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A Progression and Bundling Model for Developing Integrated, Socially-Relevant Science and Engineering Curricula Aligned with the Next Generation Science Standards, Grades 6-8

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ABSTRACT

As an increasing number of school districts around the country adopt the Next Generation Science Standards (NGSS), curricula aligned with these standards are in demand. Progression models provide a foundation for developing curricular units that sequentially support one another to guide students through coherent learning. Various models are possible for a given set of standards. The selected model must address the unique conditions and needs of the education initiative. Here we present and explain a progression model and bundling of the 59 performance expectations for the NGSS middle-school grade band. This model, the *Unit Challenge Progression Model,* ***provides the basis for developing units that engage students in addressing challenges of societal relevance while learning and applying content and practices from multiple STEM (science, technology, engineering, and mathematics) disciplines in a coherent progression. Preliminary results from pilot testing of curricular units indicates that the bundling of performance expectations presented here, and the incorporation of supporting subcomponents of performance expectations, help to achieve integration of STEM disciplines while allowing for learning of STEM content within units. This progression model continues to be refined as additional curricular units are pilot-tested in schools.***

INTRODUCTION

As states and school districts transition to new ways of engaging students in science and engineering as called for by the Next Generation Science Standards (NGSS), demand is increasing for NGSS-aligned curriculum resources. The level of curriculum reform needed to fully embrace the learning strategies envisioned by NGSS authors will require complete revamping of most existing K-12 science curricula. To support student learning, new curricular resources should be developed around learning progression models, which specify the order in which material can be addressed as part of a pathway for student learning (Duschl ***et al.***, 2011). Curriculum that is developed based on learning progression models allows for greater coherence than curriculum developed as discreet units without attention to the sequencing of concepts and practices between units (Duschl ***et al.***, 2011). Curricular coherence addresses the arrangement of ideas, the extent to which ideas are addressed, and the sequencing of topics within and across grades (Schmidt et al., 2005, Fortus and Krajcik, 2012). Progression models should be understood as possible approaches that education agencies refine as they develop their own sequences (NGSS Lead States, 2013). Learning progression models based on the NGSS performance expectations will provide important starting places for many educators and curriculum developers as they refine and develop NGSS-aligned curricula (Duncan and Rivet, 2013), yet few models are currently available.

Multiple permutations of progression models are potentially feasible (NGSS Lead States, 2013). Selection of a model for a specific application should be based on factors that will best promote student learning, given the unique objectives, context, and populations to be served by a curriculum (NGSS Lead States, 2013). The NGSS lead states and the California Department of Education offer example progression models as an appendix to the NGSS (NGSS Lead States, 2013). These provide potential arrangements of disciplinary core ideas but do not suggest bundling of performance expectations into units. While these are valuable for many audiences, the authors of the *Unit Challenge Progression Model* (*UCPM*) identified a need for a new progression model that would provide sequencing and bundling performance expectations to design curricular units that engage students in applying multiple science and engineering disciplines while exploring real-world 21st-century challenges.

The *UCPM* is the result of work conducted by the Michigan Science Teaching and Assessment Reform (Mi-STAR) initiative. Mi-STAR is designing curriculum for grades six through eight that is authentically aligned with the NGSS and is designed to incorporate curricular and pedagogical attributes that have been found to engage students as learners and help students to apply science in real-world decision-making. The curriculum is developed using a backwards-design approach (Wiggins and McTighe, 2005) using the NGSS performance expectations and associated evidence statements as key design criteria. Because of the difference between the NGSS and pre-existing science standards, Mi-STAR's work is resulting in an entirely new NGSS-aligned curriculum, as opposed to an updated version of a pre-existing curriculum that may partially overlap with the standards. The distinction is important between fully NGSS-aligned curricula and a curriculum whose relationship to the NGSS can be catalogued because NGSS requires entirely new strategies for the teaching and learning of science such that **disciplinary core ideas, science and engineering practices, and crosscutting concepts are all fully integrated as three-dimensions in all science teaching and learning**. While a pre-existing curriculum will typically address much of the content that is articulated in the NGSS, it is rare for such a curriculum to fully integrate all three dimensions in accordance with the vision underpinning the NGSS as articulated in the National Academies' Framework for K-12 Science Education (Schweingruber *et al.*, 2012).

In the Mi-STAR middle-school curriculum, each unit is developed around a *Unit Challenge* that involves students in a series of performance-based tasks that build upon one another from lesson to lesson throughout each unit. Through Unit Challenges, students explore scientific phenomena or engineering problems and identify real-world implications of decisions. Unit Challenges involve the application of practices and concepts from multiple science and engineering disciplines because multiple disciplines are required to understand and address real-world problems. The Mi-STAR curriculum is augmented by in-service professional development and pre-service training, since many teachers who implement a reformed NGSS-aligned curriculum will need to update their teaching practice (*e.g.* Trygstad *et al.,* 2013). The Mi-STAR initiative is a partnership that includes K-12 teachers and administrators; highereducation faculty, staff, and graduate students; and representatives of professional societies. Although Mi-STAR is focusing its efforts on developing NGSS-aligned middle-school curricula for the state of Michigan, the results of its work are widely applicable and readily adaptable to other states.

OVERVIEW OF THE *UCPM*

In order to provide the framework for development of a coherent curriculum that engages students through unit challenges, the ***UCPM*** has several design criteria.

- Bundling of performance expectations: ***The UCPM*** specifies how three-dimensional performance expectations can be bundled into units of instruction based on coherent sequencing of disciplinary core ideas. This differs from some progression models outlined to date, which address only the planned sequence of NGSS disciplinary core ideas without bundling these into instructional units (NGSS Lead States, 2013). Bundling of performance expectations is essential to helping students learn and make connections across the sciences and engineering (Pruitt, 2014). The bundled performance expectations provide the foundation for articulating learning performances addressed by each curricular unit.
- Conceptual Connection to a Societal Issue: Each performance expectation bundle is designed to address a topic of societal relevance in the 21st century, such as how the stimulus from digital technology reaches and affects humans, how to minimize waste through understanding the properties and life cycle of materials, how antibiotic resistance affects people and can be mitigated, or how to manage invasive species to reduce impacts on ecosystems. The focal topic serves as the basis of the Unit Challenge, allowing students the opportunity to propose innovative solutions to contemporary problems.
- Integration: The model, together with the convention of supporting sub-components described in text box 1, allows for integration of different STEM disciplines at the unit level and ensures that students experience multiple STEM disciplines throughout each semester. This includes integration of the four NGSS disciplines (physical science; life science; earth and space science; engineering, technology, and applications); the practices associated with mathematics, science, and engineering; and the concepts that cut across and are common to all science and engineering studies. Integrated STEM curriculum allows students to experience how multiple disciplines are applied to address real-world issues, and has shown positive effects on student achievement at the middle-school level in multiple studies (Becker and Park, 2011).
- Coherence: Curricular coherence has been identified as a leading factor in student performance (Schmidt ***et al.,*** 2005), and was an important factor in the design of the ***UCPM*** and the convention of supporting sub-components (see text box 1). A valuable progression enables students to build on their previous learning, learn and practice prerequisites in a meaningful order, and explore how new concepts relate to old ones (National Research Council, 2007). A coherent curriculum allows students to make conceptual connections for themselves, see how details and facts fit into broader contexts, and grasp the importance of what they are learning (AAAS, 2001).
- Unifying crosscutting concepts: One factor that promotes curricular coherence is organizing content around big ideas (Shin ***et al.***, 2009). Through the ***UCPM***, students apply their learning to a particular unifying crosscutting concept or pair of concepts each semester. These unifying crosscutting concepts allow students to see connections between units while deepening their ability to recognize each crosscutting concept in multiple

contexts. In each unit, students explore how the semester's unifying crosscutting concept applies to phenomena or problems that students are investigating at key points throughout their interactions with the Unit Challenge. It is important to note that additional crosscutting concepts are also addressed within each unit, as specified by the performance expectations that are bundled together for the unit. This allows students to gain experience recognizing the relationships among the crosscutting concepts.

- Themes: A set of seven interdisciplinary themes, or broad topics that are relevant to 21st-century society, are used to ensure that students learn about and address priority issues through the Unit Challenges (Table 1). The *UCPM* ensures that students address each theme at least twice throughout the middle-school grade band. The Mi-STAR team identified these themes based on topics recognized as being of particular importance to society in the 21st century by several professional science and engineering organizations (Gochis ***et al.***, 2015; American Chemical Society, 2009; American Geosciences Institute, 2012; American Physical Society, 2015; Patel and Jarudi, 2003; Field ***et al.***, 2014; National Academy of Engineering, 2008; National Academy of Sciences, 2015; National Research Council, 2001, 2009).
- All performance expectations of the middle grade band: The *UCPM* provides a framework for teaching and learning all 59 performance expectations of the middle grade band.

TEXT BOX 1. SUPPORTING SUB-COMPONENTS: A MECHANISM FOR ACHIEVING INTEGRATED AND COHERENT CURRICULUM

For curriculum developers, the use of an integrated approach requires special care in order to ensure that content typically associated with each discipline is addressed coherently. For example, if a specific unit includes life and physical science content, it is necessary to ensure, as part of the curriculum design process, that prerequisite knowledge and abilities are developed in both life and physical science prior to students' exploration of more advanced concepts within the unit. In order to allow for integration and coherence within and across units, Mi-STAR curriculum developers apply the convention of 'supporting sub-components' of performance expectations. These are components (disciplinary core ideas; science and engineering practices; crosscutting concepts; nature of science components; or science engineering and society components) of additional performance expectations beyond the 'primary performance expectations' in a bundle. Curriculum developers incorporate supporting sub-components into the backwards design of each unit. These promote:

- Disciplinary coherence by allowing the curriculum developer to bring in concepts that reinforce previous knowledge or introduce knowledge that will be explored in-depth at a later stage.
- Integration by allowing curriculum developers to incorporate disciplinary core ideas from another discipline if a bundle of primary performance expectations includes core ideas from only one NGSS discipline.
- Scaffolding by enabling students to explore concepts multiple times in the context of different science and engineering practices. This approach supports findings from the research synthesis of *Taking Science to School* (NRC 2007), which indicate that students should experience disciplinary content iteratively and in the context of various scientific practices in order to develop a depth of conceptual knowledge.

The *UCPM* outlined here (Table 2) indicates only primary performance expectations. This is to allow for flexibility for adopters of the *UCPM* to incorporate supporting sub-components that are appropriate or needed to support instruction and learning for each unit.

The bundling and detailed sequencing within the *UCPM* primarily focus on disciplinary core ideas. Crosscutting concepts are scaffolded through the unifying crosscutting concepts. They, as with science and engineering practices, are addressed iteratively within units and over the course of each school year.

DEVELOPMENT PROCESS

Development of the *UCPM* is an iterative process, with refinements implemented based on systematic review and feedback from educators and curriculum development specialists at key stages of curriculum design and testing. The process of testing and refinement is essential to the development of learning progressions (Duschl *et al.,* 2011). The initial *UCPM* was developed by a team of scientists, engineers, and educators through a series of intensive work sessions conducted over the course of three months (January – April, 2015). In these work sessions, content specialists and educators:

- Identified the necessary prerequisites and sequencing of sub-ideas within each discipline represented in the NGSS (physical science; life science; earth and space science; engineering, technology, and applications), based on learning performances associated with each performance expectation. The development of an appropriate progression model was guided by clear articulation of learning performances (Wilson, 2009), which served as the basis for designing student learning experiences and associated assessments (Black and William, 1998).
- Grouped disciplinary core ideas into bundles such that the concepts within each bundle could collectively address an issue of societal relevance that required content from multiple disciplines to address.
- Iteratively reviewed and refined the bundling and sequencing of bundles until each theme was addressed at least twice within the grade band and the units were coherent within and across grades.
- Described the conceptual relationship between performance expectations within bundles as they related to an issue of societal importance that could form the basis of a Unit Challenge.

Once the initial progression model was established, curriculum development teams (teachers, content experts and curriculum design experts) worked face-to-face and virtually to develop and refine units that addressed a specific bundle of performance expectations (May – August, 2015). This effort resulted in development of an initial set of three units, one for each of the middle-school grades, was refined and pilot tested in six school districts with eight teachers and over 600 students (October, 2015 – March, 2016).

Refining the Draft UCPM

Data related to the effectiveness of the units was collected from teachers and students involved in the initial pilot-testing phase. Analysis of the data resulted in revisions to the initial *UCPM*. In particular, pilot testing revealed that each unit's performance expectation bundle should include no more than three or four primary performance expectations. Teachers suggested that reducing the number of bundled primary performance expectations it would be possible to decrease the length of the units. Teachers indicated that limiting the duration of a unit is important to maintaining high levels of student interest and engagement with the Unit Challenge. As a result, the revised *UCPM* now requires that a maximum of four primary performance expectations can be bundled in any unit. The revised *UCPM* was reviewed by scientists, teachers, and curriculum development specialists prior to implementation. Reviewers were asked to critically evaluate the potential for the progression model to achieve curricular coherence within disciplines and within and across grades. Reviewers also considered the bundling of performance expectations for coherence and conceptual connection to a societal issue. Further refinements, including clarifications of terms used to describe components of the model were incorporated as a result of the review process. While reviewers were generally supportive of the refined progression model, additional revisions will likely be made in the future based on the results of additional pilot testing as well as the assessment of student learning outcomes.

THE *UCPM*

The ***UCPM*** (Table 2) lays out performance expectations for the three years of instruction that occurs during grades 6-8. The model is designed to progressively build students expertise across the disciplines of science (Table 3). As an example, students build understanding of the NGSS topical area "Forces and Interactions" ("PS2," or the second [2] NGSS physical science [PS] topical area) through progressive experiences with related Disciplinary Core Ideas throughout all three grades. In early 6th grade, students learn about the basic laws governing mechanical forces through the disciplinary core idea "Forces and Motion" (PS2.A). Students learn that the force exerted by one object on a second object is equal and opposite in strength and direction to the force that the second object exerts. They also learn that the motion of an object is determined by the sum of the forces acting on it and that the motion of an object will change if the total force on the object is non-zero. In the beginning of 7th grade, students begin to explore more abstract forces and their interactions through the disciplinary core idea "Types of Interactions" (PS2.B). They learn that electric and magnetic forces can be attractive or repulsive and that the strength of a force depends on multiple factors. In 8th grade, students encounter even more abstract concepts related to the disciplinary core idea "Types of Interactions" (PS2.B), including the idea that forces that act at a distance are explained by fields that can be mapped, and that gravitational forces are attractive and depend on the mass of interacting objects.

UNIFYING CROSSCUTTING CONCEPTS

Unifying crosscutting concepts were sequenced to allow for a progressive understanding of how the various concepts relate to each other and to the broad concept of system dynamics (Table 4). Students begin the 6th grade with an exploration of the crosscutting concept ***Systems and system models.*** Because all scientific phenomena occur within systems and affect system dynamics, this crosscutting concept provides a basis for understanding and exploring the other crosscutting concepts. Through repeated application of this concept across units, students refine an understanding of what a system is, how to define system boundaries, and how to model a system. In the second semester of the 6th grade, students build on their understanding of ***Systems and system models*** by considering the ***Patterns*** found in systems, and how ***Cause and effect*** relationships can explain those patterns.

In the first semester of the 7th grade, students consider ***Energy and matter*** by modeling and constructing explanations for how energy and matter flow into, out of, and within systems. This crosscutting concept builds on ***Patterns*** and ***Cause and effect*** in that energy and matter flows can be observed by identifying patterns and can be explained using cause and effect. In the second semester of 7th grade, students consider ***Structure and function*** by modeling and constructing explanations for how the structure of a system or system component affects its function.

In the first semester of 8th grade, students consider ***Scale, proportion, and quantity*** by exploring how components interact within systems over different time and spatial scales. Systems, patterns, cause and effect relationships, energy and matter cycling, as well as the relationship of structure and function, can all be observed at different scales and magnitudes. Students can therefore build on their previous knowledge while identifying a new crosscutting concept. In the final semester of the grade band, students consider ***Stability and change*** by identifying the conditions under which a system is stable or changing. This concept builds on all previous crosscutting concepts. From the beginning of 6th grade through the end of 8th grade, the unifying crosscutting concepts build on one another in order to deepen student understanding of individual crosscutting concepts as well as the relationships among them.

RATIONALES FOR BUNDLING OF PERFORMANCE EXPECTATIONS

Within each grade, the rationale for bundling the performance expectations within each unit was carefully considered in order to ensure that each bundle would relate to each Unit Challenge as well as the semester's unifying crosscutting concept.

6TH GRADE

Unit 6.1 Students develop an in-depth understanding of how gravity and sunlight drive the water cycle (MS-ESS2-4) by considering the energy and motion of water molecules as they undergo phase changes (MS-PS1-4) and how changes to a watershed can affect the magnitude of water moving along different pathways in the water cycle. Through the ***Unit Challenge***, students model the water cycle in a watershed with different types of land cover, in order to demonstrate how human land use impacts how water moves through the watershed and the magnitude of different types of flows. Students also define the criteria and constraints of a water-related problem in the watershed (MS-ETS1-1) and use that list to refine a list of potential land use options that might help solve the problem. Students tie the watershed concepts back to the unifying crosscutting concept ***Systems and system models*** by defining the watershed as a system.

Unit 6.2 In this unit, students develop a model for cellular respiration that describes how energy is released from the bonds of food molecules through an exothermic reaction (MS-LS1-7). They use their model to explain that products and reactants have different properties (MS-PS1-2) and that matter is conserved in chemical reactions (MS-PS1-5). Related to eating and chemical reactions, students design and test a device that creates an endothermic or exothermic reaction (MS-PS1-6), for example, a device to keep their food warm or cold. Students use their model and investigations to solve an issue related to nutrition through the ***Unit Challenge***. Students relate this to the unifying crosscutting concept ***Systems and system models*** by developing an understanding of digestion as occurring within a body system and modeling how the digestive tract functions as a system.

Unit 6.3 In this unit, students address a challenge related to human health involving the functions of the human body that requires them to model cells, tissues, and body systems. Students create a model of the subsystems of the human body (MS-LS1-3). In order to create the model, they first have to demonstrate that living things are made of cells (MS-LS1-1) and model the structures and functions of cells (MS-LS1-2) within tissues. The unit relates to the unifying crosscutting concept ***systems and system models*** as students model how cells and tissues comprise body systems.

Unit 6.4 In this unit, students plan an investigation to provide evidence for Newton's 3rd law (MS-PS2-2) and use the law to design a solution to the problem of the collision of two objects (MS-PS2-1). This relates to the unifying crosscutting concept ***systems and system models*** because students model how forces interact with system components. Students use their investigation of Newton's 3rd law to solve an issue related to transportation through the Unit Challenge.

Unit 6.5 Students create a model for how resource availability and different environmental factors such as sunlight, water, and soil affect plant growth (MS-LS1-5, MS-LS2-1). They also investigate how the uneven distribution of soil resources affects plant growth (ESS3.A from MS-ESS3-1). Through the Unit Challenge, students use their model of the factors affecting plant growth to propose a solution to improve the growth of an agricultural product. Students explore the unifying crosscutting concepts as they identify ***patterns*** between resource availability and organism growth. They construct an explanation for the ***cause and effect*** relationship of how the resources available to an organism affect its growth.

Unit 6.6 Students create a model of a dynamic ecosystem, including patterns of interactions between living and nonliving things (MS-LS2-2), how changes in one population can ripple throughout the ecosystem (MS-LS2-1, MS-LS2-4), and how changes in abiotic factors such as climate can affect population sizes (MS-LS2-4). During the unit students model species interactions, predict how a new invasive species would affect the ecosystem, and compare options for managing an invasive species (ETS1.B from MS-ETS1-2). Students explore the unifying crosscutting concepts by identifying ***patterns*** of interactions between organisms in an ecosystem and use those patterns to predict how a change in one population affects other populations (***cause and effect***).

Unit 6.7 Students model the cycling of energy in a food web in an ecosystem (MS-LS2-3) and develop an explanation for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms (MS-LS1-7). For their ***Unit Challenge,*** students use their model and investigations to address an issue related to food webs, for example health of Great Lakes fisheries. Students explore the ***unifying crosscutting concepts by*** identifying ***patterns*** in how energy is captured and stored by organisms, and ***cause and effect*** relationships of energy transfer between organisms. Students use these patterns and relationships to explain food webs.

7TH GRADE

Unit 7.1 Students model how electricity is generated from mechanical work of air and water by combining the concepts of electromagnetic forces (MS-PS2-3), potential energy storage (MS-PS3-2), kinetic energy relationships (MS-PS3-1), and transfers of energy between objects in a system (MS-PS3-5). This provides an introduction to the unifying crosscutting concept of ***energy and matter.*** Through the ***Unit Challenge***, students use their understanding of energy transfer and electromagnetism to design an electricity generation plan for a house "off the grid."

Unit 7.2 Students model the rock cycle (MS-ESS2-1), plate tectonics (MS-ESS2-3), and how Earth's system changes the planet on varying scales (MS-ESS2-2), with geologic time (ESS1.C from MS-ESS1-4) introduced as a supporting concept. As part of the model, students describe minerals as solids made of molecules organized into extended structures with repeating subunits (part of PS1.A from MS-PS1-1). Students explore the unifying crosscutting concept of ***energy and matter*** by modeling the cycling of earth materials between different rock types and forms of materials due to energy from the sun and earth. Through the Unit Challenge, students use their model to describe the origin of minerals or construction materials.

Unit 7.3 Students investigate the life cycle of insulation materials including their geologic origin (MS-ESS3-1), chemical synthesis (MS-PS1-3), properties (PS3.A and PS3.B from MS-PS3-3), and environmental impacts, including how population growth impacts the environment (MS-ESS3-4). Through the ***Unit Challenge***, students compare several insulation materials based on their life cycle in order to choose the most sustainable. Students explore the unifying crosscutting concept of ***energy and matter*** by modeling the life cycle of a synthetic product and constructing explanations for how it is converted from one form of matter to another.

Unit 7.4 Building on their knowledge from the previous unit, students combine an investigation into thermal energy transfer (MS-PS3-4) with an iterative design of a device to minimize/maximize thermal energy transfer (MS-PS3-3). In completing the design, students develop a model to iteratively test and modify their device to achieve an optimum design (MS-ETS1-4). Through the Unit Challenge, students build a device to solve a problem related to thermal energy transfer. Students explore the unifying crosscutting concept ***energy and matter*** through their investigation and design.

Unit 7.5 Students investigate the reproduction of organisms and the specialized plant structures and animal behaviors that lead to reproduction (MS-LS1-4). They use their understanding to design a method for monitoring and minimizing human impacts on organism reproduction (MS-ESS3-3). Students explore the crosscutting concept of ***structure and function*** by constructing explanations for how plant structures affect their reproduction. For the Unit Challenge, students investigate how humans have disrupted the reproduction of organisms and ramifications for agriculture (e.g. pesticides and honey bee collapse affecting plant reproduction). They design a way to monitor and minimize that impact.

Unit 7.6 Students investigate genetic variation (MS-LS3-1), sexual vs. asexual reproduction (MS-LS3-2), how genes affect growth (LS1.B from MS-LS1-5), and human technologies for artificial selection (MS-LS4-5). This unit is the first of three on genetic diversity and evolution. This bundle focuses on artificial selection, providing a concrete modern context for learning concepts that are foundational to understanding past evolution driven by natural selection over geologic history. Students relate their work to the unifying crosscutting concept of ***structure and function*** by constructing explanations for how structural changes to genes may affect the structure of organisms (i.e. their body characteristics) as well as their functions such as growth and health. For the Unit Challenge, students investigate how humans have modified the genes of a food they consume, and communicate their findings in a brochure, poster, podcast, video, presentation, or webpage.

Unit 7.7 Students investigate water quality, including atomic composition of molecules (MS-PS1-1), surface water flow and erosion (MS-ESS2-1), subterranean water flow (MS-ESS2-2), and uneven distribution of groundwater flow (ESS3.A from MS-ESS3-1, excluding distribution of other resources covered elsewhere in the sequence). Using their investigation of surface water flow, water resource distribution, and the substances found in water, students design a plan to monitor water quality issues for their Unit Challenge (supporting MS-ESS3-3). Students relate their work to the unifying crosscutting concept ***structure and function*** by constructing explanations for how thermal pollution affects the physical properties and functions of water.

Unit 7.8 Students apply their knowledge of ecosystems and biodiversity from previous units to compare designs for maintaining an ecosystem service (MS-LS2-5, MS-ETS1-2). They take the best characteristics of each to identify a final design (MS-ETS1-3). For the Unit Challenge, the comparison focuses on a water-related ecosystem service such as water purification. Students relate their work to the unifying crosscutting concept ***structure and function*** by analyzing how the structures of the different compared designs affect their function. For example, a change in the structure of a water purification or erosion control system may affect the amount of purification or erosion control.

8TH GRADE

Unit 8.1 Students investigate how mutations (MS-LS3-1) help to drive natural selection by increasing the probability some organisms will survive and reproduce (MS-LS4-4), leading to increases or decreases in traits in populations over time (MS-LS4-6). This unit is the second of three on genetic diversity and evolution. This bundle focuses on basic mechanisms of natural selection (in a modern context). In the following unit, natural selection is investigated in more depth in context of historic ecosystems recorded in the fossil record. Through the Unit Challenge, students compose a public information piece (brochure, fact sheet, or webpage) explaining why antibiotic resistance is an important issue and how to avoid it. Students explore the unifying crosscutting concept of ***scale, proportion, and quantity*** by identifying the timescales over which natural selection occurs in different modern organisms.

Unit 8.2 Students analyze evidence to infer that many species have existed and gone extinct, while some species have evolved into new species (MS-LS4-1). This evidence includes patterns in the fossil record (MS-ESS1-4), as well as analogous structures in extinct species (preserved in fossils) and modern species (MS-LS4-2, MS-LS4-3). Students use this evidence to explain that natural selection of traits (LS4.B from MS-LS4-5) has led to species extinction as well as the formation of new species. Students explore the unifying crosscutting concept of ***scale, proportion, and quantity*** by identifying the timescales over which patterns of evolution and extinction occur in modern and fossil organisms. Through the Unit Challenge students investigate how past changes in environmental conditions led to extinction and use their investigations to write a management plan for a Michigan endangered species.

Unit 8.3 Students examine how waves are used to communicate by modeling wave structure and transmission (MS-PS4-1, MS-PS4-2) as well as magnetic induction (MS-PS2-5) used in speakers / megaphones. Students also research how human sense receptors take in and respond to sound and light stimuli from digital technology (MS-LS1-8). Students explore the unifying crosscutting concept of ***scale, proportion, and quantity*** by identifying that waves have the same structure at varying scales. For their Unit Challenge, students model the mechanisms behind a particular form of digital technology, use their model to explain how the stimulus reaches human sense receptors as electromagnetic or mechanical stimulus, and obtain/communicate information about how people respond to that stimulus (i.e. blue light from iPhones disrupts sleep, people have a happier mood when they hear a favorite song).

Unit 8.4 Students investigate that gravitational forces are attractive and depend on the mass of interacting objects (MS-PS2-4), leading to a model for how gravitational forces cause orbits in the solar system (MS-ESS1-2). At the same time, students model the apparent motion (ESS1.A associated with MS-ESS1-1) and scale of the solar system (MS-ESS1-3) as part of their model of orbits. Students explore the unifying crosscutting concept of ***scale, proportion, and quantity*** by identifying patterns in the motions and role of gravity in those motions over the scale of the solar system. As part of their Unit Challenge students model the motion and location of communication satellites in space.

Unit 8.5 Students create a model of factors causing atmospheric circulation and regional climate (MS-ESS2-6), including in their model the tilt of the Earth's axis and variation in seasons (MS-ESS 1-1). Students also model the causes of local weather patterns (MS-ESS2-5), and use this model to distinguish between weather and climate. Students investigate how weather variability affects the profitability of agriculture in the region. Students explore the unifying crosscutting concept of ***stability and change*** by identifying the conditions that produce change and stability in the weather and climate system. For the Unit Challenge students use their model to identify average water availability for a particular region and investigate how that would affect the types of crops generally grown in their chosen region.

Unit 8.6 Students analyze data on the frequency, magnitude, and location of hazard events, including geologic hazards, severe weather hazards, and surface hazards (MS-ESS3-2). They model the movement of tectonic plates at plate boundaries (MS-ESS2-3) and the motions of atmospheric air masses (supporting ESS2.D from MS-ESS2-5) in order to understand why hazards occur where they do (MS-ESS2-3). Students also investigate how digital signals (MS-PS4-3) have improved the mitigation of hazards by allowing for easier transmission, storage, and analysis of signals. Students explore the unifying crosscutting concept of ***stability and change*** by identifying how natural hazards disrupt the stability of a place or region. For the Unit Challenge, students create a series of hazard maps for the United States and Michigan, identify a U.S. city affected by a hazard of their interest, and develop a Hazard Mitigation Plan and Public Service Announcement for that city including an explanation of the causes of the hazard as well as suggested mitigation measures and links to real-time early warning data.

Unit 8.7 Students examine evidence of the factors causing climate change and ask questions to clarify that evidence (MS-ESS3-5). They also engage in argumentation to describe how humans have had an impact on Earth's climate system and how engineered solutions could mitigate those impacts (MS-ESS3-4). Students explore the unifying crosscutting concepts of ***stability and change*** by investigating the conditions that influence global climate and have caused it to change in Earth's history. For the Unit Challenge students model the factors affecting global climate and prepare a communication piece (letter, poster, video) to a local authority that argues, with evidence and reasoning, that humans are the main driver of climate change, that climate change will have impacts on people and Earth systems, and that engineered solutions can mitigate local sources of greenhouse gases.

CONCLUSION

It is essential to recognize that this and other NGSS progression models proposed to date are living documents that should be refined through iterative testing of the associated curriculum in classrooms (NGSS Lead States, 2013). Like curriculum itself, progression models must undergo a rigorous process of review and refinement based on lessons learned through curriculum development and implementation. For the study described in this paper, further empirical evidence about student learning of the concepts and practices embodied in the middle school grade band NGSS performance expectations will be required to verify the sequence of performance expectations for different populations of students. Mi-STAR continues to refine and pilot test curricular units associated with this model. Annually, the Mi-STAR team facilitates a comprehensive review of the proposed changes to make adjustments that result in the most coherent curriculum that supports maximum learning.

Progression models are an essential framework for the development of coherent curriculum aligned to the NGSS (NGSS Lead States, 2013). The ***UCPM*** provides a foundation that enables teams of curriculum developers to prepare and test units that engage students in multiple STEM disciplines throughout a unit and school year. Currently, few NGSS progression models for the middle grade band exist, and no other models address unifying crosscutting concepts, or are explicitly designed to bundle performance expectations toward addressing themes of particular relevance to 21st-century society. The ***UCPM*** can therefore serve as a starting framework from which other curriculum developers can work. Because of its intentional inclusion of unit challenges, this model may particularly be useful for curriculum developers who are interested in engaging students in project based or problem based learning. Units developed from these bundles of performance expectations enable students to experience how multiple STEM disciplines are applied to solve challenges in the real world.

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Appendix - Tables

TABLE 1: MI-STAR THEMES*

Built Environment
Earth and Space Systems
Energy and Earth Resources
Food and Agriculture
Public and Human Health
Sustainable Ecosystems
Water Resources

**Themes represent categories of topics identified as priority for the 21st century by professional societies of scientists and engineers*

TABLE 2: THE MI-STAR PROGRESSION MODEL AND BUNDLING OF PRIMARY PERFORMANCE EXPECTATIONS

Grade	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8
	Systems and system models				Patterns / Cause and effect			
6 (18,3)	**6.1** MS-ESS2-4 MS-PS1-4 MS-ETS1-1 ***Water Resources, Built Environment***	**6.2** MS-LS1-7 MS-PS 1-2 MS-PS1-5 MS-PS1-6 ***Food & Agriculture***	**6.3** MS-LS1-1 MS-LS1-2 MS-LS1-3 ***Human/Public Health***	**6.4** MS-PS2-1 MS-PS2-2 ***Built Environment***	**6.5** MS-LS1-5 MS-LS2-1 MS-ESS3-1* (ESS3.A) ***Food & Agriculture***	**6.6** MS-LS2-1* (LS2.A) MS-LS2-2 MS-LS2-4 ETS 1-2* (ETS1.B) ***Sustainable Ecosystems***	**6.7** MS-LS1-6 MS-LS2-3 ***Sustainable Ecosystems***	
	Energy and matter				Structure and function			
7 (20, 7)	**7.1** MS-PS2-3 MS-PS3-1 MS-PS3-2 MS-PS3-5 ***Energy & Earth Resources, Built Environment***	**7.2** MS-ESS2-1 MS-ESS2-2 MS-ESS2-3* (ESS2.B) MS-PS1-1* (PS1.A) ***Earth & Space Systems, Energy & Earth Resources***	**7.3** MS-PS 1-3 MS-ESS 3-1 MS-ESS 3-4* (ESS3.C) MS-PS 3-3* (PS3.A, PS3.B) ***Energy & Earth Resources, Built Environment***	**7.4** MS-PS 3-3 MS-PS 3-4 MS-ETS1-4 ***Built Environment***	**7.5** MS-LS 1-4 MS-ESS 3-3 ***Sustainable Ecosystems***	**7.6** MS-LS1-5* (LS1.B) MS-LS3-1 MS-LS3-2 MS-LS4-5 ***Food & Agriculture***	**7.7** MS-PS1-1 MS-ESS2-2* (ESS2.C) MS-ESS3-1* (ESS3.A) ***Human & Public Health Water Resources***	**7.8** MS-LS2-5 MS-ETS1-2 MS-ETS1-3 ***Water Resources***
	Scale, proportion, quantity				Stability and change			
8 (21, 3)	**8.1** MS-LS3-1* (LS3.B) MS-LS4-4 MS-LS4-6 ***Human/Public Health***	**8.2** MS-LS4-1 MS-LS4-2 MS-LS4-3 MS-ESS1-4 ***Sustainable Ecosystems***	**8.3** MS-PS2-5 MS-PS4-1 MS-PS4-2 MS-LS1-8 ***Built Environment, Human/Public Health***	**8.4** MS-ESS1-1* (ESS1.A) MS-ESS1-2 MS-ESS1-3 MS-PS2-4 ***Earth & Space Systems***	**8.5** MS-ESS1-1 MS-ESS2-5 MS-ESS2-6 ***Food & Agriculture***	**8.6** MS-ESS3-2 MS-ESS2-3 MS-PS4-3 ***Human/Public Health, Built Environment***	**8.7** MS-ESS2-6* (ESS2.D) MS-ESS3-4 MS-ESS3-5 ***Water Resources, Earth & Space Systems***	

The relevant grade (i.e., 6th, 7th, or 8th) is indicated in the leftmost column. The unifying crosscutting concept(s) associated with each unit are indicated in the first row for each grade.

The primary performance expectations bundled for each unit are listed using the notation associated with NGSS (REFERENCE) where ESS represents earth and space science; ETS represents engineering, technology, and society; LS represents life science; and PS represents physical sciences.

Where a specific disciplinary core idea is noted in parentheses following a PE, only the disciplinary core idea is primary in the bundle. The CCC, SEP, or other disciplinary core ideas associated with the performance expectation are not primary.

Themes are indicated using abbreviations: BE = Built environment; EER = Earth and energy resources, ESS = Earth and space systems; FA = Food and agriculture; HPH = Human and public health; SE = Sustainable Ecosystems; WR = Water resources.

TABLE 3: PROGRESSION OF DISCIPLINARY CORE IDEAS IN THE MI-STAR PROGRESSION MODEL

Unit 6.1: PS1.A: Structure and Properties of Matter PS3.A: Definitions of Energy ESS2.C: The Role of Water in Earth's Surface Processes ETS1.A: Defining and Delimiting an Engineering Problem **Unit 6.2:** PS1.A: Structure and Properties of Matter PS1.B: Chemical Reactions LS1.C: Organization for Matter and Energy Flow in Organisms **Unit 6.3:** LS1.A: Structure and Function **Unit 6.4:** PS2.A: Wave Properties **Unit 6.5:** LS1.B: Growth and Development of Organisms LS2.A: Interdependent Relationships in Ecosystems ESS3.A: Natural Resources **Unit 6.6:** LS2.A: Interdependent Relationships in Ecosystems LS2.C: Ecosystems Dynamics, Functioning, and Resilience ETS1.B: Developing Possible Solutions **Unit 6.7:** PS3.D: Energy in Chemical Processes and Everyday Life LS1.C: Organization for Matter and Energy Flow in Organisms LS2.B: Cycle of Matter and Energy Transfer in Ecosystems	**Unit 7.1:** PS2.B: Types of Interactions PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer PS3.C: Relationship Between Energy and Forces **Unit 7.2:** PS1.A: Structure and Properties of Matter ESS2.A: Earth Materials and Systems ESS2.B: Plate Tectonics and Large-Scale Systems ESS2.C: The Role of Water in Earth's Surface Processes **Unit 7.3:** PS1.B: Chemical Reactions PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer ESS3.A: Natural Resources ESS3.C: Human Impacts and Earth Systems **Unit 7.4:** PS3.A: Definitions of Energy PS3.B: Conservation of Energy and Energy Transfer ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution **Unit 7.5:** LS1.B: Growth and Development of Organisms ESS3.C: Human Impacts and Earth Systems **Unit 7.6:** LS1.B: Growth and Development of Organisms LS3.A: Inheritance of Traits LS3.B: Variation of Traits LS4.B: Natural Selection **Unit 7.7:** PS1.A: Structure and Properties of Matter ESS2.C: The Role of Water in Earth's Surface Processes ESS3.A: Natural Resources **Unit 7.8:** LS2.C: Ecosystems Dynamics, Functioning, and Resilience LS4.D: Biodiversity and Humans ETS1.B: Developing Possible Solutions ETS1.C: Optimizing the Design Solution	**Unit 8.1:** LS3.B: Variation of Traits LS4.B: Natural Selection LS4.C: Adaptation **Unit 8.2:** LS4.A: Adaptation ESS1.C: The History of Planet Earth **Unit 8.3:** PS2.B: Types of Interactions PS4.A: Wave Properties PS4.B: Electromagnetic Radiation LS1.D: Information Processing **Unit 8.4:** LS3.B: Variation of Traits LS4.B: Natural Selection LS4.C: Adaptation **Unit 8.5:** ESS2.C: The Role of Water in Earth's Surface Processes ESS2.D: Weather and Climate **Unit 8.6:** PS4.C: Information Technologies and Instrumentation ESS1.C: The History of Planet Earth ESS3.B: Natural Hazards **Unit 8.7:** ESS2.D: Weather and Climate ESS3.C: Human Impacts and Earth Systems ESS3.D: Global Climate Change

TABLE 4: PROGRESSION OF UNIFYING CROSSCUTTING CONCEPTS IN THE MI-STAR CURRICULUM

Grade & Semester			Unifying Crosscutting Concept	Unit-Based Crosscutting Concepts
6th	1st	Systems and System Models	Students begin the 6th grade with an exploration of the crosscutting concept Systems and system models. Since all scientific phenomena occur within systems and affect system dynamics, this crosscutting concept provides a basis for understanding and exploring the other crosscutting concepts. Through repeated application of this concept across units, students refine an understanding of what a system is, how to define system boundaries, and how to model a system. In the second semester of the 6th grade, students build on their understanding of Systems and system models by considering the Patterns found in systems, and how Cause and effect relationships can explain those patterns.	• Systems and Systems Models • Patterns • Cause and Effect • Energy and Matter • Structure and Function • Scale, Proportion, and Quantity
	2nd	Patterns and Cause and Effect		• Patterns • Cause and Effect • Energy and Matter • Stability and Change
7th	1st	Energy and Matter	In the first semester of the 7th grade, students consider Energy and matter by modeling and constructing explanations for how energy and matter flow into, out of, and within systems. This crosscutting concept builds on Patterns and Cause and effect in that energy and matter flows can be observed by identifying patterns and can be explained using cause and effect. In the second semester of 7th grade, students consider Structure and function by modeling and constructing explanations for how the structure of a system or system component affects its function.	• Systems and Systems Models • Energy and Matter • Scale, Proportion, and Quantity
	2nd	Structure and Function		• Cause and Effect • Structure and Function • Scale, Proportion, and Quantity • Stability and Change
8th	1st	Scale, Proportion, and Quantity	In the first semester of 8th grade, students consider Scale, proportion, and quantity by exploring how components interact within systems over different time and spatial scales. Systems, patterns, cause and effect relationships, energy and matter cycling, as well as the relationship of structure and function, can all be observed at different scales and magnitudes. Students can therefore build on their previous knowledge while identifying a new crosscutting concept. In the final semester of the grade band, students consider Stability and change by identifying the conditions under which a system is stable or changing. This also builds on all previous crosscutting concepts. From the beginning of 6th grade through the end of 8th grade, the unifying crosscutting concepts build on one another in order to deepen student understanding of individual crosscutting concepts as well as the relationships between them.	• Systems and Systems Models • Patterns • Cause and Effect • Structure and Function • Scale, Proportion, and Quantity
	2nd	Stability and Change		• Systems and Systems Models • Patterns • Cause and Effect • Structure and Function • Stability and Change