadlines, and be accountable for developing viable solutions to the problems they and others face.

Engineering Habit of Mind: *Collaboration (EM-CO)*
Collaboration is the ability to work with others to complete a task and achieve desired goals, which includes effective *Communication* abilities. A collaborative habit of mind enables an engineering literate individual to connect with, and draw upon, the perspectives, knowledge, and capabilities of others to best achieve a common purpose. This *Engineering Habit of Mind* is important to *Engineering Literacy* as most engineering projects are undertaken as a team and successful solutions require the participation from team members with diverse backgrounds. Engineering successes are built through a willingness to work with others, listen to stakeholders, think independently, and communicate ideas collaboratively (NAE, 2019). Therefore, by the end of secondary school, engineering literate students should be able to be **collaborative/communicative** throughout the course of a team-based engineering project/activity to leverage diverse perspectives in successfully completing designated tasks.

Engineering Habit of Mind: *Creativity (EK-CR)*
Creativity is the ability to think in a way that is different from the norm in order to develop original ideas. A creative habit of mind enables an engineering literate individual to perceive the world in novel ways, to find unknown patterns, and make new connections between seemingly unrelated information, in an effort to develop innovative ideas or solutions to problems. This *Engineering Habit of Mind* is important to *Engineering Literacy* as finding new ways to apply knowledge and experience is essential in engineering design and is a key ingredient of innovation. When everyone thinks exactly the same way, there can be a lack of technological and societal advancement (NAE, 2019). Therefore, by the end of secondary school, engineering literate students should be able to be **creative** throughout the course of an engineering project/activity through the repetitive use of creativity strategies and tools to develop innovative solutions to the problems they and others face.

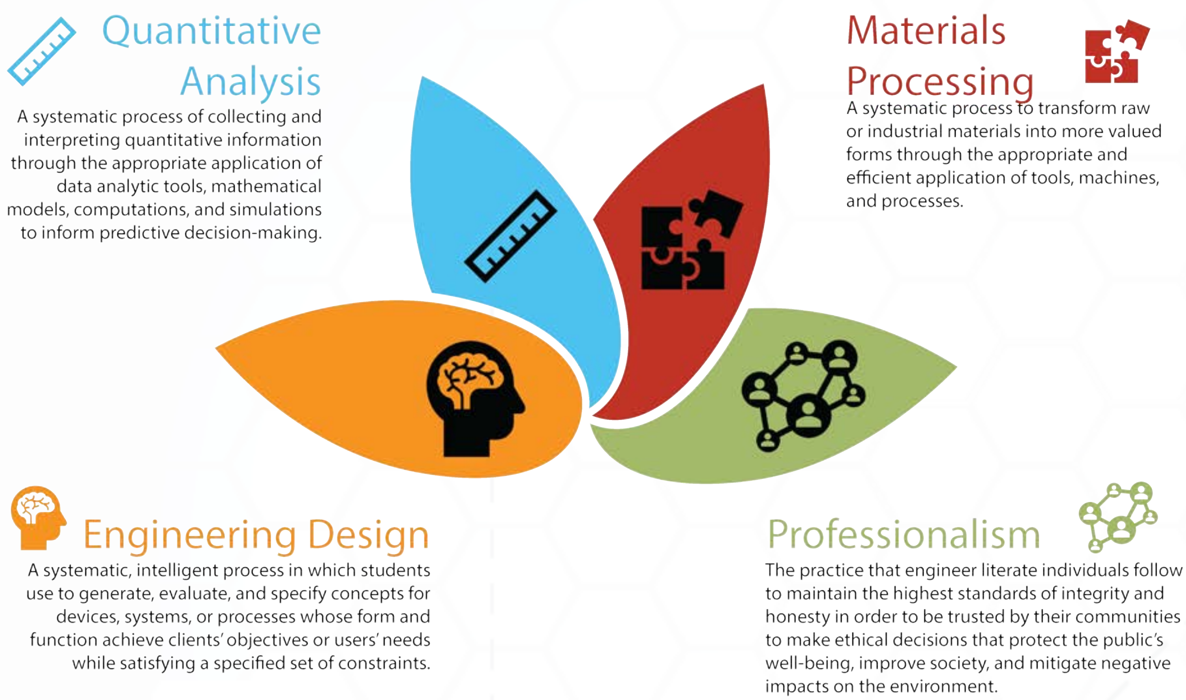
Engineering Habit of Mind: *Conscientiousness (EM-CS)*
Conscientiousness is the ability to focus on performing one's duties well and with the awareness of the impact that their own behavior has on everything around them. A conscientious habit of mind enables an engineering literate individual to maintain the highest standards of integrity, quality, ethics, and honesty, when making decisions and developing solutions, to ensure the public's safety, health, and

welfare. This *Engineering Habit of Mind* is important to *Engineering Literacy* as engineering has a significant ethical dimension. The technologies and methods that engineering literate individuals develop can have a profound effect on people's lives. That kind of power demands a high level of responsibility to consider others and to consider the moral issues that may arise from one's work (NAE, 2019). <u>Therefore, by the end of secondary school, engineering literate students should be able to be **conscientious** when making decisions throughout the course of an engineering project/activity, through repetitive questioning and critiques, to develop ethical solutions to the problems they and others face.</u>

Engineering Habit of Mind: *Systems Thinking (EK-ST)*
Systems Thinking is the ability to recognize that all technological solutions are systems of interacting elements that are also embedded within larger man-made and/or natural systems and that each component of these systems are connected and impact each other. A systems thinking habit of mind enables an engineering literate individual to understand how each component of a solution design or idea fits with other components while forming a complete design or idea. Additionally, it enables them to consider how a solution idea or design interacts as a part of the larger man-made and/or natural systems in which they are embedded. This *Engineering Habit of Mind* is important to *Engineering Literacy* as our world is a system made up of many other systems. Things are connected in remarkably complex ways. To solve problems, or to truly improve conditions, engineering literate individuals need to be able to recognize and consider how all those different systems are connected (NAE, 2019). <u>Therefore, by the end of secondary school, engineering literate students should be able to think in terms of **systems** when making decisions throughout the course of an engineering project/activity, through recurring design critiques, in order to consider how a solution idea or design interacts with, and impacts, the world.</u>

Engineering Practices - HS

Engineering Practices are the combination of skills and knowledge that enable a student to authentically act or behave like an engineering literate individual. The core concepts of engineering practice should represent the knowledge associated with performing a particular practice well and with increased sophistication. Competence in these practices build over time with multiple experiences. This framework is oriented around 4 comprehensive and fundamental practices which include (1) *Engineering Design*, (2) *Material Processing*, (3) *Quantitative Analysis*, and (4) *Professionalism*. Each fundamental practice will be described in the following sections and detail what students should master by the end of secondary school in order to be engineering literate. As a goal of P-12 Engineering Learning, by the end of secondary school, engineering literate students should be able to demonstrate competence in the practices of engineering. These practices are:



Engineering Practice: Engineering Design (EP-ED)

Engineering Design is the practice that engineering literate individuals use to develop solutions to problems. It is defined as a systematic, intelligent process in which people generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints (Dym et al., 2005, p.104). While this practice is often depicted as a step-by-step process, in actuality it is often a messy, iterative, and complicated practice that follows no one-set procedure. As such, this practice can involve a variety of methods and techniques that requires a wide-range of knowledge. As a goal of P-12 Engineering Learning, by the end of secondary school, engineering literate students should be able demonstrate competence in the practice of *Engineering Design*. Competency in this practice requires knowledge of the following core concepts:

Core Concept 1: *Problem Framing (EP-ED-1)*
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. Therefore, by the end of secondary school, engineering literate students should be able to 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.

Core Concept 2: *Project Management (EP-ED-2)*
Project Management is the process of scoping a project and planning, organizing, and managing resources to complete the project within defined constraints (Nembhard, Yip, & Shtub, 2009). Sophistication in this process requires knowledge related to project management strategies, techniques, and tools for (a) initiating and planning project activities; (b) scoping the project and managing timelines and costs; (c) tracking and evaluating risks, quality, teams, and procurement; and (d) managing product lifecycles. This core concept is important to the practice of *Engineering Design* as design projects are carried out within dynamic environments involving a variety of limitations. Therefore, by the end of secondary school, engineering literate students should be able to plan and manage a design project to achieve the desired goals within the established constraints through the application of appropriate project management strategies and techniques (e.g. team charters, Gantt charts).

Core Concept 3: *Information Gathering (EP-ED-3)*
Information Gathering is the process of searching for the knowledge necessary to develop an informed resolution to a design problem. This process includes (a) identifying the specific areas to be researched/investigated, (b) collecting and synthesizing data from multiple sources, and (c) assessing the quality of the information available. This core concept is important to the practice of *Engineering Design* because once a design problem has been defined, engineering literate individuals use must decide what information they need to acquire as they work through the iterative stages of the design process to develop a design solution. Therefore, by the end of secondary school, engineering literate students should be able to collect, evaluate, and synthesize data and knowledge from a variety of sources to inform their design process.

Core Concept 4: *Ideation (EP-ED-4)*
Ideation is the process of mentally expanding the set of possible solutions to a design problem in order to generate a large number of ideas, in hopes to then, find a better, and more innovative, resolution. Sophistication in this process requires knowledge related to (a) divergent thinking and brainstorming techniques, (b) convergent thinking methods (including functional decomposition which is the process breaking down the overall function of a device, system, or process into its smaller parts), and (c) employing visual-spatial abilities to convey ideas through sketching. This core concept is important to *Engineering Design* as this practice seeks to develop creative and innovative solutions to ill-structured

and open-ended problems. Therefore, by the end of secondary school, engineering literate students should be able to generate multiple, innovative ideas through both divergent and convergent thinking processes while communicating and recording ideas in two- and three-dimensional sketches using visual-spatial techniques.

Core Concept 5: Prototyping *(EP-ED-5)*

Prototyping is the process of transforming an idea into a form (physical or digital) that communicates the idea with others with the intention to improve the idea, over time, through testing and the collection of feedback. Sophistication in this process requires knowledge related to (a) computer-aided design and manufacturing, (b) material selection for low, mid-, and high-fidelity prototypes, (c) manufacturing processes for manipulating the materials, and (d) procedures for testing and modifying physical and digital prototypes. This core concept is important to the practice of *Engineering Design* as it allows engineering literate individuals to communicate, test, and optimize their design solutions. Therefore, by the end of secondary school, engineering literate students should be able to build a prototype of an idea using the appropriate tools and materials for the desired prototype fidelity level while establishing the appropriate testing/data collection procedures to improve their design.

Core Concept 6: *Decision Making (EP-ED-6)*

Decision Making is the process of making a logical choice from a variety of options through the gathering of information and assessment of alternatives. Within the practice of *Engineering Design, Decision Making* includes (a) making evidence/data/logic-driven decisions, (b) the application of *Engineering Knowledge* for justifying a design decision, (c) balancing trade-offs between conflicting design criteria and constraints, (d) using decision making tools, such as a decision matrix, and (e) functioning within a group setting to make team-based decisions. This core concept is important to the practice of *Engineering Design* as engineering literate individuals are decision makers. They make multiple decisions throughout the design process that impact the outcome of the process which can have variety of consequences to themselves, their employer, society, public health, and the environment. Therefore, by the end of secondary school, engineering literate students should be able to make informed (data/evidence/logic-driven) choices within a design scenario through the application of *Engineering Knowledge* and the use of decision-making tools to converge on one decision within a team-setting.

Core Concept 7: *Design Methods (EP-ED-7)*

Design Methods are the processes that people apply to devise novel solutions to a broad range of problem scenarios that have an identified goal and one or more reasonable pathways toward resolution. This core concept includes knowledge related to (a) iterative design cycles, (b) user-centered design, (c) systems design, (d) reverse engineering, and (e) troubleshooting. *Design Methods* are important to the practice of *Engineering Design* as engineering literate individuals take a more disciplined, informed, and organized approach to solve problems rather than general trial-and-error tactics. This makes it important to know and understand what design methodologies are available and how to use them. Therefore, by the end of secondary school, engineering literate students should be able to develop a plan to manage an engineering project through the appropriate application of a specified design strategy.

Core Concept 8: *Engineering Graphics (EP-ED-8)*

Engineering Graphics are detailed and well-annotated visual illustrations that communicate the features and functions of a design or idea. Oftentimes, these representations are initially created by hand but

they almost always transferred to a digital format using three-dimensional computer aided design software following a specific set of rules and guidelines. Sophistication in this process requires knowledge related to (a) the conventions for creating and reading engineering drawings, (b) dimensioning and tolerances, (c) two-dimensional sketching and computer aided design, and (d) three-dimensional parametric modeling. This core concept is important to the practice of *Engineering Design* as engineering literate individuals embody, communicate, and record their ideas through graphical representations that accurately detail and convey the features and performance expectations of their designs. Therefore, by the end of secondary school, engineering literate students should be able to interpret, analyze, and create graphical representations of a design idea following commonly accepted conventions.

Core Concept 9: *Design Communication (EP-ED-9)*
Design Communication is the process of effectively and efficiently sharing ideas, decisions, information, and results with team members and various stakeholders throughout the design process as well as with the intended audiences at the conclusion of a design project (which can include conveying the information necessary to describe the results of the project, produce/implement a design solution, and to use the design product). Sophistication in this process requires knowledge related to (a) technical writing, (b) presentation delivery methods and tools, (c) informational graphics, and (d) visual design. This core concept is important to the practice of *Engineering Design* as an engineering literate individual's work is only as good as their ability to communicate to it others. Therefore, by the end of secondary school, engineering literate students should be able to articulate their ideas, decisions, and information throughout, and at the conclusion of, a design project, with the consideration of the target audience through a variety of verbal and visual communication strategies and tools.

Engineering Practice: Material Processing (EP-MP)

Material Processing is the practice that engineering literate individuals use to convert materials into products, often referred to as *making*. It is defined as a systematic process to transform raw or industrial materials into more valued forms through the appropriate and efficient application of tools, machines, and processes. As a goal of P-12 Engineering Learning, by the end of secondary school, engineering literate students should be able demonstrate competence in the practice of *Materials Processing*. Competency in this practice requires knowledge of the following core concepts:

Core Concept 1: *Manufacturing (EP-MP-1)*
Manufacturing is the process of using technology to transform resources into valuable products. This core concept includes knowledge related to (a) design for manufacturability, (b) additive manufacturing processes, and (c) subtractive manufacturing methods. This core concept is important to the practice of *Material Processing* as the design of products is affected by factors that are specific to the ability to effectually manufacture the product itself. Accordingly, engineering literate individuals are required to apply the appropriate knowledge, processes, tools, and equipment for developing effective and efficient processes for producing quality products. Therefore, by the end of secondary school, engineering literate students should be able to design a product in such a way that it is easy to produce and then make the product by applying appropriate manufacturing processes.

Core Concept 2: *Measurement & Precision (EP-MP-2)*
Measurement is the process of comparing the qualities of an object, such as size, shape, or volume, to an established standard in order to describe, analyze, or plan to modify the object. ***Precision*** in measurement includes the determination of the tolerances and dimensional controls necessary for the quality production of products. Accordingly, this core concept includes knowledge related to the appropriate application of (a) measurement tools and instruments (including linear, diameter, and angle measuring devices as well as indirect-reading/automated instruments), (b) performing precise measurements for the accurate layout of a production process, and (c) ensuring accuracy through appropriate unit analysis and engineering notation. This core concept is important to the practice of *Material Processing* as engineering literate individuals are required to apply appropriate measurement practices and tools in the design, fabrication, and communication of technological products and systems. Also, as measurements are provided in many different forms and inaccuracy in measurement calculations can cause major problems, engineering professionals need the mathematical skills to conduct unit conversions or analyses. <u>Therefore, by the end of secondary school, engineering literate students should be able to select the appropriate measurement devices and units and apply them with precision to design, produce, and evaluate quality products</u>.

Core Concept 3: *Fabrication (EP-MP-3)*
Fabrication is the process of making a product or the parts of a product to be assembled into a final product. Sophistication in this process requires knowledge related to (a) tool selection, (b) product assembly, (c) hand tools, (d) equipment and machine tools, and (e) quality and reliability. This core concept is important to the practice of *Material Processing* as engineering literate individuals are required to use appropriate processes, tools, and equipment to produce technological products and systems that are of reliable quality. <u>Therefore, by the end of secondary school, engineering literate students should be able to choose the appropriate tools, processes, techniques, equipment, and/or machinery to make a quality and reliable product/system based on a plan, or workable approach, to meet the specified design criteria of a customer in accordance with engineering standards.</u>

Core Concept 4: *Material Classification (EP-MP-4)*
Material Classification is the process of cataloging solid materials by their atomic and molecular characteristics and properties to aid in the selection of a suitable material for a particular application as well as the processes necessary for manipulating the materials in a suitable manner. This core concept includes knowledge related to the micro and macro-structures of the four main divisions of the material class system which are (a) metals/alloys, (b) polymers, (c) ceramics, and (d) composites. *Material Classification* is important to the practice of *Material Processing* as engineering literate individuals must consider material properties in order to make informed decisions when selecting and applying the most appropriate materials for the production of technological products and systems. Material selection is based on fabrication requirements, such as the material's machinability, castability, and weldability as well as its intended final shape, required mechanical properties, service necessities, tolerances, availability, and the cost. <u>Therefore, by the end of secondary school, engineering literate students should be able to distinguish between different materials in terms of their structures and properties and determine how to apply the materials to design/create quality products in a suitable and safe manner.</u>

Core Concept 5: *Casting/Molding/Forming (EP-MP-5)*
Casting and Molding are the processes that give materials shape by introducing a liquid material into a mold that has a cavity of the desired size and shape, and then, allowing the material to solidify before being removed from the mold. ***Forming*** is the process of applying pressure to a material to cause it to

flow into a new shape. This core concept includes knowledge related to (a) producing and implementing molds, (b) forging, (c) extruding, and (d) rolling. This core concept is important to the practice of *Material Processing* as most metals, ceramics, and plastics can be shaped and sized to meet specified needs through the processes of casting and molding as well as forming. Engineering literate individuals apply an understanding of these processes to inform their decisions when developing a design and actually changing the shapes of materials. Therefore, by the end of secondary school, engineering literate students should be able to use knowledge of Casting/Molding/Forming to inform their decisions when developing a design as well as to physically change the shapes of materials.

Core Concept 6: *Separating/Machining (EP-MP-6)*

Separating/Machining include the processes that give an object a desired form by removing excess materials which includes knowledge related to basic machine operations of (a) drilling, (b) cutting, (c) milling, (d) turning, (e) grinding, and (f) shearing. This core concept is important to the practice of *Material Processing* as the related operations are the foundation for production and manufacturing of physical products. Furthermore, engineering literate individuals apply an understanding of these processes to inform their decisions when developing a design and performing the operations to remove undesired materials to achieve a desired form of a product. Therefore, by the end of secondary school, engineering literate students should be able to use knowledge of *Separating/Machining* to inform their decisions when developing a design as well as to physically change the shapes of objects by removing excess material.

Core Concept 7: *Joining (EP-MP-7)*

Joining is the process of creating a product from two or more parts through the actions of bonding and/or mechanical fastening. This core concept includes knowledge related to the basic methods of (a) fastening through both mechanical fasteners and mechanical force, (b) adhesive bonding, (c) flow bonding (brazing and soldering), and (d) welding. *Joining* is important to the practice of *Material Processing* as very few products are made from just one part. Furthermore, engineering literate individuals apply an understanding of these joining processes to inform their decisions when developing a design and performing the operations to assemble a product from multiple parts. Therefore, by the end of secondary school, engineering literate students should be able to use knowledge of joining methods to inform their decisions when developing a design as well as to physically assemble parts into a quality product.

Core Concept 8: *Conditioning/Finishing (EP-MP-8)*

Conditioning is the process of changing the internal structure of a material to adjust the material's properties to better meet desired criteria*.* ***Finishing,*** on the other hand*,* is the process of beautifying and extending the life of a product through establishing a protective coating on the object. This core concept includes knowledge related to the basic methods of (a) conditioning internal structures, (b) polishing & burnishing, (c) surface coat finishing and (c) conversion finishing. *Conditioning/Finishing* is important to the practice of *Material Processing* as materials can be conditioned to enhance their properties in order to better achieve desired results, changed to enhance their attractiveness, and protected to increase their durability. Furthermore, engineering literate individuals apply an understanding of these processes to inform their decisions when developing a design and performing the related operations to enhance a material's properties, improve a product's appearance, and increase the product's durability. Therefore, by the end of secondary school, engineering literate students should be able to use knowledge of conditioning and finishing methods to inform their decisions when developing a design as well as to physically produce a quality end-product.

Core Concept 9: *Safety (EP-MP-9)*
Safety is the process of reducing the chance of injury or harm through thoughtful action and, in engineering settings, includes knowledge related to (a) laboratory guidelines and standards, (b) machine and tool safety, and (c) personal protective equipment and attire. This core concept is important to the practice of *Material Processing* as life is full of many hazards, which can be particularly true in engineering-related environments or facilities where machines and materials are being used by people. Furthermore, engineering literate individuals apply an understanding of safety principles and guidelines to inform their decisions when developing a design and performing the related operations toward improving their work environment. <u>Therefore, by the end of secondary school, engineering literate students should be able to safely, responsibly, and efficiently process materials within a working environment without the cause of harm or injury to themselves or others.</u>

Engineering Practice: Quantitative Analysis (EP-QA)

Quantitative Analysis is the practice that engineering literate individuals use to support, accelerate, and optimize the resolution of problems. It is defined as a systematic process of collecting and interpreting quantitative information through the appropriate application of data analytic tools, mathematical models, computations, and simulations to inform predictive decision-making. <u>As a goal of P-12 Engineering Learning, by the end of secondary school, engineering literate students should be able demonstrate competence in the practice of *Quantitative Analysis.*</u> Competency in this practice requires knowledge of the following core concepts:

Core Concept 1: *Computational Thinking (EP-QA-1)*
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 literate individuals 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, 2012). <u>Therefore, by the end of secondary school, engineering literate students should be able to design, develop, implement, and evaluate algorithms/programs that are used to visualize/control physical systems that address an engineering problem/task.</u>

Core Concept 2: *Computational Tools (EP-QA-2)*
Computational Tools are the programs, languages, and computer applications that facilitate engineering

tasks which includes (a) spreadsheet tools (e.g. Microsoft Excel), (b) system design tools (e.g. LabView), and (c) computational environments (e.g. MATLAB). *Computational Tools* are important to the practice of *Quantitative Analysis* as mathematical modeling is an integral part of the engineering design process. Engineering literate individuals use such tools to facilitate the tasks of computing complex equations, managing large amounts of data, developing programs to process/analyze quantitative data, and communicating information. Furthermore, these tools enable users to design digital prototypes of solutions and perform statistical calculations to determine how well a solution will perform as well as why a solution performed in the way that it did. <u>Therefore, by the end of secondary school, engineering literate students should be able to select and use the appropriate computational tools to analyze quantitative data related to an engineering problem to communicate/predict the effectiveness of a solution design.</u>

Core Concept 3: *Data Collection, Analysis, & Communication (EP-QA-3)*
Data Collection, Analysis, & Communication is the process of gathering, recording, organizing, examining, interpreting, and sharing data from a variety of sources, such as experiments, design calculations, economic analyses, and statistical procedures, throughout an engineering project. Sophistication in this process requires knowledge related to (a) data collection techniques, (b) using data to inform decisions, (c) data visualization, (d) estimation, and (e) appropriately reporting data to the designated audience. *Data Collection, Analysis, & Communication* is important to the practice of *Quantitative Analysis* as engineering literate individuals collect, organize, and analyze quantitative data to understand and solve a problem as well as regularly communicate information about the results of their work with their clients and invested stakeholders. <u>Therefore, by the end of secondary school, engineering literate students should be able to select and implement the most appropriate method to collect and analyze quantitative data and then make, justify, and share a conclusion based on the analysis.</u>

Core Concept 4: *System Analytics (EP-QA-4)*
System Analytics is the process of investigating systems and calculating the way in which a system's components interact with each other, how they function over time, and the way in which they operate within the context of larger technological and natural systems. A system can be described as any entity or object that consists of parts, each of which has a relationship with all other parts and to the entity as a whole. These parts work together in a predictable or planned way to achieve a specific goal. *System Analytics* requires knowledge related to (a) system inputs (i.e. people, materials, tools/machines, energy, information, finances, and time), (b) system processes (i.e. design, production, management), (c) system outputs (including desirable, undesirable, intended, unintended, immediate, and delayed outputs), (d) system feedback and control (including both internal and external controls), and (e) system optimization. This core concept is important to the practice of *Quantitative Analysis* as every physical and digital system is intertwined with a variety of natural, social, and technological systems, and is a system itself as well as developed through a system. The ability to analyze the design, function, and interaction of systems enables the development of dynamic controls that use data-comparing devices and sensors to optimize and automate system operations. <u>Therefore, by the end of secondary school, engineering literate students should be able to analyze an engineering system through identifying its inputs, outputs, processes, and feedback loops to implement controls to predict and optimize system performance.</u>

Core Concept 5: *Modeling & Simulation (EP-QA-5)*
Modeling & Simulation is the process of using a variety of media, both physical and digital, to determine

how well a design idea will perform as well as to communicate a design idea to others. Sophistication in this process requires knowledge related to (a) creating scaled physical models, (b) developing computational simulations, (c) establishing mathematical models, (d) collecting data through destructive testing and failure analysis, and (e) design validation through calculations. This core concept is important to the practice of *Quantitative Analysis* as modeling and simulating actual events, products, structures, or conditions through mathematical, physical, and graphical/computer models helps engineering literate individuals to predict the effectiveness of their solutions prior to producing a high-fidelity prototype which can save valuable resources (time, materials, money, etc.). <u>Therefore, by the end of secondary school, engineering literate students should be able to develop and use a variety of models to simulate, evaluate, improve, and validate design ideas.</u>

Engineering Practice: Professionalism (EP-P)

Professionalism is the practice that engineering literate individuals follow to maintain the highest standards of integrity and honesty in order to be trusted by their communities to make ethical decisions that protect the public's well-being, improve society, and mitigate negative impacts on the environment. This includes the conventions associated with professional ethics, workplace behavior and operations, honoring intellectual property, and functioning within engineering-related careers. In addition, engineering *Professionalism* includes understanding the intended and unintended impacts of technology and the role society plays in technological development. <u>As a goal of P-12 Engineering Learning, by the end of secondary school, engineering literate students should be able demonstrate competence in the practice of *Professionalism.*</u> Competency in this practice requires knowledge of the following core concepts:

Core Concept 1: *Professional Ethics (EP-P-1)*
Professional Ethics are the principles of conduct that govern the actions of an individual or group. In engineering, ethics enable engineering professionals to make the best choices and do the "right" thing even when no one is looking. This core concept includes knowledge related to (a) the morals, values, & ethics continuum, (b) the engineering code of ethics, and (c) legal and ethical considerations. *Professional Ethics* is important to *Professionalism* as engineering literate individuals are expected to maintain the highest standards of integrity and honesty when making decisions. These decisions, and the resulting design solutions, must be ethical to protect the public's safety, health, and welfare. However, knowing what is the "right thing" can sometimes be difficult, and it often involves making choices between conflicting alternatives. <u>Therefore, by the end of secondary school, engineering literate students should be able to personally interpret the engineering code of ethics in an effort to make ethical decisions while engaged in an engineering project.</u>

Core Concept 2: *Workplace Behavior/Operations (EP-P-2)*
Workplace Behavior/Operations are the actions and activities of managing the internal functions of the business or organization in which one operates, following the appropriate rules of conduct and ethical guidelines, so that the entity runs as efficiently and honorably as possible. This core concept includes knowledge related to (a) ethical guidelines for public health, safety, and welfare, (b) responsible conduct of research, (c) maintaining a professional workplace culture, (d) ethical business operations, (e) creating and honoring agreements/contracts, (f) professional liability, and (g) public policy and

regulations. *Workplace Behavior/Operations* is important to *Professionalism* as engineering literate individuals are required to observe the ethical standards for performing their services including developing and delivering solutions to the public, communicating and cooperating with other professionals, and working for organizations and communities. <u>Therefore, by the end of secondary school, engineering literate students should be able to establish the appropriate work culture amongst team members in order to maintain honesty and integrity within an engineering project.</u>

Core Concept 3: *Honoring Intellectual Property (EP-P-3)*
Honoring Intellectual Property concerns protecting one's work, and the work of others, to ensure that ideas, inventions, or innovations are not stolen, used without permission, or claimed as another's work in order to uphold professional integrity in the creative pursuit that is engineering and design. This core concept includes knowledge related to (a) intellectual property terminology and regulations, (b) patents, copyright, and licensure, and (c) referencing sources and plagiarism. This core concept is important to Professionalism, as engineering literate individuals must honor and leverage the value of others' creations and innovations and protect their own intellectual property to ensure the highest standards of quality and integrity are upheld when solving problems. In this area, students should learn a variety of intellectual properties and the process of accessing or applying for the intellectual properties. <u>Therefore, by the end of secondary school, engineering literate students should be able to leverage the work of others, while protecting their own, following the appropriate, and ethical, conventions related to intellectual property.</u>

Core Concept 4: *Technological Impacts (EP-P-4)*
Technological Impacts are the effects, both positive and negative, that result from developing and using technologies. It is impossible to explore how each technological product or process will impact the future. However, it is important to understand how engineering problems and their solutions are interconnected with relevant (a) environmental, (b) global, (c) social, (d) cultural, (e) economic, (f) individual, and (g) political issues in order to evaluate/revise solutions in terms of these various non-technical factors. This core concept is important to *Professionalism*, as engineering literate individuals recognize that having control over Earth's future carries with it serious responsibilities and thus, they must consider non-technical factors as well as technical factors when analyzing and solving problems. <u>Therefore, by the end of secondary school, engineering literate students should be able to analyze the potential impacts of their decisions within an engineering project, considering a variety of non-technical concerns, to evaluate their work in respect to relevant societal issues.</u>

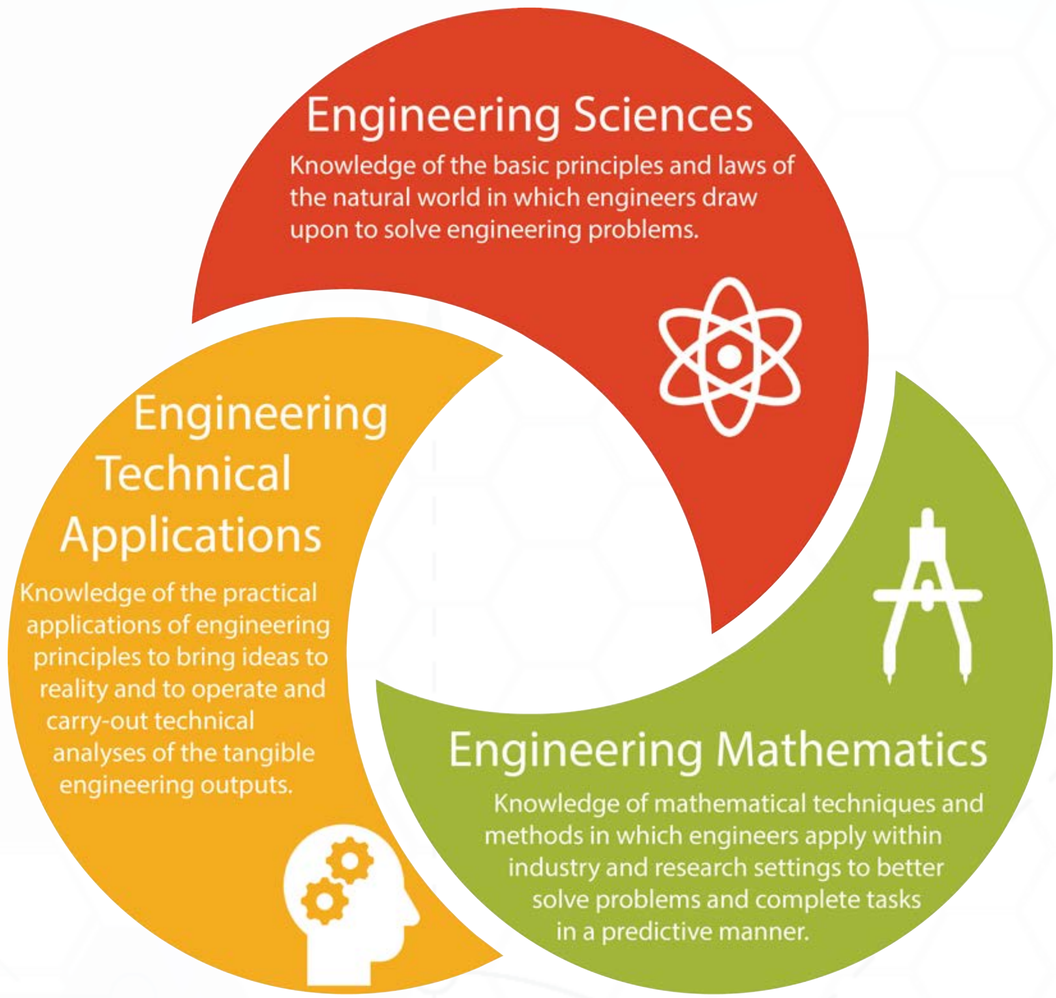
Core Concept 5: *Role of Society in Technological Development (EP-P-5)*
The ***Role of Society in Technological Development*** involves humanity's input in the decisions regarding the creation and implementation of technologies based on the predicted outcomes of its applications as well as the evaluation of its unpredicted outcomes. This core concept includes knowledge related to (a) society's needs and desires, (b) designing for sustainability, (c) cultural influences, (d) appropriate technology applications, (e) inclusion and accessibility, (f) public participation in decision making, and (g) scaling technology. The *Role of Society in Technological Development* is important to *Professionalism* as technology by itself, is neutral and does not affect people or the environment. However, it is the way in which people develop and use technology that determines if it is helpful or harmful. As such, engineering literate individuals must work along with communities to address their needs and develop appropriate engineering solutions. <u>Therefore, by the end of secondary school, engineering literate students should be able to evaluate the interactions between engineering activities and society in order to create solutions to engineering problems that consider the voice, culture, needs, and desires of the</u>

<u>people in which the solution touches.</u>

Core Concept 6: *Engineering-Related Careers (EP-P-6)*
Engineering-Related Careers are the wide variety of occupations that require technical knowledge to design, assess, implement, use, sale, and/or maintain technologies across industries, which includes a range of jobs including, but not limited to, skilled production workers, technicians, engineering technologists, engineers, engineering managers, and engineering entrepreneurs. This core concept includes knowledge related to (a) the nuances of engineering-related career pathways and disciplines, (b) professional licensing, (c) professional/trade organizations, and (d) engineering entrepreneurship. Knowledge of *Engineering Related Careers* is important to *Professionalism*, as there are a variety of professions and employment opportunities in engineering and technology fields across industries, such as manufacturing, construction, medicine, transportation, and the military, in which one can make a difference and earn their livelihood. <u>Therefore, by the end of secondary school, engineering literate students should be able to appraise engineering-related careers and the general requirements of the associated employment opportunities to create a long-term plan to pursue their career goals, whether it be engineering related or not.</u>

Engineering Knowledge - HS

Engineering is often considered the practical application of science, mathematics, and technical know-how to effectively and efficiently solve problems through the design, development, and evaluation of products, processes, systems, and structures. Therefore, and in addition to the broad set of competencies related to the *Engineering Practices*, a strong understanding of mathematical, scientific, and technical concepts is essential to solve such problems. Accordingly, one dimension of engineering literacy is *Engineering Knowledge* which consists of the concepts that are necessary to situate one's habits and practices in a conceptual domain. However, <u>the Engineering Knowledge dimension is defined as concepts that students should recognize and be able to draw upon when appropriate.</u>



While there are many disciplines and sub-disciplines of engineering, engineering literate individuals have similar qualities such as competence in the *Engineering Practices* (Engineering Design, Material Processing, Quantitative Analysis, and Professionalism) as well as a knowledge base in the scientific, mathematical, and technical domains. Therefore, this framework posits that Engineering Knowledge spans 3 broad domains which include (1) *Engineering Sciences*, (2) *Engineering Mathematics*, and (3) *Engineering Technical Applications*. <u>However, by the end of secondary school one would not expect a student to fully understand the entirety of these areas in depth. But, to be engineering literate</u>

<u>individuals, they should be able to deploy their engineering practices and engineering habits of mind to acquire and apply the knowledge necessary to complete engineering tasks. Accordingly, the concepts for the knowledge dimension are labeled as "auxiliary concepts".</u>

> ***NOTE:*** While the concepts related to the Engineering Practices are labeled as "core" and deemed essential to achieve Engineering Literacy, it should not be expected that an engineering literate student gain knowledge of all the concepts available in the Engineering Knowledge domain. Engineering Knowledge concepts are auxiliary in nature and could be drawn upon, when appropriate to (1) help students solve problems in a manner that is analytical, predictive, repeatable, and practical, (2) situate learning in an authentic engineering context, and (3) guide the development of engineering programs. In addition, there may be instances when an engineering program may choose to identify and teach "auxiliary concepts" within the engineering knowledge dimension that are not listed in this document. It is expected that schools that specialize in STEM areas (e.g. biomedical, aerospace, nanotechnology) may want to expand the selection of concepts listed below. This expansion is encouraged. Programs should use the concepts and sub-concepts listed here as a starting point to align with the overall intent of this framework.

Engineering Knowledge Domain: Engineering Sciences (EK-ES)

Engineering Science is a knowledge base consisting of the basic principles and laws of the natural world in which engineering professionals draw upon to solve engineering problems. This knowledge, which may include auxiliary concepts such as *statics*, *mechanics of materials*, and *dynamics*, relies heavily on, and is inseparable from, the application of mathematics and technical knowledge. This knowledge base is essential as engineering tasks are typically open-ended and ill-defined whereas different solution approaches may draw on a student's knowledge gained from a variety of domains of knowledge. In the P-12 classrooms, students should engage in experiences that position *Engineering Sciences* as a way to inform their engineering practice. <u>As a goal of P-12 Engineering Learning, engineering literate students should be able to recognize and, when appropriate, apply *Engineering Science* concepts to inform their engineering practice in order to solve problems in a manner that is analytical, predictive, repeatable, and practical.</u> For example, students ***may*** be able to recognize and, when appropriate, draw upon knowledge of:

Auxiliary Concept 1: *Statics (EK-ES-1)*
Statics is a fundamental physics concept that focuses on the equilibrium of bodies that are subjected to a force system. It primarily concerns the application of Newton's laws of motion to analyze loads placed on objects at rest or at a constant velocity. Because these objects are resting or have a constant velocity, the sum of all of the forces applied to the object must be equal to zero. *Statics* is important to *Engineering Literacy,* as it is the basis on which engineering professionals analyze physical systems that are void of acceleration. For example, the application of statics enables the analysis of forces applied to physical objects/systems such as trusses, cables, and chains. In addition, statics enables engineering professionals to calculate the magnitudes of the components of forces applied to an object using a series of equations. <u>Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of statics content, such as (a) *determining the*</u>

resultants of force systems, (b) *finding equivalent force systems*, (c) *conditions of equilibrium for rigid bodies*, (d) *the analysis of frames/trusses*, (e) *finding the centroid of an area*, and (f) *calculating area moments of inertia*, to analyze the forces within a static system to solve problems in a manner that is analytical, predictive, repeatable, and practical.

Auxiliary Concept 2: *Mechanics of Materials (EK-ES-2)*
Mechanics of Materials concerns the mechanical behavior of deformable bodies when they are subjected to stresses, loads, and other external forces. This concept is important to *Engineering Literacy,* as it is the basis on which engineers select materials and modify their forms to create mechanical devices and systems. For example, the application of this knowledge enables professionals to predict structural failure by using Stress-Strain analyses and Young's modulus to evaluate an object's deformation resulting from applied loads. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of the *Mechanics of Materials*, such as (a) *stress types and transformations*, (b) *material characteristics*, (c) *stress-strain analysis*, (d) *material deformations*, (e) *material equations,* (f) phase diagram, (g) *Mohr's circle, and* (h) *Young's modulus,* to analyze the properties, compositions, and behaviors of available, or needed, materials to solve problems in a manner that is analytical, predictive, repeatable, and practical.

Auxiliary Concept 3: *Dynamics (EK-ES-3)*
Dynamics concerns the analysis of objects that are accelerating as a result of acting forces. This indicates that the sum of all forces acting upon the object under investigation is not equal to zero. *Dynamics* can be divided into two main areas, kinetics and kinematics. Kinetics focuses on the study of forces that cause motion, such as gravity or torque, while kinematics focuses on the study of describing motion using quantities such as time, velocity, and displacement without the concern of the forces involved. *Dynamics* is important to *Engineering Literacy,* as it is the basis on which engineering professionals analyze physical systems that are in motion. For example, the application of dynamics enables professionals to solve problems where the forces are not in equilibrium by relating the forces and moments acting on a body to the resulting motion. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Dynamics* content, such as (a) *kinetics*, (b) *kinematics*, (c) *mass moments of inertia*, (d) *force acceleration*, (e) *impulse momentum*, and (d) *work, energy, and power*, to analyze the forces within a dynamic system to solve problems in a manner that is analytical, predictive, repeatable, and practical.

Auxiliary Concept 4: *Thermodynamics (EK-ES-4)*
Thermodynamics is the science of transferring energy from one place or form into another place or form which includes the study of heat and temperature and the relation of these factors to work, energy, and power. This concept is important to *Engineering Literacy*, as it is the basis on which engineering professionals calculate and predict how forms of energy are converted into other forms in order to create, improve, and create technological products and systems such as power plants, air-conditioning/heating units, and automobile engines. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Thermodynamics* content, such as (a) the *Laws of Thermodynamics*, (b) *equilibrium*, (c) *gas properties*, (d) *power cycles and efficiency*, and (e) *heat exchangers*, to analyze the forces within an energy system to solve problems in a manner that is analytical, predictive, repeatable, and practical.

Auxiliary Concept 5: *Fluid Mechanics (EK-ES-5)*
Fluid Mechanics concerns how the laws of force and motion apply to liquids and gases. This concept is

important to *Engineering Literacy*, as it is the knowledge that informs how engineering professionals understand, design, create, and analyze systems involving fluids such as heating and cooling equipment, pump systems, fans, turbines, pneumatic equipment, and hydraulic equipment. For example, one may use Bernoulli's equation and the conservation of mass to determine flow rates, pressure changes, minor and major head losses for viscous flows through pipes and ducts, and the effects of pumps, fans, and blowers in such systems. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Fluid Mechanics* content, such as (a) *fluid properties*, (b) *lift, drag, and fluid resistance*, (c) *pumps, turbines, and compressors*, (d) *fluid statics and motion (Bernoulli's Equation)*, and (e) *pneumatics and hydraulics*, to analyze how fluids behave and measure/control their flow to solve problems in a manner that is analytical, predictive, repeatable, and practical.

Auxiliary Concept 6: *Heat Transfer (EK-ES-6)*
Heat Transfer is the scientific knowledge that builds upon the principles of thermodynamics and fluid dynamics to describe how heat moves from one body to another. For heat to transfer, a temperature difference or gradient is needed. Heat will move from a higher temperature to a lower one (hot to cold). This concept is important to *Engineering Literacy*, as it is the knowledge that informs how engineering professionals understand, design, create, and analyze material selections, machinery efficiency, reaction kinetics, heat exchangers, and cooling towers. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Heat Transfer* content, such as (a) *conductive, convective, and radiation heating* and (b) *heat transfer coefficients*, to analyze how heat moves from one system (solid, liquid or gas) to another in order to solve problems in a manner that is analytical, predictive, repeatable, and practical.

Auxiliary Concept 7: *Mass Transfer & Separation (EK-ES-7)*
Mass Transfer & Separation is the science that explains and governs a range of separation processes to include absorption, distillation, humidification and drying, and membrane separations, as well as transport processes in equilibrium. This concept is important to *Engineering Literacy* as it is the basis on which engineers design equilibrium staged chemical processes and analyze chemical or physical principles of materials in order to select appropriate techniques for mass transfer and separation operations. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Mass Transfer & Separation* content, such as (a) *molecular diffusions* (b) *separation systems* (c) *equilibrium state methods*, (d) *humidification and drying* (e) *continuous contact methods* and (f) *convective mass transfer*, to analyze the mechanism of transfer due to difference in concentrations to solve problems in a manner that is analytical, predictive, repeatable, and practical.

Auxiliary Concept 8: *Chemical Reactions & Catalysis (EK-ES-8)*
Chemical Reactions & Catalysis concerns the analysis of the chemical changes that happen when two or more particles interact (chemical reactions) as well as controlling the rate at which these chemical changes occur by adding substances referred to as catalysts (catalysis). This concept is important to *Engineering Literacy* as it is the knowledge in which engineering professionals use to analyze and design new products and processes by controlling and using chemical reactions. For example, developing more efficient catalysts can reduce the production of environmentally harmful by-products and can enable enhanced energy efficient production processes. More efficient catalysts can also lower the costs of producing important chemical products. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Chemical Reactions & Catalysis*

content, such as (a) *reaction rates, rate constants, and order*, (b) *conversion, yield, and selectivity*, (c) *chemical equilibrium and activation energy*, and (d) *fuels*, to analyze the factors influencing the processes of reaction and catalysis with mathematical models to solve problems in a manner that is analytical, predictive, repeatable, and practical.

Auxiliary Concept 9: *Circuit Theory (EK-ES-9)*
Circuit Theory is the collection of scientific knowledge used to describe the flow of electrical energy through an electrical circuit. This concept is important to *Engineering Literacy* as it enables an engineering professional to mathematically represent and verify how electrical components relate to one another in order to design and develop electrical circuits to perform specific tasks appropriately. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Circuit Theory* content, such as (a) *series and parallel circuits,* (b) *Ohm's Laws*, (c) *Kirchoff's Laws*, (d) *resistance, capacitance and inductance*, (e) *wave forms*, (f) *signals*, and (g) *current, voltage, charge, energy, power, and work*, to design, and mathematically justify, an electrical circuit to solve problems in a manner that is analytical, predictive, repeatable, and practical.

Engineering Knowledge Domain: Engineering Mathematics (EK-EM)

Engineering Mathematics is a knowledge base consisting of practical mathematical techniques and methods in which engineering professionals apply within industry and research settings to better solve problems and complete engineering tasks in a predictive manner. This knowledge, which includes applied analysis concepts in *algebra*, *geometry*, *statistics and probability*, and *calculus*, is intimately tied to, and necessary for, expanding scientific and technical knowledge. The *Engineering Mathematics* knowledge base is essential as engineering tasks are typically open-ended and ill-defined whereas different solution approaches may draw on a student's knowledge gained from a variety of domains of knowledge. In the P-12 classrooms, students should engage in experiences that position *Engineering Mathematics* as a way to inform their engineering practice. As a goal of P-12 Engineering Learning, engineering literate students should be able to recognize and, when appropriate, apply *Engineering Mathematics* concepts to inform their engineering practice in order to solve problems in a manner that is analytical, predictive, repeatable, and practical. For example, students ***may*** be able to recognize and, when appropriate, draw upon knowledge of:

Auxiliary Concept 1: *Engineering Algebra (EK-EM-1)*
Algebra is a branch of mathematics that focuses on the conventions related to the use of letters and other general symbols, known as variables, to represent numbers and quantities, without fixed values, in formulae and equations. *Algebra* is important to *Engineering Literacy* as engineering professionals habitually select and use algebraic content and practices in the analysis, design, and making of solutions to engineering problems. For example, the related mathematical applications are used on a daily basis to solve formulas to determine an unknown value using a measured or known value such as the voltage in an electrical circuit using Ohm's Law. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of algebraic content and practices, such as (a) *the basic laws of algebraic equations*, (b) *reasoning with equations and inequalities*, (c) *representing equations in 2D and 3D coordinate systems*, and (d) *linear algebra*, to solve problems in a manner that is analytical, predictive, repeatable, and practical.

Auxiliary Concept 2: *Engineering Geometry & Trigonometry (EK-EM-2)*
Geometry is a branch of mathematics that focuses on the measurement, properties, and relationships of points, lines, angles, surfaces, and solids. Historically emerging from applications of geometry, is *Trigonometry* which specifically studies angles and angular relationships of planar and three-dimensional figures. These areas of mathematics are important to *Engineering Literacy* as engineering professionals frequently select and use geometric/trigonometric content and practices in the analysis, design, and making of solutions to engineering problems. For example, the related mathematical applications can help one to calculate distances and angles of velocity, enable efficiency when processing materials to make a physical product, support the development of engineering graphics through computer aided design software, and accurately create models and simulations to predict the functionality of a design idea. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of geometric/trigonometric content and practices, such as (1) *geometric measurement and dimensions*, (2) *expressing geometric properties with equations*, (3) *right triangles*, (4) *trigonometric functions*, and (5) *vector analysis*, to solve problems in a manner that is analytical, predictive, repeatable, and practical.

Auxiliary Concept 3: *Engineering Statistics & Probability (EK-EM-3)*
Statistics is a branch of mathematics that focuses on the methods of collecting, representing, collating, comparing, analyzing, and interpreting data. *Statistics* is typically combined with the study of probability theory which involves the mathematical analysis of random phenomena to determine how likely they are to occur. These areas of mathematics are important to *Engineering Literacy* as engineering professionals frequently select and use statistical content and practices in the testing, simulation, and analysis of solutions to engineering problems. For example, the related mathematical applications can help one to calculate how likely an outcome of repeated experiments may be, and how a specific intervention may influence the outcome, based on the analysis of collected data. As such, engineers use statistics and probability theory to evaluate the outcome of possible solutions to engineering problems. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of statistics/probability content and practices, such as (1) *probability distributions*, (2) *descriptive statistics and measures of central tendencies (mean, median, mode)*, (3) *inferential statistics and tests of significance*, and (4) *using probability to make decisions*, to evaluate/justify solutions to problems in a manner that is analytical, predictive, repeatable, and practical.

Auxiliary Concept 4: *Engineering Calculus (EK-EM-4)*
Calculus is a branch of mathematics that focuses on understanding the changes between values that are related by functions of time. This involves determining how something changes, or how items add up, by breaking them into really tiny pieces. There are two different divisions of calculus; (1) differential calculus which focuses on calculating how things change from one moment to the next by dividing it in small fragments, and (2) integral calculus which focuses on understanding how much of something there is by piecing small fragments together. This area of mathematics is important to *Engineering Literacy* as engineering professionals frequently select and use calculus content and practices in the analysis and design of solutions to engineering problems. For example, the related mathematical applications can help one to accurately and efficiently calculate quantities like rates of flow of water from a tunnel or the rate of decay of a radioactive chemical. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of calculus content and practices such as (1) *derivatives*, (2) *integrals*, (3) *differential and integral equations*, and (4) *vectors including dot*

<u>*and cross products*, to solve problems in a manner that is analytical, predictive, repeatable, and practical.</u>

Engineering Knowledge Domain: Engineering Technical Applications (EK-ET)

Engineering Technical Applications involves an interdisciplinary knowledge base consisting of the practical applications of engineering principles necessary to bring ideas to reality and to operate and carry-out technical analyses of the tangible engineering outputs. This knowledge, which includes auxiliary concepts of *electrical power*, *communication technologies*, *electronics*, *computer architecture*, *chemical applications*, *process design*, *mechanical design*, *structural analysis*, *transportation infrastructure*, *hydrologic systems*, *geotechnics*, and *environmental considerations*, relies heavily on, and is inseparable from, the application of mathematical and scientific knowledge. The *Engineering Technology* knowledge base is essential as engineering tasks are typically open-ended and ill-defined whereas different solution approaches may draw on a student's knowledge gained from a variety of domains. In the P-12 classrooms, students should engage in experiences that position *Engineering Technical Applications* as a way to inform their engineering practice. <u>As a goal of P-12 Engineering Learning, engineering literate students should be able to recognize and, when appropriate, apply *Engineering Technical Application* concepts to inform their engineering practice in order to solve problems in a manner that is analytical, predictive, repeatable, and practical.</u> For example, students ***may*** be able to recognize and, when appropriate, draw upon knowledge of:

Auxiliary Concept 1: *Mechanical Design (EK-ET-1)*
Mechanical Design is the process of developing the mechanisms/machines necessary to convert energy into useful mechanical forms and transform resources into a desired output. This includes determining what factors influence the design of a mechanical system, how the factors relate with each other throughout the design process, and how to configure the factors to meet design criteria and constraints. This concept is important to *Engineering Literacy* as it encompasses the knowledge necessary to analyze, design, and manufacture mechanical devices and systems. For example, mechanical design principles enable one to incorporate the analysis of items such as gears, shafts, fasteners, and gearboxes in regards to the fatigue and heating effects resulting from working stresses and repeated loadings in the creation of a mechanical system. <u>Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Mechanical Design* content and practices, such as (a) machine elements/mechanisms, (b) manufacturing processes, and (c) machine control, to forecast and validate the design performance of a mechanism or machinery component in order to solve problems in a manner that is analytical, predictive, repeatable, and practical.</u>

Auxiliary Concept 2: *Structural Analysis (EK-ET-2)*
Structural Analysis concerns the process of determining the effects of loads, or forces, on physical structures, as well as their individual components, and examining what factors influence the deflection and deformation of these structural elements. This includes determining how and why structural elements may fail, break or deform, and preventing such failures. This concept is important to *Engineering Literacy* as all structures are constantly under some type of strain or stress due to a variety

of forces applied to them. As such, structural analyses enable one to make informed decisions about how structures should be designed by performing the proper calculations to determine whether or not various structural members will be able to support the forces applied to them. <u>Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of Structural Analysis content and practices, such as (a) the physical properties of construction materials, (b) material deflection, (c) material deformation, (d) column and beam analysis, and (e) the implementation of design codes, to evaluate the structural elements of an structure design using the proper formulas and conventions necessary to calculate the effects of applied stresses or strains.</u>

Auxiliary Concept 3: *Transportation Infrastructure (EK-ET-3)*
Transportation Infrastructure encompasses all of the interrelated physical support systems that provide the services, utilities, and commodities necessary for moving people and cargo within, and between communities/countries, in order for society to function proficiently. This concept is important to *Engineering Literacy*, as a suitable infrastructure is necessary for technological systems to function and sustaining, as well as enhancing, a community's living conditions and economy. For example, knowledge of infrastructures enables people to design, build, and maintain appropriate transportation systems by examining factors that can influence the efficient and safe movement of people and goods and determining how to best control these factors. <u>Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Transportation Infrastructure* content, such as (a) street, highway, and intersection design, (b) transportation planning and control (including safety, capacity, and flow), (c) traffic design, and (d) pavement design, to plan/create facilities and systems that are needed to serve a county or community while considering of a variety of criteria and constraints about the safe and efficient movement of people and goods.</u>

Auxiliary Concept 4: *Hydrologic Systems (EK-ET-4)*
Hydrologic Systems encompass all of the interrelated physical structures and devices as well as the natural environment (including precipitation, evaporation, streamflow, surface runoff, groundwater movement, etc.) that effect, and help manage, the movement, distribution, and properties of water. This also includes knowledge of the fundamental principles of hydrology necessary to analyze and evaluate environmental conditions and determine the characteristics of hydrologic systems needed to meet design objectives. This concept is important to *Engineering Literacy*, as it enables one to leverage the knowledge of runoff, stream flow, soil moisture, and ground water flow to innovate tools and methods in water distribution and collection necessary for sustaining, as well as enhancing, a community's living conditions and economy. For example, methods of data collection and error analysis associated with water in hydrology and water resources, assist in the development, construction, and application of systems necessary to manage a community's water resources. <u>Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Hydrologic Systems* content and practices, such as (a) hydrology principles, (b) water distribution and collection systems, (c) watershed analysis processes, (d) open channel systems, (e) closed channel systems (pressurized conduits), (f) pumping stations, and (g) hydrologic field tests and codes, to analyze/model the flow of water in and out of a system, using the appropriate mathematical equations and conventions, in order to solve problems in a manner that is analytical, predictive, repeatable, and practical.</u>

Auxiliary Concept 5: *Geotechnics (EK-ET-5)*
*Geotechni**cs*** concerns the knowledge of the ways in which Earth's materials (i.e. rock and soil) behave

under stresses and strains in order to determine how structures and products interact, or will interact, with their surrounding environments as well as how the Earth's materials can be used to mitigate, prevent, or solve problems. This concept is important to *Engineering Literacy*, as it enables one to design the foundations of structures, plan the excavation of build sites, select the route for roads and highways, minimize the negative impacts that structures have on the environment, and prevent the damages caused by natural hazards to make the Earth's surface more suitable for people and the development of communities. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Geotechnics* content and practices, such as (a) geological properties and classifications, (b) soil characteristics, (c) bearing capacity, (d) drainage systems, (e) slope stability, (f) erosion control, (g) foundations and retaining walls, and (e) geotechnical field tests and codes, to analyze/model the behavior of Earth's materials, using the appropriate mathematical equations and conventions, in order to solve problems in a manner that is analytical, predictive, repeatable, and practical.

Auxiliary Concept 6: *Environmental Considerations (EK-ET-6)*
Environmental Considerations focuses on managing the use of natural resources to minimize the negative impacts that human activity can have on the environment. This includes work developing new and better ways to dispose of waste and to clean up pollution while understanding the impact government regulations and the methods for analyzing environmental change. This concept is important to Engineering Literacy, as extracting natural resources and transforming them into industrial/consumer products and structures can take a major toll on the environment. For example, building a hydroelectric dam to generate electricity can alter the ecosystem for aquatic life; extraction of natural gas from subterranean rock formations could potentially contaminate water sources; and burning of fossil fuels such as coal can contribute to increased levels of greenhouse gases in the atmosphere. As such, the knowledge relevant to Environmental Considerations, such as sampling and analysis techniques for surface water, groundwater, soil, and air, can aid in designing strategies to prevent/mitigate/remediate problems in an effort measurably enhance environmental quality. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Environmental Considerations* content and practices, such as (a) ground and surface water quality, (b) wastewater management, (c) air quality, and (d) environmental impact regulations and tests, in order to design methods to protect and manage our air, water, soil, and related ecosystems.

Auxiliary Concept 7: *Chemical Applications (EK-ET-7)*
Chemical Applications are the activities and knowledge related to converting materials into more usable substances as well as selecting the best materials for specific applications. This concept is important to *Engineering Literacy* as engineering professionals apply their understanding of chemistry, and the properties of the materials, to solve a variety of problems. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Chemical Applications* content, such as (a) inorganic chemistry, (b) organic chemistry, (c) chemical, electrical, mechanical, and physical properties, (d) material types and compatibilities, (e) corrosion, and (f) membrane science to analyze and select, or propose a novel combination of, materials to produce a desired product or process.

Auxiliary Concept 8: *Process Design (EK-ET-8)*
Process Design concerns the development and organization of facilities to support the desired transformation of materials, both physically and chemically. This concept is important to *Engineering Literacy* as it encompasses the knowledge necessary for coordinating the appropriate production

procedures and manufacturing processes involved with transforming materials into desired end products. In addition, this knowledge supports the continual optimization of production processes and manufacturing facilities to minimize the waste of resources, enhance production efficiency, and increase an organization's profits. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Process Design* content and practices, such as (a) process controls and systems, (b) process flow, piping, and instrumentation diagrams, (c) recycle and bypass processes, and (d) industrial chemical operations, to visually represent the procedures and facilities necessary to produce a desired product.

Auxiliary Concept 9: *Electrical Power (EK-ET-9)*
Electrical Power concerns the knowledge related to the systems that generate, store, transform, distribute, and use electricity to perform work. *Electrical Power* is important to *engineering literacy* as it enables engineering professionals to make informed decisions related to the use and creation of electrical devices and components to generate, transfer, and use electrical energy which is critical as these decisions can greatly impact our society and environment. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Electrical Power* content, such as (a) *motors and generators*, (b) *alternating and direct current*, (c) *electrical materials*, (d) *electro-magnetics*, (e) *voltage regulation*, (f) *electricity transmission and distribution*, and (g) *magnetism*, to determine and justify which electrical materials are most appropriate for an engineering task involving electrical power systems, using mathematical equations and the correct units.

Auxiliary Concept 10: *Communication Technologies (EK-ET-10)*
Communication Technologies are the systems and products that extend the ability to collect, analyze, store, manipulate, receive, and transmit information or data which can include anything from graphic media to computers, cellular devices, and fiber optics. *Communication Technologies* are important to *Engineering Literacy* as these systems have become intertwined with our daily lives and, in many ways, society has become increasingly dependent on them. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Communication Technologies* content, such as (a) *digital communication*, (b) *telecommunication*, (c) *graphic communication*, (d) *photonics*, and (e) *network systems*, to visually represent, analyze, and propose the procedures and products necessary to effectively, efficiently, and appropriately communicate data and/or information.

Auxiliary Concept 11: *Electronics (EK-ET-11)*
Electronics are the systems and products that use small amounts of electricity for collecting, storing, retrieving, processing, and communicating data/information necessary to perform a task. This includes creating electrical circuits using both traditional analogue components as well as digital electronic components, microprocessors and microcontrollers, and programmable logic devices. This concept is important to *Engineering Literacy* as engineering professionals use and apply this knowledge to design and troubleshoot the electronic devices that we use every day. Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Electronics* content, such as (a) *electronic instrumentation*, (b) *electronic components (diodes, transistors, resistors, power supplies, capacitors, breadboards, etc.)*, (c) *digital logic (integrated circuits, gates, flip-flops, counters, etc.)*, and (d) *electrical diagrams/schematics*, to successfully choose different instrumentation, components, and materials to visually represent, analyze, design, and test an electronic device to perform a specific task.

Auxiliary Concept 12: *Computer Architecture (EK-ET-12)*
Computer Architecture concerns the knowledge related to understanding how a computer's sub-components are organized, and interact with each other, to perform desired functions. This includes the physical components (hardware) and operating instructions (software). The hardware is comprised of the computer system's central processing unit (CPU), memory, input devices, and output devices. The software includes both operating software (the programs that manage the computer's processes, memory, and operation of all other hardware and software) as well as application software (the programs that work with the operating software to perform specific tasks, which includes applications such as word processors, computer aided design programs, and games). *Computer Architecture* is important to *Engineering Literacy* as computer systems are the heart of all information-processing and communication technologies and perform countless functions related to extending capabilities for calculations, automation, and communication between people and machines across the world and beyond. <u>Therefore, by the end of secondary school, engineering literate students may be able to, when appropriate, draw upon the knowledge of *Computer Architecture* content, such as (a) *computer hardware*, (b) *computer operating software and applications*, (c) *memory*, (d) *processors and microprocessors*, and (e) *coding* to visually represent the how the components of a computer system relate to one another and how to configure the components for desired performance.</u>